

ORIGINAL PAPER

Productivity and water use efficiency of okra cultivated under water stress in a tropical climate

Juvenaldo Florentino Canj¹, Jonnathan Richeds da Silva Sales¹, Benito Moreira de Azevedo¹, Diogo Sales Frazo¹, Geocleber Gomes de Sousa², Gleyciane Rodrigues Lins¹, James do Nascimento Costa¹, Paula Ingrid Maia Machado¹, Jose Thomas Machado de Sousa^{1*} & Thales Vinicios de Araujo Viana¹

¹Federal University of Ceara, Fortaleza, Ceara, Brazil

²University of International Integration of Afro-Brazilian Lusofonia, Redenao, Ceara, Brazil

Abstract: Efficient irrigation management is crucial for okra production in tropical climates, where irregular water availability, resulting in water deficit or excess, can affect agricultural yield. Thus, the objective was to evaluate, in two consecutive years, the agronomic characteristics and water use efficiency of the okra crop under irrigation depths as a function of crop evapotranspiration. The experiment was conducted in two consecutive years, from October to January 2022 and 2023, in Fortaleza, Ceara, Brazil. The experimental design was randomized blocks, with five treatments and five replications. The treatments consisted of 30, 60, 90, 120, and 150% of crop evapotranspiration. The water deficit severely affected the vegetative growth and fruit quality of the okra crop. However, this condition allowed high efficiency in water use in irrigated okra cultivation in both years of cultivation. Water stress, whether due to water deficit or excess, had a significant negative impact on okra productivity.

Keywords: *Abelmoschus esculentus* L., irrigated agriculture, evapotranspiration.

Introduction

Okra (*Abelmoschus esculentus* L.) is a monocotyledonous herbaceous plant belonging to the Malvaceae family, playing a significant role in both human nutrition and medicine. Due to these characteristics, okra cultivation offers good economic returns (Patra et al., 2023). It is cultivated mainly by small producers, in tropical and subtropical regions, where climatic conditions are favorable, with a fast cycle

and, when well-managed, can produce all year round (Dantas et al., 2021). Technological advances in irrigation methods and systems can maximize crop productivity. However, the irrigation strategy needs to consider both the quality and quantity of water, which can influence the achievement of high yields in the field (Frizzone et al., 2021).

Irrigated agriculture is considered one of the human activities with the highest water

* Corresponding author: E-mail: thssousa2015@gmail.com

Editors: Mairton Gomes da Silva & Petterson Costa Conceiao Silva

Received in: 04 January, 2025

Accepted in: 09 July, 2025

consumption worldwide (Barideh and Nasimi, 2022). This becomes a challenge for agricultural production due to competing demand in various sectors of the economy, such as fast industrialization and high population growth (Rosenzweig et al., 2020; Leal Filho et al., 2022). In addition to the impacts of climate change, shifts in the frequency and intensity of rainfall have become more evident, with semi-arid and arid regions increasingly experiencing prolonged periods of drought. These changes directly affect water availability for agricultural crops, making irrigation an ever more essential practice (Bouabdelli et al., 2022; Costa et al., 2025).

Irrigated agriculture is one of the fundamental pillars of food production worldwide, playing a crucial role in ensuring food security. By enabling cultivation in regions with limited water availability, it not only expands the area of arable land, but also significantly increases crop productivity and improves quality of life (Qureshi, 2019).

Irrigation, when properly managed, can mitigate the impacts of climate change on agricultural production and water use

efficiency (Segovia-Cardozo et al., 2019; Segovia-Cardozo et al., 2022; Silva et al., 2024). By providing water directly to plants when needed, assists ensure an adequate supply regardless of weather conditions. This is essential during periods of drought or dry spells, when rainfall is insufficient to meet crop needs (Mesquita et al., 2023).

Thus, the objective was to evaluate, in two consecutive years, the agronomic characteristics and water use efficiency of the okra crop under irrigation depths as a function of crop evapotranspiration.

Materials and Methods

Location and characterization of the experimental area

The experiment was conducted in two consecutive years, from October to January 2022 and 2023, in the experimental area belonging to the Department of Agricultural Engineering of the Federal University of Ceará, in Fortaleza, Ceará, Brazil, with geographic coordinates 3° 44' S, 38° 34' W, and 19.5 m altitude in relation to the mean sea level (Figure 1).

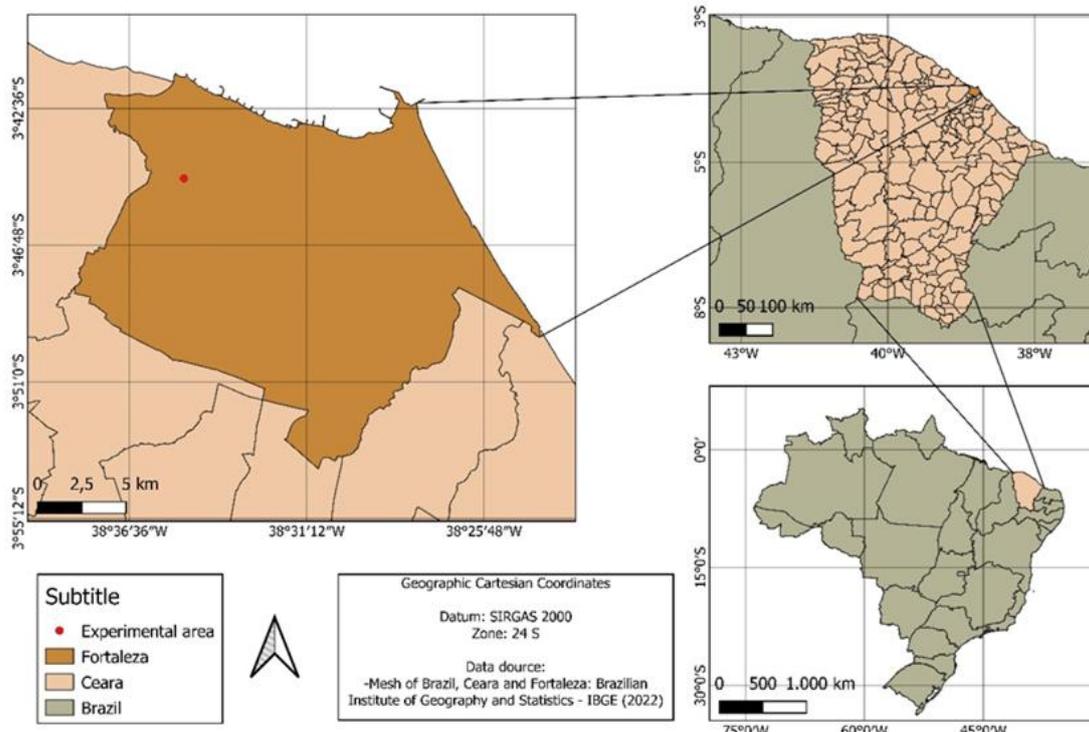


Figure 1. Location of the experimental area at the Federal University of Ceará, Fortaleza, Ceará, Brazil.

According to the Köppen classification (Köppen, 1923), the region's climate is Aw', characterized by being tropical rainy, with summer-autumn precipitation. Meteorological data on rainfall,

temperature, and relative air humidity were monitored from the automatic station of the National Institute of Meteorology (INMET), as shown in the Figure 2.

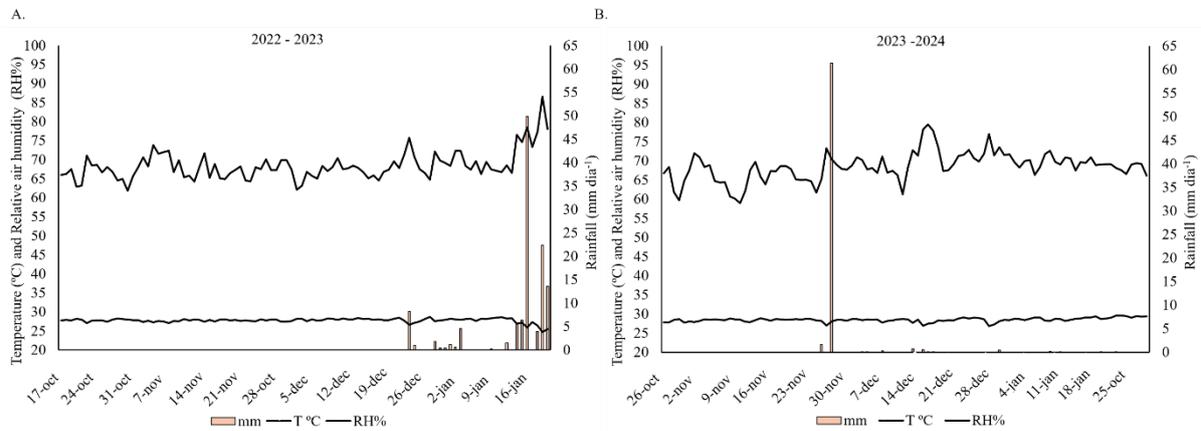


Figure 2. Mean values of temperature, relative air humidity, and rainfall during the experimental period for the 2022/2023 (A) and 2023/2024 (B) growing season.

Treatments, experimental design, and growing conditions

The experimental design was randomized blocks, with five treatments and five replicates. The treatments consisted of 30, 60, 90, 120, and 150% of the crop evapotranspiration (ETc).

Spacing was set at 0.8 m between rows and 0.6 m between plants within rows. Each row contained seven plants, five of which were useful. The total cultivation area was 101 m². The soil in the experimental area was classified as Red Yellow Argisol, with a sandy loam texture (EMBRAPA, 2018). Tables 1 and 2 show the results of the physical-hydric and chemical analysis of the soil in the experimental area, before the application of the treatments, in the years 2022 and 2023.

The soil was manually plowed. The 'Santa Cruz 47' okra was sown in late October across two cycles, with three seeds placed per furrow. Seedlings were thinned at 20 days after sowing (DAS). Before experimental treatments began, a uniform irrigation depth of 100% ETc was applied to all plants.

Mineral fertilization was applied in split doses totaling 80 kg ha⁻¹ of N, 100 kg ha⁻¹

of P₂O₅, and 60 kg ha⁻¹ of K₂O. A partial application was made at sowing (establishment stage), with the remainder applied as topdressing at 20 and 30 days after sowing (DAS), following the recommendation of Trani et al. (2008). The nutrient sources used were urea, single superphosphate, and potassium chloride, respectively.

Treatment differentiation began at 21 DAS. A surface drip irrigation system was used, comprising a motor-pump unit, a main line, submains, and lateral lines, with emitters operating at an average flow rate of 2 L h⁻¹.

The irrigation depth was estimated based on ETc according to Equation 1.

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

Where: ETc – crop evapotranspiration, in mm day⁻¹; ETo – reference evapotranspiration, in mm day⁻¹; Kc – crop cultivation coefficient, dimensionless.

Based on the meteorological data previously described, we estimated the ETo using the parameterized Penman-Monteith method (Allen et al., 1998), according to Equation 2.

$$ET_{ToPM} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_m + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (2)$$

Where: ET_{ToPM} – reference evapotranspiration, in mm day^{-1} ; R_n – radiation balance, in $\text{MJ m}^{-2} \text{day}^{-1}$; G – soil heat flux, in $\text{MJ m}^{-2} \text{day}^{-1}$; T_m – mean air

temperature, in $^{\circ}\text{C}$; u_2 – mean wind speed at 2 m height, in m s^{-1} ; $(e_s - e_a)$ – vapor pressure deficit, in kPa; Δ – tangent of the vapor saturation pressure curve as a function of air temperature, in $\text{kPa } ^{\circ}\text{C}^{-1}$; γ – psychrometric constant, in $\text{kPa } ^{\circ}\text{C}^{-1}$.

Table 1. Physical-water analysis of the soil in the experimental area in the 0.0 to 0.2 m depth.

Parameters	Year 2022	Year 2023
Soil density (g cm^{-3})	1.54	1.55
Particle density (g cm^{-3})	2.66	2.59
Moisture at field capacity ($\text{cm}^3 \text{cm}^{-3}$)	0.316	0.345
Moisture at permanent wilting point ($\text{cm}^3 \text{cm}^{-3}$)	0.160	0.192
Total porosity ($\text{cm}^3 \text{cm}^{-3}$)	0.412	0.415

Table 2. Chemical analysis of the soil in the experimental area in the 0.0 to 0.2 m depth.

Assortative complex ($\text{cmol}_c \text{dm}^{-3}$)					% (mg dm^{-3})		(g kg^{-1})		
2022									
pH (CaCl)	K^+	Ca^{2+}	Mg^{2+}	Na^+	$\text{H}^+ + \text{Al}^{3+}$	Al^{3+}	V	P	O.M.
5.0	1.07	0.92	0.55	0.23	2.20	0.29	42	9.0	13.0
2023									
pH (CaCl)	K^+	Ca^{2+}	Mg^{2+}	Na^+	$\text{H}^+ + \text{Al}^{3+}$	Al^{3+}	V	P	O.M.
5.2	1.18	0.99	0.64	0.26	2.01	0.24	45	9.3	13.1

pH – hydrogen potential; V – base saturation; O.M. – organic matter; K^+ , Na^+ , and P – potassium, sodium, and phosphorus extracted with Mehlich 1 solution; Ca^{2+} , Mg^{2+} , and Al^{3+} – calcium, magnesium, and aluminum were extracted with 1 M KCl solution; $\text{H}^+ + \text{Al}^{3+}$ – potential acidity, extracted using the 0.5 mol L^{-1} calcium acetate method buffered at pH 7.0.

The Kc values used were as follows: 0.68 until 40 DAS; 0.79 from 41 to 70 DAS; and 0.54 from 71 DAS until the end of the experiment, according to Paes et al. (2012).

Irrigation time was quantified according to Equation 3.

$$IT = \frac{ID \times S_L + S_D + C_F}{IE \times D_R} \quad (3)$$

Where: IT – irrigation time, in h; ID – irrigation depth, in mm day^{-1} ; S_L – spacing between irrigation lines, in m; S_D – spacing between drippers, in m; C_F – land cover factor, dimensionless (the value 1 was used); IE – irrigation efficiency (the value 92% was used); D_R – dripper flow rate, in L h^{-1} .

According to Table 3, the total depth applied in the experiment during the crop cycle is observed according to each treatment.

The irrigation schedule adopted was fixed, carried out daily, varying the applied depth according to the crop's evapotranspiration, except for periods when there was rainfall. The control of the irrigation time and the applied depth was carried out manually, through individual records for each treatment.

Table 3. Evapotranspiration percentages (ETc) and irrigation depths (Id) applied for each crop cycle.

Treatments	ETc (%)	Irrigation depth (mm)	
		2022	2023
Id ₃₀	30	104.0	83.0
Id ₆₀	60	209.0	167.0
Id ₉₀	90	313.0	250.0
Id ₁₂₀	120	417.0	334.0
Id ₁₅₀	150	522.0	417.0

Variables analyzed

In both years, growth variables were measured at 45 DAS. The variables assessed were leaf area (LA), plant height (PH), stem diameter (SD), and number of leaves (NL).

LA was estimated from leaf length and width measurements as described by Oliveira et al. (2014) using Equation 4. The equation provides the area of an individual leaf. Total leaf area per plant was obtained by multiplying the mean leaf area by the total number of leaves per plant at the time of evaluation.

$$LA = L \times W \times CF \quad (4)$$

Where: LA – leaf area, in cm²; L – leaf length, in cm; W – leaf width, in cm; CF – correction factor, dimensionless (the value 0.63 was used).

PH (in cm) was measured using a graduated ruler from the plant collar to the tip of the main stem. SD (in mm) was determined with the aid of a digital caliper, at a height of approximately 2 cm above the soil surface. NL was determined by manual counting from the base of the plant to the apex.

The first harvest occurred at 55 DAS in the first cycle and 49 DAS in the second. Subsequently, fruits were harvested at four-day intervals, with a total of seven harvests per cycle. The final harvests occurred at 83 DAS in the first cycle and 77 DAS in the second cycle, concluding the season in January of both production years. At each

harvest, the following variables were evaluated: fruit length (FL, in cm), fruit diameter (FD, in mm), and fruit mass (FM, g plant⁻¹).

Productivity per area (PROD) was calculated from FM per plant (useful area of each plot) and expressed in kg ha⁻¹. Water use efficiency (WUE) was also calculated, with results expressed in kg m⁻³. WUE was obtained from fruit productivity and water consumption data according to the treatments applied.

Statistical analysis

The data obtained were subjected to the Kolmogorov-Smirnov test ($p \leq 0.05$) to evaluate the normality. After verifying normality, analysis of variance by the F-test ($p \leq 0.05$) was carried out. In cases of statistical significance, the data were subjected to regression analysis, selecting the equations that best fit the data based on the significance of the regression coefficients ($p \leq 0.05$) by the F test and with the highest coefficient of determination (R^2). The statistical analysis was performed using the software ASSISTAT 7.7 Beta (Silva and Azevedo, 2016).

Results

Results of the analysis of variance for the evaluated variables (plant height – PH, leaf area – LA, number of leaves – NL, stem diameter – SD, fruit length – FL, fruit diameter – FD, fruit productivity – PROD, and water use efficiency – WUE based on PROD) are summarized in Table 4. In both cultivation years, irrigation depth, which

was based on crop evapotranspiration (ETc), had a significant effect on all evaluated variables.

Table 4. Summary of the analysis of variance for plant height (PH), leaf area (LA), number of leaves (NL), stem diameter (SD), fruit length (FL), fruit diameter (FD), fruit productivity (PROD), and water use efficiency (WUE) of okra grown at different irrigation depths, in two years of cultivation.

Source of variation	Mean squares			CV (%)	
	DF	Treatment	Block		
Variables		5	4	16	
PH		1218.32**	45.11 ^{ns}	35.15	3.46
LA		91614.54*	12555.74 ^{ns}	26548.95	11.92
NL		3.07*	2.15 ^{ns}	1.86	5.80
SD		0.86*	0.22 ^{ns}	0.19	10.58
FL		68.32**	1.49 ^{ns}	1.26	9.89
FD		0.27**	0.004 ^{ns}	0.007	5.62
PROD		468681.67**	194796.76 ^{ns}	394602.19	18.87
WUE		10.56**	0.55 ^{ns}	0.52	18.36
Variables					
PH		1020.75**	61.66 ^{ns}	22.78	2.66
LA		73341.71**	23434.28 ^{ns}	76583.23	14.23
NL		20.56*	16.16 ^{ns}	13.26	8.14
SD		0.46*	0.03 ^{ns}	0.14	8.94
FL		39.81**	1.46 ^{ns}	1.68	10.47
FD		0.28**	0.008 ^{ns}	0.007	5.61
PROD		394883.19**	197838.21 ^{ns}	274196.87	14.58
WUE		24.68**	1.12 ^{ns}	0.62	14.43

DF – degree of freedom; CV – coefficient of variation; ns, * and ** – not significant, significant at $p < 0.05$ and significant at $p < 0.01$, respectively, by F-test.

Vegetative growth

Figure 3A shows that okra PH increased linearly with irrigation depth. The highest depth (150% ETc) resulted in a 25.97 and

20.17% increase in PH compared to the lowest depth (30% ETc) in 2022 and 2023, respectively.

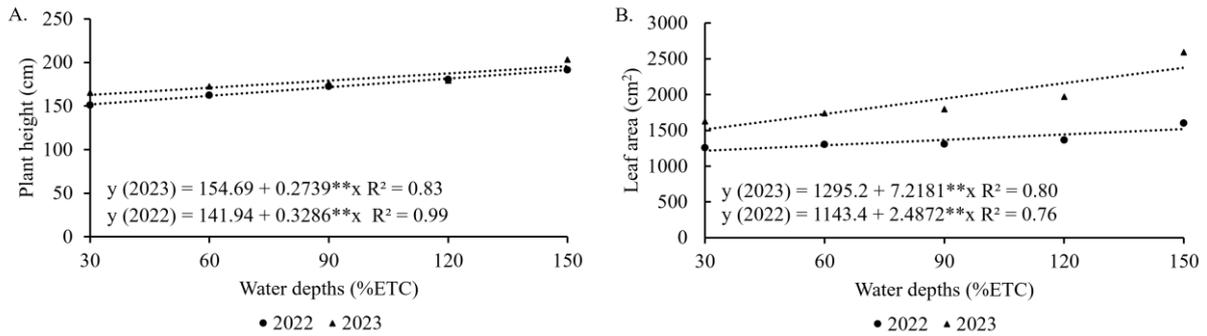


Figure 3. Plant height (A) and leaf area (B) of okra plants grown at different irrigation depths, in two years of cultivation.

A similar trend was observed for LA (Figure 3B), which also increased linearly with irrigation depth. In 2022 and 2023, the 150% ETc treatment increased LA by 24.50 and 57.29%, respectively, compared to the 30% ETc treatment. Notably, despite receiving 20.1% less total irrigation water, the 150% ETc treatment in 2023 still achieved a higher LA than the same treatment in 2022.

The response NL to irrigation depth differed between the two cultivation years

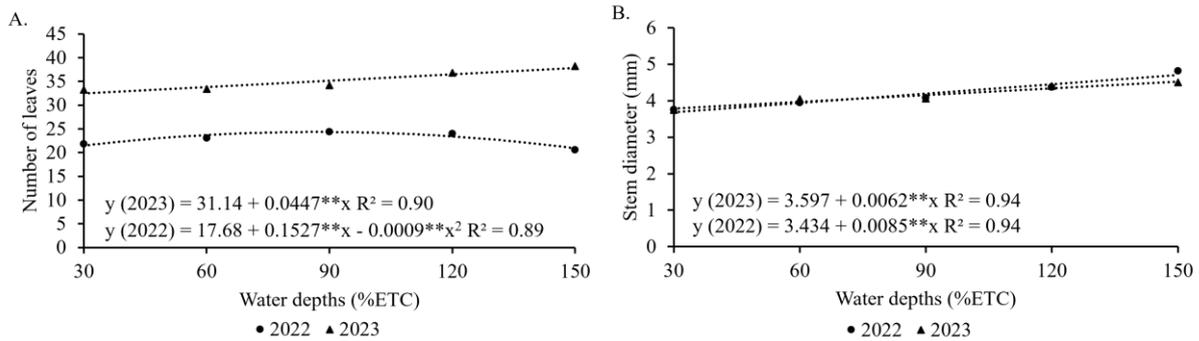


Figure 4. Number of leaves (A) and stem diameter (B) of okra plants grown at different irrigation depths, in two years of cultivation.

Despite the lower total irrigation volume applied in 2023 (Table 3), all irrigation treatments resulted in a higher NL than in 2022. This suggests that the higher irrigation volumes (120 and 150% ETc) applied in 2022 may have induced water excess stress, thereby limiting leaf production.

SD increased linearly with irrigation depth in both years (Figure 4B). Gains of 27.64 in 2022 and 19.84% in 2023 were observed when comparing the 150% ETc treatment to the 30% ETc treatment.

(Figure 4A). In 2022, the relationship was best described by a quadratic polynomial model. This model indicated a maximum NL of 24.16 leaves at an optimal irrigation depth of 84.83% ETc, followed by a 15.81% decrease under the highest irrigation depth (150% ETc). In 2023, NL increased linearly with irrigation depth, rising by 16.53% under the 150% ETc treatment compared to the 30% ETc treatment.

Physical quality of fruits

Okra FL increased with higher irrigation depth (Figure 5A). Compared to the 30% ETc treatment, the 150% ETc treatment increased FL by 117.02% in 2022 and 76.45% in 2023. A similar linear response was observed for FD (Figure 5B). The 150% ETc treatment increased FD by 46.67% in 2022 and 45.67% in 2023 compared to the 30% ETc treatment.

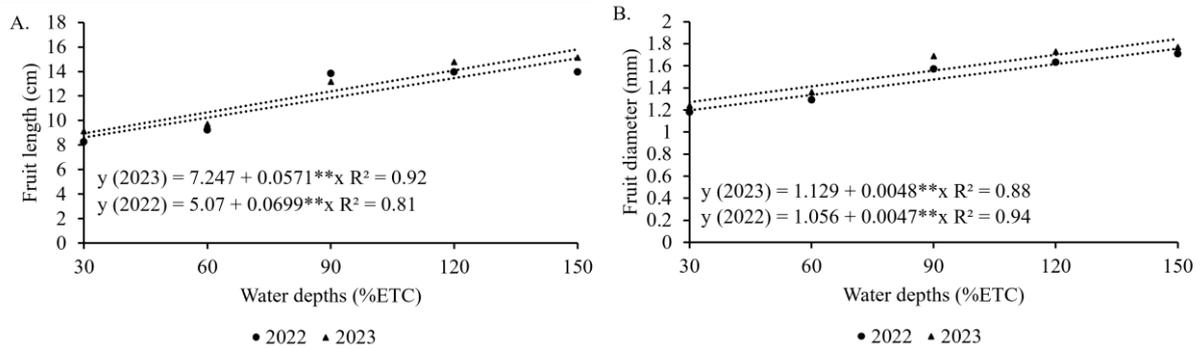


Figure 5. Fruit length (A) and fruit diameter (B) of okra plants grown at different irrigation depths, in two years of cultivation.

Despite lower total irrigation in 2023 (Table 3), fruit length and diameter were greater than in 2022. This may be attributed to better crop adaptation to the prevailing temperature conditions during the 2023 growing season.

Fruit productivity followed a quadratic response with irrigation depth in both years (Figure 6A). The fitted models indicated

maximum yields of 14,701.43 ha⁻¹ at 116.41% ETc in 2022 and 13,584.08 kg ha⁻¹ at 113.80% ETc in 2023. In both years, productivity decreased when irrigation exceeded the estimated optimum. Compared to the optimal depth, irrigation at 150% ETc reduced yield by 7.32% in 2022 and 9.08% in 2023.

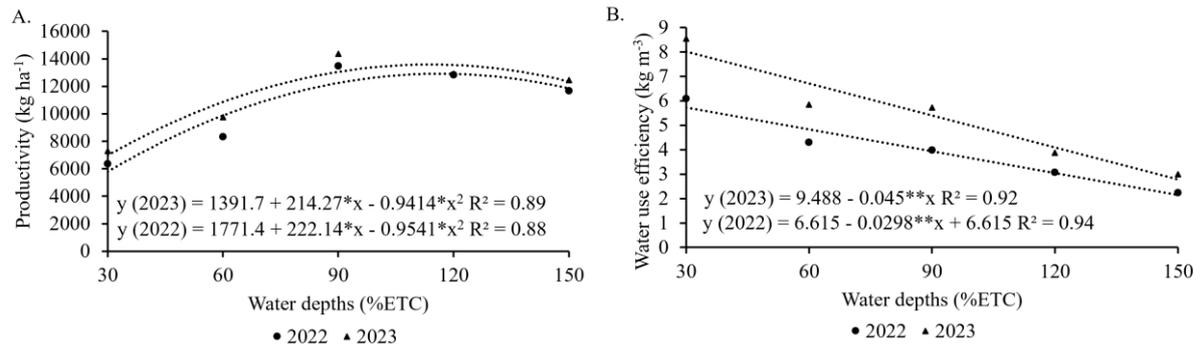


Figure 6. Fruit productivity (A) and water use efficiency (B) of okra plants grown at different irrigation depths, in two years of cultivation.

WUE decreased linearly with increasing irrigation depth in both years (Figure 6B). Compared to the 30% ETc treatment, WUE was reduced by 62.41% in 2022 and 66.34% in 2023 compared to the 150% ETc treatment.

Discussion

As demonstrated by the results presented in this study, proper irrigation management is essential to maximize the productive potential of crops and ensure the sustainability of agricultural systems. Supplying the ideal quantity of water avoids

two critical issues: (1) water deficit, which reduces plant growth, photosynthesis, and reproductive development; and (2) water excess, which can cause soil waterlogging. Waterlogging reduces oxygen availability to roots, impairing nutrient uptake and consequently lowering both productivity and quality (Kaur et al., 2021).

In general, okra exhibited lower growth potential under the lowest irrigation depths (Figures 3 and 4), a response correlated with water deficit conditions. Under water stress, plants close their stomata to minimize water loss by transpiration. This reduces stomatal

conductance and internal CO₂ concentration, thereby compromising the photosynthetic rate and directly limiting crop development (Canjá et al., 2021; Custodio et al., 2022).

The behavior of plants subjected to water stress conditions tends to reduce factors such as leaf area, number of leaves, water potential, and chlorophyll content (Ahmad et al., 2022), resulting in lower production and biomass accumulation, directly affecting the growth of okra plants.

Liang et al. (2022) emphasize that water deficit in agricultural plants affects vegetative growth and differentiation of flower buds, which limits the quantity and quality of fruits, as also found in the study. However, increasing the water supply led to significant improvements in both plant growth (Figures 3 and 4) and fruit dimensions (length and diameter) (Figure 5).

The reduction in okra plant growth under conditions of low water availability is associated with the limitation of essential morphological processes, such as cell division, differentiation, and expansion (Kaur et al., 2021). Water deficit also compromises fruit quality, affecting parameters such as length and diameter, possibly due to the negative effects on the synthesis, accumulation, and translocation of photoassimilates (Taiz et al., 2021).

Water stress, both due to deficit and excess, negatively affected okra crop productivity in both growing years (Figure 6A). Low water availability limits the production of photoassimilates and nutrient transport, reducing crop productivity (Cavalcante et al., 2021). Therefore, with the increase in irrigation depths, there was an increase in the productivity of the okra crop. However, the excessive increase in water in the soil promoted excess water stress, which culminated in reductions in crop production.

Ferreira et al. (2021) report that excess moisture below the soil surface, resulting in water stress, decreases the productive potential of agricultural crops. According to

Taiz et al. (2021), stomatal closing and reduced photosynthesis are typical responses to lack of oxygen in the soil due to waterlogging, negatively affecting productivity in agriculture.

The high WUE observed under deficit irrigation (Figure 6B) can be attributed to a plant's adaptive response to water stress. To conserve water, plants close their stomata, reducing transpirational loss at the cost of lower photosynthetic rates. This prioritization of water conservation over carbon fixation results in a more efficient use of each unit of water transpired (Rascón-Castillo et al., 2024).

Plants under adequate irrigation have less need to conserve water. They maintain open stomata to sustain high photosynthetic activity, which leads to greater transpirational water loss, resulting in lower WUE (Bielsa et al., 2019), as observed in the present study.

In this context, Kukal and Irmak (2020) and Li et al. (2020) highlight the importance of efficient management of agricultural irrigation water, especially for developing countries such as Brazil. However, Brazilian agricultural production is often associated with inadequate irrigation management, a factor that leads to reduced productivity and fruit quality.

Therefore, efficient irrigation, based on monitoring the plant's water needs, based on the climatological management of crop evapotranspiration, is essential to optimize water use and avoid productivity losses, thus optimizing the efficiency of water use in irrigated agriculture, especially in tropical climates.

Conclusions

Water deficit consistently enhanced water use efficiency in both years, despite its negative impact on vegetative growth and fruit quality, which was more pronounced in the 2022 crop.

Okra productivity is reduced by both water deficit and excess. Thus, proper irrigation management is critical for

sustaining high yields under tropical conditions.

Acknowledgments

The authors thank the Coordination for the Improvement of Higher Education Personnel (CAPES) for granting scholarships to the students.

References

Ahmad, H. M.; Wang, X.; Rahman, M. U.; Fiaz, S.; Azeem, F.; Shaheen, T. Morphological and physiological response of *Helianthus annuus* L. to drought stress and correlation of wax contents for drought tolerance traits. *Arabian Journal for Science and Engineering*, v. 47, n. 6, p. 6747-6761. 2022. <https://doi.org/10.1007/s13369-021-06098-1>

Allen, R. G.; Pereira, L. S.; Raes, D.; Smith, M. Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO – Food and Agriculture Organization of the United Nations, 1998. 300p. (FAO Irrigation and Drainage Paper, 56).

Barideh, R.; Nasimi, F. Investigating the changes in agricultural land use and actual evapotranspiration of the Urmia Lake basin based on FAO's WaPOR database. *Agricultural Water Management*, v. 264, 107509, 2022. <https://doi.org/10.1016/j.agwat.2022.107509>

Bielsa, B.; García-Brunton, J.; Sanz, M. A.; Rubio-Cabetas, M. J. Caracterización de la respuesta adaptiva a sequía en dos cultivares de melocotonero en condiciones de aridez. *Información Técnica Económica Agraria*, v. 115, n. 4, p. 307-325, 2019. <https://doi.org/10.12706/itea.2019.010>

Bouabdelli, S.; Zeroual, A.; Meddi, M.; Assani, A. Impact of temperature on agricultural drought occurrence under the effects of climate change. *Theoretical and Applied Climatology*, v. 148, n. 1, p. 191-209, 2022. <https://doi.org/10.1007/s00704-022-03935-7>

Canjá, J. F.; Sales, J. R. S.; Pinho, L. L.; Sousa, N. I. G.; Lacerda, C. F.; Sousa, G. G. Production and water use efficiency of peanut under salt stress and soil cover. *Ciência Agronômica*, v. 52, n. 2, e20217818, 2021. <https://doi.org/10.1590/1983-40632023v5376910>

Cavalcante, E. S.; Lacerda, C. F.; Costa, R. N. T.; Gheyi, H. R.; Pinho, L. L.; Bezerra, F. M. S.; Oliveira, A. C.; Canjá, J. F. Supplemental irrigation using brackish water on maize in tropical semi-arid regions of Brazil: Yield and economic analysis. *Scientia Agrícola*, v. 78, n. 1, e20200151, 2021. <https://doi.org/10.1590/1678-992X-2020-0151>

Costa, L. F.; Azevedo Neto, A. D.; Soares, T. M.; Santos, I. L. N.; Silva, M. G.; Silva, P. V. S. R.; Ferreira, W. J. O.; Rosario, A. S. Produtividade e tolerância salina da alface e da rúcula em diferentes sistemas hidropônicos com águas salobras. *Water Resources and Irrigation Management*, v. 14, n. 1-3, p. 88-108, 2025. <https://doi.org/10.19149/wrim.v14i1-3.5255>

Custodio, A. M.; Menezes, S. P. E.; Santos, T. R. D.; Lourenço, L. L.; Avila, R. G.; Silva, A. R.; Silva, F. H. L.; Espindula, M. C.; Dias, J. R. M.; Silva, F. G. Seasonal variation in physiological traits of Amazonian *Coffea canephora* genotypes in cultivation systems with contrasting water availability. *Agronomy*, v. 12, n. 12, 3197, 2022. <https://doi.org/10.3390/agronomy12123197>

Dantas, T. L.; Buriti, F. C. A.; Florentino, E. R. Okra (*Abelmoschus esculentus* L.) as a potential functional food source of mucilage and bioactive compounds with technological applications and health benefits. *Plants*, v. 10, n. 8, 1683, 2021. <https://doi.org/10.3390/plants10081683>

EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária. Sistema brasileiro de classificação de solos. 5.ed., rev. e ampl. Brasília: Embrapa, 2018. 356p.

Ferreira, A. M. F.; Parizi, A. R. C.; Gomes, A. C. S.; Chuquel, M. D. L.; Segabinazzi, E. M.; Ponte, V. H. S. Desempenho produtivo e retorno econômico do milho irrigado por aspersão. *Irriga*, v. 1, n. 2, p. 381-396, 2021. <https://doi.org/10.15809/irriga.2021v1n2p381-396>

Frizzone, J. A.; Lima, S. C. R. V.; Lacerda, C. F.; Mateos, L. Socio-economic indexes for water use in irrigation in a representative basin of the tropical semiarid region. *Water*, v. 13, n. 19, 2643, 2021. <https://doi.org/10.3390/w13192643>

- Kaur, H.; Kohli, S. K.; Khanna, K.; Bhardwaj, R. Scrutinizing the impact of water deficit in plants: Transcriptional regulation, signaling, photosynthetic efficacy, and management. *Physiologia Plantarum*, v. 172, n. 2, p. 935-962, 2021. <https://doi.org/10.1111/ppl.13389>
- Köppen, W. P. *Die Klimate der Erde: Grundriss der Klimakunde*. Walter de Gruyter & Company, 1923.
- Kukul, M. S.; Irmak, S. Impact of irrigation on interannual variability in United States agricultural productivity. *Agricultural Water Management*, v. 234, 106141, 2020. <https://doi.org/10.1016/j.agwat.2020.106141>
- Leal Filho, W.; Setti, A. F. F.; Azeiteiro, U. M.; Lokupitiya, E.; Donkor, F. K.; Etim, N. N.; Matandirotya, N.; Olooto, F. M.; Sharifi, A.; Nagy, G. J.; Djekic, I. An overview of the interactions between food production and climate change. *Science of the Total Environment*, v. 838, 156438, 2022. <https://doi.org/10.1016/j.scitotenv.2022.156438>
- Li, M.; Xu, Y.; Fu, Q.; Singh, V. P.; Liu, D.; Li, T. Efficient irrigation water allocation and its impact on agricultural sustainability and water scarcity under uncertainty. *Journal of Hydrology*, v. 586, 124888, 2020. <https://doi.org/10.1016/j.jhydrol.2020.124888>
- Liang, B.; Shi, Y.; Yin, B.; Zhou, S.; Li, Z.; Zhang, X.; Xu, J. Effect of different dwarfing interstocks on the vegetative growth and nitrogen utilization efficiency of apple trees under low-nitrate and drought stress. *Scientia Horticulturae*, v. 305, 111369, 2022. <https://doi.org/10.1016/j.scienta.2022.111369>
- Mesquita, J. B. R.; Azevedo, B. M.; Sousa, G. G.; Viana, T. V. A.; Sales, J. R. S.; Goes, G. F. Desempenho agrônômico do milho cultivado no litoral cearense sob lâminas de irrigação. *Irriga*, v. 28, n. 2, p. 286-297, 2023. <https://doi.org/10.15809/irriga.2023v28n2p286-297>
- Oliveira, S. P.; Melo, E. N.; Melo, D. R. M.; Costa, F. X.; Mesquita, E. F. Formação de mudas de quiabeiro com diferentes substratos orgânicos e biofertilizante. *Revista Terceiro Incluído*, v. 4, n. 2, p. 219-235, 2014. <https://doi.org/10.5216/teri.v4i2.35280>
- Paes, H. M. F.; Esteves, B. D. S.; Sousa, E. F. D. Determinação da demanda hídrica do quiabeiro em Campos dos Goytacazes, RJ. *Revista Ciência Agronômica*, v. 43, n. 2, p. 256-261, 2012. <https://doi.org/10.1590/S1806-66902012000200007>
- Patra, S. K.; Poddar, R.; Pramanik, S.; Bandopadhyay, P.; Gaber, A.; Hossain, A. Growth, yield, water productivity and economics of okra (*Abelmoschus esculentus* L.) in response to gravity drip irrigation under mulch and without-mulch conditions. *Scientia Horticulturae*, v. 321, 112327, 2023. <https://doi.org/10.1016/j.scienta.2023.112327>
- Qureshi, A. S. Increasing water productivity in the agricultural sector. In: Khan, S. I.; Adams, T. E. (ed.). *Indus River Basin: Water security and sustainability*. Kidlington: Elsevier, 2019. p. 229-244. <https://doi.org/10.1016/B978-0-12-812782-7.00011-4>
- Rascón-Castillo, M.; Lozano-Martínez, C. A.; Jacobo-Cuellar, J. L.; Frias-Moreno, M. N.; Cruz-Álvarez, O.; Hernández-Rodríguez, O. A.; Ojeda-Barrios, D. L.; Parra-Quezada, R. Á. Portainjertos de manzano [*Malus sylvestris* (L.) Mill. var *domestica* (Borkh) Mansf.] sometidos a estrés hídrico. *Terra Latinoamericana*, v. 42, e1773, 2024. <https://doi.org/10.28940/terra.v42i0.1773>
- Rosenzweig, C.; Mbow, C.; Barioni, L. G.; Benton, T. G.; Herrero, M.; Krishnapillai, M.; Liwenga, E. T.; Pradhan, P.; Rivera-Ferre, M. G.; Sapkota, T.; Tubiello, F. N.; Xu, Y.; Contreras, E. M.; Portugal-Pereira, J. Climate change responses benefit from a global food system approach. *Nature Food*, v. 1, n. 2, p. 94-97, 2020. <https://doi.org/10.1038/s43016-020-0031-z>
- Segovia-Cardozo, D. A.; Franco, L.; Provenzano, G. Detecting crop water requirement indicators in irrigated agroecosystems from soil water content profiles: An application for a citrus orchard. *Science of the Total Environment*, v. 806, 150492, 2022. <https://doi.org/10.1016/j.scitotenv.2021.150492>
- Segovia-Cardozo, D. A.; Rodríguez-Sinobas, L.; Zubelzu, S. Water use efficiency of corn among the irrigation districts across the Duero

River basin (Spain): Estimation of local crop coefficients by satellite images. *Agricultural Water Management*, v. 212, p. 241-251, 2019. <https://doi.org/10.1016/j.agwat.2018.08.042>

Silva, A. E. B.; Sousa, G. G.; Nogueira, R. S.; Freire, M. H. C.; Sousa, H. C.; Goes, G. F.; Pereira, M. J. L.; Lopes, D. J. G. Desempenho agrônômico da cultura do sorgo sob estratégias de irrigação e cobertura morta vegetal. *Water Resources and Irrigation Management*, v. 13, n. 1-3, p. 120-130, 2024. <https://doi.org/10.19149/wrim.v13i1-3.4862>

Silva, F. A. S. E.; Azevedo, C. A. V. The Assistat Software version 7.7 and its use in the analysis of experimental data. *African Journal Agricultural Research*, v. 11, n. 39, p. 3733-3740, 2016. <https://doi.org/10.5897/AJAR2016.11522>

Taiz, L.; Zeiger, E.; Møller, I. M.; Murphy, A. *Fundamentos de fisiologia vegetal*. 1.ed. Porto Alegre: Artmed, 2021. 584p.

Trani, P. E.; Passos, F. A.; Teodoro, M. C. C. L.; Santos, V. J.; Frare, P. Calagem e adubação para a cultura do quiabo. 2008. Disponível em: <http://www.infobibos.com/Artigos/2008_1/Quiabo/index.htm>. Acesso em: 04/01/2025.