12

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Citric Acid Foliar Application Impact on Growth and Yield Parameters of Maize (*Zea Mays*) Under Drought Stress Conditions

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THIS experimental investigation was carried out on maize Giza 10 (*Zea mays*) during the course of two consecutive seasons, 2022 and 2023. By spraying applications with varying concentrations of citric acid (0, 100, 200, 300, and 400 ppm) via drip irrigation system, this study sought to improve maize growth and yield under various levels of drought stress (100, 75, and 50% of evapotranspiration ETc) to save irrigation water due to its scarcity at the moment. These treatments reflected conditions achieved as optimal water stress, moderate level of water supply, and severe level of water supply, respectively. In the Belbeis district of the El Sharkia Governorate of Egypt, maize plants are grown in sandy loam soil under water stress. The data demonstrated that the highest values for most of parameters was always for a water supply level of 100% ETc and that when citric acid was used, the best results were in favor of 300 and 400 ppm without any statistical differences between the two concentrations. As for the interaction between the two factors, we find that the highest results were in favor of the interaction between the irrigation level of 100% ETc with spraying at 400 ppm, but we recommend using 300 ppm of citric acid with a water supply level of 75% ETc because it led to increased corn growth and increased its productivity higher than the comparison treatment, which may save 25% of irrigation water while achieving a higher yield and quality than the control treatment.

Keywords: Maize, Water stress, Drought stress, Citric acid, Drip irrigation.

Introduction

Maize (*Zea mays* L.) is one of the most important crops farmed globally, especially in humid tropical and subtropical regions, with an area of 203,470,0007 hectares. It produced 1163,947,383 tons in total in 2022, with an average yield of 5 tons per hectare (FAOSTAT, 2022). Because it has a higher potential for production than other cereal crops, it is referred to as the "Queen of Cereals". Being a C4 plant, it can use solar light much more quickly, even at higher radiation intensities. Around the world, 67 percent of corn is used for animal feed, 25 percent is used for human consumption and industry, and 5 percent can be used as seeds to plant the following crop. As a result, maize is on par with rice and ranks second behind wheat. It serves both human and animal use and is vital to Egyptian diets. Consequently, great care has been taken to increase its overall output. Additionally, efforts are being made to increase the productivity of the maize crop by cultivating high-yielding varieties and/or improving agronomic practices including fertilization and irrigation (El-Yazal, 2019 and Youssef and Hozayen, 2019).

Abiotic environmental factors, such as drought stress, are important in limiting agricultural productivity and can negatively impact maize plant output capacity. On the other hand, maize plants are extremely sensitive to conditions of water scarcity. In semi-arid and rain-fed regions, drought stress lowers agricultural output as well as availability and productivity efficiency. Drought stress affects a number of physiological and biochemical processes, including ion uptake, photosynthesis, food metabolism, respiration, transport, stem expansion, root propagation, ionic imbalance, disturbances in solute accumulation, depression of enzymatic activities, alteration of metabolic activities, or a combination of these processes. The severity of the damage depends on the growth stages and exposure to drought. It is regarded as one of the most notable and common ecological stresses (Ghazi, 2017 and Youssef, Hozayen, 2019; Soroori and Danaee, 2023; Youssef, 2023 and Youssef and Abdelaal, 2023).

Several studies have demonstrated the advantages of use different substances to lessen the effects of drought. Citric acid, a weak organic acid with pH-regulating and antioxidant qualities, is one of these substances (Soroori *et al.*, 2021). As a source of carbon and energy, this molecule is essential for the Krebs cycle, membrane integrity, transport enzyme activation, and carbohydrate metabolism and transport. Furthermore, it promotes plant growth and fresh and dry weight for roots and shoots while also

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having a favorable effect on chelating free radicals. Additionally, it enhances protein, carotenoids, antioxidant enzyme activity, and chlorophyll (Mujahid *et al.*, 2017; El-Yazal, 2019 and Soroori and Danaee, 2023). The goal of the current study is to enhance certain growth and yield characteristics of maize (*Zea mays* L.) under drought stress conditions by applying citric acid topically in varying doses.

Materials and Methods

This experimental investigation was carried out on maize Giza 10 (*Zea mays*) during the course of two consecutive seasons, 2022 and 2023. The purpose of this study was to increase maize production and growth under varying drought stress levels (100, 75, and 50% of evapotranspiration ETc) by using a drip irrigation system to spray varying concentrations of citric acid (0, 100, 200, 300, and 400 ppm). In the Belbeis district of the El Sharkia Governorate of Egypt, maize plants are grown in sandy loam soil under water stress. With the exception of the experimental treatments, all maize plants in this study were subjected to the identical applicable agricultural methods. Five replicates, each measuring 10.50 m^2 (3.00×3.50 m), were used in the experimental setup, which was a split plot arrangement of a complete randomized block design (factorial experiment-split plot design). A backpack sprayer with a 20-liter capacity was used to add a wetting agent (Triton B) to the spraying solution at a concentration of 0.1%. The main plot contained 100, 75, and 50% ETc, and the sub-plot included five citric acid concentrations (0, 100, 200, 300, and 400 ppm). 15 kg of maize seeds per feddan were manually seeded in mid-April. Mid-May and mid-June saw two applications of the necessary rates of citric acid treatments. Irrigation ended at the end of July, but the experiment continued until the end of mid-August. The tested irrigation levels—2647, 1985, and 1324 m^3/feddan/season for the first season, and 2634, 1976, and 1317 m^3/feddan/season for the second season—were determined by different rates of irrigation water and are displayed in Tables 1 and 2. The CROPWAT (2012) version 8.0.1.1 computer program used the region's meteorological data (2022-2023 seasons) to produce these figures. Additionally, the estimated crop water need (ETc) is calculated by multiplying the reference evapotranspiration (ETo) by the specific crop coefficient (Kc), so that ETc = ETo × Kc.

Growth and yield parameters

The tested treatments were evaluated through the following parameters The fresh and dried weight (g) of the flag leaf was measured and recorded 70 days after it was planted. Furthermore, at the conclusion of each experimental season (harvest time), the following parameters were measured and recorded: plant height (cm), stem diameter (cm), number of leaves per plant, fresh weight per plant (g), dry weight per plant (g), ear length (cm), ear diameter (cm), number of grains per ear, grain weight/ear (g), 100-grains weight (g), ear weight/plant (g), grain yield ton per feddan, ear yield ton per feddan, and straw yield ton per feddan.

Photosynthetic pigments Acetone (80%) was used to extract chlorophyll a, b, and total carotenoids from fresh leaves. The quantities of these compounds were then calculated as mg/100g fresh weight in accordance with Von-Wettestein, 1957. **proline content** The Bates *et al.*, 1973 method was used to calculate the proline content of fresh leaves (μ moles/g fresh weight).

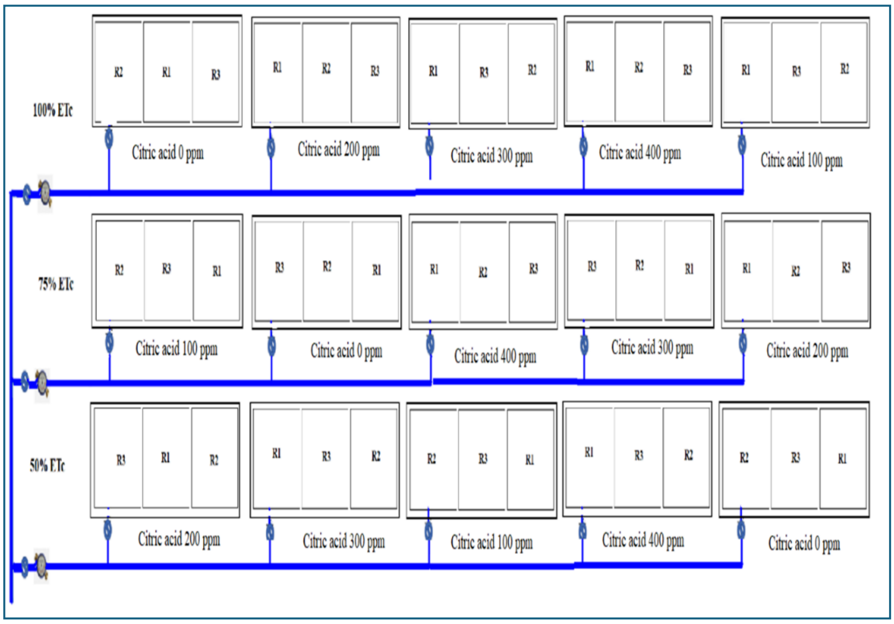

Fig. 1. The experiment layout.

Table 1. The rate of reference crop evapotranspiration (ETo) determined with computer program (CROPWAT V.8.00) by climatic data under Belbeis region – El Sharkia Governorate using FAO – Penman-Monteith equation by Ndulue & Ramanathan, 2021; Youssef *et al.*, 2023 and Mahmoud *et al.*, 2024 method (season 2022).

Month	April	May	June	July	August	Total
No. of days/month	16.00	31.00	30.00	31.00	-	
Crop coefficient	**0.40**	**0.80**	**1.15**	**1.15**	-	
ETo-100%	4.82	5.92	6.62	6.29	-	
ETc-100%	1.93	4.74	7.61	7.23	-	
W.R (m^3/fed./Day)	8.10	19.89	31.97	30.38	-	
W.R (m^3/ fed. Month)	129.56	616.63	959.24	941.80	-	2647
ETo-75%	3.62	4.44	4.97	4.72	-	
ETc-75%	1.45	3.55	5.71	5.43	-	
W.R (m^3/fed./Day)	6.07	14.92	23.98	22.79	-	
W.R (m^3/ fed. Month)	97.17	462.47	719.43	706.35	-	1985
ETo-50%	2.41	2.96	3.31	3.15	-	
ETc-50%	0.96	2.37	3.81	3.62	-	
W.R (m^3/fed./Day)	4.05	9.95	15.99	15.19	-	
W.R (m^3/ fed. Month)	64.78	308.31	479.62	470.90	-	1324

Table 2. The rate of reference crop evapotranspiration (ETo) determined with computer program (CROPWAT V.8.00) by climatic data under Belbeis region – El Sharkia Governorate using FAO – Penman-Monteith equation by Ndulue & Ramanathan, 2021; Youssef *et al.*, 2023 and Mahmoud *et al.*, 2024 method (season 2023).

Month	April	May	June	July	August	Total
No. of days/month	16.00	31.00	30.00	31.00	-	
Crop coefficient	**0.40**	**0.80**	**1.15**	**1.15**	-	
ETo-100%	4.91	5.84	6.58	6.28	-	
ETc-100%	1.96	4.67	7.57	7.22	-	
W.R (m^3/fed./Day)	8.25	19.62	31.78	30.33	-	
W.R (m^3/ fed. Month)	131.98	608.29	953.44	940.30	-	2634
ETo-75%	3.68	4.38	4.94	4.71	-	
ETc-75%	1.47	3.50	5.68	5.42	-	
W.R (m^3/fed./Day)	6.19	14.72	23.84	22.75	-	
W.R (m^3/ fed. Month)	98.99	456.22	715.08	705.23	-	1976
ETo-50%	2.46	2.92	3.29	3.14	-	
ETc-50%	0.98	2.34	3.78	3.61	-	
W.R (m^3/fed./Day)	4.12	9.81	15.89	15.17	-	
W.R (m^3/ fed. Month)	65.99	304.15	476.72	470.15	-	1317

Statistical Analysis

Five replicates, each measuring 10.5 m^2 (3X3.5), were used in the experimental setup, which was a split plot arrangement of a complete randomized block design (factorial experiment-split plot design). Three citric acid concentrations (0, 100, 200, 300, and 400 ppm) were included in the sub-plot, whereas the main plot had 100, 75, and 50% ETc. According to Snedecor and Cochran (1980), the analysis of variance approach was used to statistically examine the collected data. Duncan's range test was used to distinguish between the mean differences (Duncan, 1955.

Results

Growth vigor parameters (Plant height, stem diameter, numbers of leaves per plant, dry weight of leaves per plant, leaf flag fresh weight and leaf flag dry weight

Plant height, stem diameter, number of leaves per plant, dry weight of leaves per plant, leaf flag fresh weight, and leaf flag dry weight were all significantly impacted by water irrigation levels and citric acid concentrations in both seasons, according to the findings in Table (3). ETc for water stress in the first season, 50% water irrigation reduced plant height, leaf count, and leaf flag fresh weight by 229.07 cm, 14.75, and 12.61 g, respectively, in comparison to 100% ETc water irrigation. Citrus acid 300 and 400 ppm spraying also produced the highest results, reaching 237.24 cm, 14.88, and 13.02 g for 300 ppm and 238.13 cm, 14.89, and 13.07 g for 400 ppm under plant height, number of leaves per plant, and leaf flag fresh weight, respectively, in comparison to citric acid ppm. Furthermore, the heights values of 247.40 cm, 15.08, and 13.85 g for citric acid 300 ppm and 248.22 cm, 15.08, and 13.85 g for citric acid 400 ppm were obtained by spraying them with 100% ETc water irrigation. Additionally, under plant height, number of leaves per plant, and leaf flag fresh weight, citric acid 300 and 400 ppm with ETc 50% of water irrigation achieved 221.31 cm, 14.85, and 11.86 g for citric acid 300 ppm and 223.45 cm, 14.64, and 12.01 g for citric acid 400 ppm. With 100% ETc of water irrigation, those results were statistically higher than citric acid 0 ppm. In terms of plant height, the number of leaves per plant, and the fresh weight of the leaf flags, the second season follows the same pattern as the first. Additionally, in both seasons, the stem diameter, dry weight of leaves per plant, and dry weight of leaf flags show the same tendency with regard to plant height.

Yield parameters (ear length, ear diameter, number of grains per ear, grain weight per ear, 100-grains weight and ear weight per plant) The information in Table (4) demonstrated that, in both seasons, ear length, ear diameter, number of grains per ear, grain weight per ear, 100-grains weight, and ear weight per plant were significantly impacted by water irrigation levels and citric acid concentrations. ETc water stress in comparison to 100% ETc water irrigation in the first season, 50% water irrigation reduced the number of grains per ear and the ear weight per plant, which were 407.97 and 191.07 g, respectively. Furthermore, when compared to citric acid ppm, the greatest values were obtained by spraying 300 and 400 ppm of citric acid, reaching 460.06 and 248.14 g for 300 ppm and 461.48 and 249.97 g for 400 ppm under number of grains per ear and ear weight per plant, respectively. Additionally, spraying 300 and 400 ppm of citric acid along with 100% ETc water irrigation increased the heights by 482.28 and 273.48 g for 300 ppm and 481.98 and 273.63 g for 400 ppm, respectively. Additionally, under the number of grains per ear and ear weight per plant, respectively, citric acid 300 and 400 ppm with ETc 50% of water irrigation reached 429.69 and 214.82 g and 434.12 and 220.05 g, respectively. With 100% ETc of water irrigation, those results were statistically higher than citric acid 0 ppm. In terms of ear weight per plant and quantity of grains per ear, the second season follows the same pattern as the first. Additionally, in both seasons, the trend for the number of grains per ear and ear weight per plant is the same for ear length, ear diameter, grain weight per ear, and 100-grains weight.

Yield (grain, ear and straw yield ton per feddan)

The information in Table (5) demonstrated that the amount of water used for irrigation and the concentration of citric acid significantly impacted the amount of grain, ear, and straw produced per feddan over both seasons. ETc water stress in comparison to 100% ETc water irrigation in the first season, 50% water irrigation reduced the production of grain, ear, and straw per feddan, which were 3.29, 0.43, and 4.14 tons per feddan, respectively. Furthermore, spraying 300 and 400 ppm of citric acid had the maximum results, reaching 4.12, 0.50, and 4.50 tons per feddan for 300 ppm of citric acid, respectively. Citric acid 400 ppm under grain, ear, and straw yields ton per feddan at 4.14, 0.50, and 4.51 tons, respectively, in comparison to citric acid 0 ppm. Additionally, the heights values of 4.44, 0.52, and 4.62 tons per feddan g for citric acid 300 ppm and 4.45, 0.53, and 4.63 tons per feddan for citric acid 400 ppm were achieved by spraying the acid with 100% ETc of water irrigation. Additionally, under grain, ear, and straw yield tons per feddan, the citric acid 300 and 400 ppm with ETc 50% of water irrigation were 3.64, 0.46, and 4.31 tons per feddan for the 300 ppm and 3.70, 0.47, and 4.34 tons per feddan for the 400 ppm. With 100% ETc of water irrigation, those results were statistically higher than citric acid 0 ppm. In terms of under grain, ear, and straw yield tons per feddan, the second season follows the same pattern as the first.

Table 3. Effect of water stress and foliar application with citric acid concentrations on plant growth parameters of maize plants (2022-2023 seasons).

Treatments	Plant height (cm)	Stem diameter (cm)	Number of leaves per plant	Dry weight of leaves per plant (g)	leaf flag fresh weight (g)	leaf flag dry weight (g)
			First season (2022)			
ETc-100% (control)	229.07A	2.58A	14.75A	74.03A	12.61A	3.32A
ETc-75%	224.44B	2.51A	14.65A	73.49A	12.20B	3.18B
ETc-50%	206.86C	2.27B	14.38A	71.80B	11.14C	2.63C
C.A.0-ppm	195.93D	2.13D	14.22D	70.78D	10.59D	2.32D
C.A.100-ppm	206.67C	2.28C	14.36C	71.81C	11.17C	2.66C
C.A.200-ppm	222.65B	2.48B	14.63B	73.41B	12.09B	3.10B
C.A.300-ppm	237.24A	2.68A	14.88A	74.72A	13.02A	3.56A
C.A.400-ppm	238.13A	2.69A	14.89A	74.81A	13.07A	3.58A
ETc-100% X C.A.0-ppm	200.74f	2.21g	14.31d	71.41e	10.94f	2.48h
ETc-100% X C.A.10-ppm	215.13d	2.40e	14.48d	72.73d	11.66e	2.91f
ETc-100% X C.A.200-ppm	233.88b	2.61c	14.82b	74.43b	12.77c	3.41c
ETc-100% X C.A.300-ppm	247.40a	2.83a	15.08a	75.76a	13.85a	3.90a
ETc-100% X C.A.400-ppm	248.22a	2.84a	15.08a	75.80a	13.85a	3.92a
ETc-75% X C.A.0-ppm	196.33f	2.15g	14.25e	70.83f	10.66f	2.39h
ETc-75% X C.A.100-ppm	211.89d	2.33f	14.38d	72.16d	11.33e	2.80f
ETc-75% X C.A.200-ppm	228.22c	2.57c	14.72c	74.02b	12.33d	3.23d
ETc-75% X C.A.300-ppm	243.02a	2.77b	14.97a	75.24a	13.36b	3.75b
ETc-75% X C.A.400-ppm	242.71a	2.74b	14.95a	75.22a	13.33b	3.72b
ETc-50% X C.A.0-ppm	190.71g	2.03h	14.11f	70.11f	10.16f	2.10j
ETc-50% X C.A.100-ppm	192.99g	2.10g	14.21e	70.54f	10.53f	2.26i
ETc-50% X C.A.200-ppm	205.84e	2.26g	14.34d	71.79e	11.16e	2.66g
ETc-50% X C.A.300-ppm	221.31c	2.45d	14.58c	73.15c	11.86e	3.02f
ETc-50% X C.A.400-ppm	223.45c	2.49d	14.64c	73.41c	12.01d	3.11e
			Second season (2023)			
ETc-100% (control)	230.86A	2.56A	14.77A	74.05A	12.67A	3.32A
ETc-75%	225.93B	2.51A	14.68A	73.53B	12.32B	3.19B
ETc-50%	208.89C	2.25B	14.41A	71.94C	11.15C	2.58C
C.A.0-ppm	199.78D	2.12D	14.27D	70.82D	10.54D	2.22D
C.A.100-ppm	209.20C	2.25C	14.41C	71.88C	11.10C	2.59C
C.A.200-ppm	225.21B	2.47B	14.67B	73.54B	12.30B	3.14B
C.A.300-ppm	237.09A	2.68A	14.88A	74.75A	13.10A	3.59A
C.A.400-ppm	238.18A	2.69A	14.89A	74.86A	13.19A	3.62A
ETc-100% X C.A.0-ppm	206.73g	2.20g	14.37f	71.41e	10.92f	2.36i
ETc-100% X C.A.10-ppm	217.86e	2.33f	14.53e	72.74d	11.64e	2.86g
ETc-100% X C.A.200-ppm	235.00c	2.61c	14.82b	74.48b	13.07c	3.49d
ETc-100% X C.A.300-ppm	247.04a	2.83a	15.07a	75.79a	13.83a	3.94a
ETc-100% X C.A.400-ppm	247.65a	2.83a	15.08a	75.82a	13.87a	3.95a
ETc-75% X C.A.0-ppm	200.39h	2.15h	14.29g	70.82f	10.63f	2.25i
ETc-75% X C.A.100-ppm	212.54f	2.30f	14.49e	72.26d	11.33e	2.74g
ETc-75% X C.A.200-ppm	231.24c	2.55d	14.76c	74.16b	12.68d	3.37e
ETc-75% X C.A.300-ppm	243.06b	2.77b	14.95a	75.22a	13.47b	3.81b
ETc-75% X C.A.400-ppm	242.42b	2.77b	14.94a	75.18a	13.49b	3.77c
ETc-50% X C.A.0-ppm	192.24j	2.02i	14.14i	70.25f	10.06f	2.04k
ETc-50% X C.A.100-ppm	197.21i	2.10h	14.21h	70.65f	10.31f	2.17j
ETc-50% X C.A.200-ppm	209.37g	2.24g	14.44e	71.98e	11.14e	2.54h
ETc-50% X C.A.300-ppm	221.15d	2.44e	14.62d	73.23c	12.00d	3.03f
ETc-50% X C.A.400-ppm	224.46d	2.48e	14.66d	73.57c	12.22d	3.14f

ETc = evapotranspiration and C.A.= Citric acid.

Mean followed by the same letter\s within each column are not significantly different from each other at 0.5% level.

Table 4. Effect of water stress and foliar application with citric acid concentrations on ear growth parameters of maize plants (2022-2023 seasons).

Treatments	Ear length (cm)	Ear diameter (cm)	Number of grains per Ear	Grain weight per Ear (g)	100-grains weight (g)	Ear weight per plant (g)
			First season (2022)			
ETc-100% (control)	18.51A	4.35A	446.86A	194.93A	36.11A	233.97A
ETc-75%	17.71B	4.19B	436.50B	186.62B	34.70B	221.92B
ETc-50%	15.01C	3.68C	407.97C	162.44C	29.79C	191.07C
C.A.0-ppm	13.27D	3.34D	390.01D	146.71D	26.93D	172.85D
C.A.100-ppm	15.14C	3.71C	407.98C	163.29C	29.55C	190.28C
C.A.200-ppm	17.55B	4.17B	432.69B	183.67B	34.54B	217.02B
C.A.300-ppm	19.65A	4.55A	460.06A	206.14A	38.23A	248.14A
C.A.400-ppm	19.78A	4.58A	461.48A	206.84A	38.41A	249.97A
ETc-100% X C.A.0-ppm	14.08h	3.54i	398.03h	155.71g	28.28f	181.48g
ETc-100% X C.A.10-ppm	16.57f	3.95f	422.76f	175.61e	31.81e	205.08e
ETc-100% X C.A.200-ppm	19.03c	4.46c	449.24c	197.71c	37.58b	236.19c
ETc-100% X C.A.300-ppm	21.37a	4.90a	482.28a	222.72a	41.38a	273.48a
ETc-100% X C.A.400-ppm	21.49a	4.90a	481.98a	222.91a	41.48a	273.63a
ETc-75% X C.A.0-ppm	13.52i	3.44j	390.65h	148.26h	27.22f	174.36h
ETc-75% X C.A.100-ppm	15.93g	3.86g	414.70g	168.80f	30.43e	196.51f
ETc-75% X C.A.200-ppm	18.55d	4.30d	440.61c	193.13c	36.27c	226.38d
ETc-75% X C.A.300-ppm	20.36b	4.67b	468.20b	212.57b	40.00a	256.11b
ETc-75% X C.A.400-ppm	20.21b	4.67b	468.33b	210.34b	39.56a	256.24b
ETc-50% X C.A.0-ppm	12.23k	3.06l	381.34i	136.16i	25.27g	162.73h
ETc-50% X C.A.100-ppm	12.92j	3.33k	386.49h	145.47h	26.42f	169.24h
ETc-50% X C.A.200-ppm	15.06g	3.75h	408.22h	160.16f	29.76e	188.49g
ETc-50% X C.A.300-ppm	17.22e	4.08e	429.69e	183.13d	33.33d	214.82d
ETc-50% X C.A.400-ppm	17.63e	4.17e	434.12d	187.27d	34.19d	220.05d
			Second season (2023)			
ETc-100% (control)	18.62A	4.32A	445.31A	194.84A	36.63A	240.47A
ETc-75%	17.88B	4.14B	435.21B	186.51B	35.21B	232.57B
ETc-50%	15.05C	3.61C	408.86C	161.21C	30.24C	199.73C
C.A.0-ppm	13.41D	3.28D	391.92D	147.26D	27.37D	177.77D
C.A.100-ppm	15.08C	3.58C	410.57C	161.20C	30.51C	198.88C
C.A.200-ppm	17.66B	4.10B	430.79B	183.12B	35.13B	230.27B
C.A.300-ppm	19.78A	4.57A	457.57A	205.45A	38.46A	256.13A
C.A.400-ppm	19.99A	4.59A	458.11A	207.23A	38.67A	258.24A
ETc-100% X C.A.0-ppm	14.18h	3.47i	402.07f	158.12e	29.40f	187.99i
ETc-100% X C.A.10-ppm	16.43f	3.82f	424.71d	173.69e	32.88e	215.28f
ETc-100% X C.A.200-ppm	19.38c	4.47c	443.32c	197.23c	38.02c	249.13c
ETc-100% X C.A.300-ppm	21.50a	4.91a	477.91a	221.68a	41.44a	274.40a
ETc-100% X C.A.400-ppm	21.62a	4.93a	478.54a	223.50a	41.43a	275.57a
ETc-75% X C.A.0-ppm	13.77i	3.34j	392.26f	146.27f	27.42g	181.85i
ETc-75% X C.A.100-ppm	15.74g	3.66g	417.80e	167.56e	31.98e	208.31g
ETc-75% X C.A.200-ppm	18.76d	4.30d	437.50d	188.99d	36.74d	244.21c
ETc-75% X C.A.300-ppm	20.58b	4.71b	465.48b	215.09b	39.99b	265.23b
ETc-75% X C.A.400-ppm	20.54b	4.69b	463.04b	214.64b	39.93b	263.26b
ETc-50% X C.A.0-ppm	12.29k	3.04l	381.44h	137.39g	25.30i	163.47k
ETc-50% X C.A.100-ppm	13.07j	3.26k	389.21g	142.36f	26.67h	173.06j
ETc-50% X C.A.200-ppm	14.83h	3.52h	411.56e	163.14e	30.64e	197.48h
ETc-50% X C.A.300-ppm	17.27e	4.07e	429.33d	179.59d	33.94e	228.75e
ETc-50% X C.A.400-ppm	17.80e	4.17e	432.76d	183.55d	34.66e	235.89d

ETc = evapotranspiration and C.A.= Citric acid.

Mean followed by the same letter\s within each column are not significantly different from each other at 0.5% level.

Table 5. Effect of water stress and foliar application with citric acid concentrations on yield growth parameters of maize plants (2022-2023 seasons).

Treatments	Grain yield	Ear yield (ton per feddan)	Straw yield (ton per feddan)
	First season (2022)		
ETc-100% (control)	3.92A	0.48A	4.40A
ETc-75%	3.79B	0.47A	4.34B
ETc-50%	3.29C	0.43B	4.14C
C.A.0-ppm	3.05D	0.41D	4.03D
C.A.100-ppm	3.32C	0.43C	4.12C
C.A.200-ppm	3.70B	0.47B	4.33B
C.A.300-ppm	4.12A	0.50A	4.50A
C.A.400-ppm	4.14A	0.50A	4.51A
ETc-100% X C.A.0-ppm	3.22j	0.43a	4.07j
ETc-100% X C.A.10-ppm	3.53g	0.45a	4.22g
ETc-100% X C.A.200-ppm	3.96c	0.49a	4.45c
ETc-100% X C.A.300-ppm	4.44a	0.52a	4.62a
ETc-100% X C.A.400-ppm	4.45a	0.53a	4.63a
ETc-75% X C.A.0-ppm	3.11k	0.41a	4.03j
ETc-75% X C.A.100-ppm	3.43h	0.44a	4.17h
ETc-75% X C.A.200-ppm	3.85d	0.48a	4.40d
ETc-75% X C.A.300-ppm	4.29b	0.51a	4.56b
ETc-75% X C.A.400-ppm	4.27b	0.51a	4.56b
ETc-50% X C.A.0-ppm	2.83m	0.40a	3.98j
ETc-50% X C.A.100-ppm	3.00l	0.41a	3.97j
ETc-50% X C.A.200-ppm	3.30i	0.44a	4.12i
ETc-50% X C.A.300-ppm	3.64f	0.46a	4.31f
ETc-50% X C.A.400-ppm	3.70e	0.47a	4.34e
	Second season (2023)		
ETc-100% (control)	3.87A	0.49A	4.38A
ETc-75%	3.71B	0.48A	4.32B
ETc-50%	3.26C	0.44B	4.13C
C.A.0-ppm	3.00D	0.42D	4.01D
C.A.100-ppm	3.28C	0.44C	4.13C
C.A.200-ppm	3.67B	0.47B	4.30B
C.A.300-ppm	4.05A	0.50A	4.47A
C.A.400-ppm	4.07A	0.51A	4.48A
ETc-100% X C.A.0-ppm	3.14j	0.43a	4.08g
ETc-100% X C.A.10-ppm	3.47g	0.46a	4.22f
ETc-100% X C.A.200-ppm	3.94c	0.49a	4.41c
ETc-100% X C.A.300-ppm	4.39a	0.53a	4.59a
ETc-100% X C.A.400-ppm	4.41a	0.53a	4.60a
ETc-75% X C.A.0-ppm	3.03k	0.42a	4.03g
ETc-75% X C.A.100-ppm	3.41h	0.45a	4.18f
ETc-75% X C.A.200-ppm	3.78d	0.48a	4.36d
ETc-75% X C.A.300-ppm	4.16b	0.52a	4.53b
ETc-75% X C.A.400-ppm	4.16b	0.52a	4.53b
ETc-50% X C.A.0-ppm	2.84m	0.40a	3.92h
ETc-50% X C.A.100-ppm	2.95l	0.42a	3.99g
ETc-50% X C.A.200-ppm	3.29i	0.44a	4.14f
ETc-50% X C.A.300-ppm	3.59f	0.47a	4.28e
ETc-50% X C.A.400-ppm	3.64e	0.47a	4.31e

ETc = evapotranspiration and C.A.= Citric acid.

Mean followed by the same letter\s within each column are not significantly different from each other at 0.5% level.

Pigments and proline leaf contents

With reference to Table (6), ETC 50% had an impact on pigments and proline leaf contents, reaching 131.191 and 73.86 mg/100g f.w., respectively, while ETc 100% had an impact on chlorophyll a and b, reaching 151.67 and 83.79 mg/100g f.w. Furthermore, the administration of 300 and 400 ppm of citric acid impacted the levels of chlorophyll a and b, reaching 159.38 and 86.54 mg/100g f.w. for 300 ppm and 160.23 and 87.04 mg/100g f.w. for 400 ppm under chlorophyll a and b, respectively. It is evident that the height values for chlorophyll a and b were 169.31 and 91.88 for citric acid 300 ppm and 169.13 and 92.13 mg/100g f.w. for citric acid 400 ppm under chlorophyll a and b, respectively, when the acid was sprayed with 100% ETc of irrigation water. Furthermore, in comparison to (control) spraying citric acid 0 ppm with ETc 100% of irrigation water, which resulted in 126.34 and 71.90 mg/100g f.w. under chlorophyll a and b, respectively, the use of spraying citric acid 300 and 400 ppm with ETc 50% of irrigation water gained 143.84 and 79.96 mg/100g f.w. for citric acid 300 and 147.22 and 81.29 mg/100g f.w. for citric acid 400. In both seasons, this was accurate. Conversely, proline leaf content rose as irrigation water level decreased from ETc 100% to ETc 50% of water irrigation. It's noteworthy to note that proline content rose as irrigation water quantity decreased. Compared to 84.57 µ g/moles of fresh leaf with 100% ETc in the first season, proline content reaches a high value with ETc 50%, reaching 146.92 µ g/moles of fresh leaf. Furthermore, when 300 and 400 ppm of citric acid are applied, proline quantities decrease to 63.84 and 61.71 µ g/moles of fresh leaf, respectively. Therefore, the lowest proline concentration values—32.69 and 31.81 µ g/moles of fresh leaf, respectively were obtained by spraying citric acid at 300 and 400 ppm with 100% ETc of irrigation water. In both seasons, this was the case. Additionally, in both seasons, the total carotenoids show the similar tendency toward proline leaf content.

Discussion

In this regard, the experimental study's current findings indicate how irrigation levels affect maize's vegetative growth and production characteristics. According to the data, the highest significant values of vegetative growth and yield characteristics were obtained with irrigation that used 100% ETc. The content of proline leaves was an outlier, exhibiting the opposite trend in the first and second seasons. Drought stress, which impacts plant growth by reducing the number of leaves and leaf area, leading to less photosynthesis, may be the cause of the detrimental effects of the lowest irrigation level (ETc 50%) on vegetative growth and yield characteristics (Silber, 2005). The outcomes are consistent with those published by Sultan *et al.*, 2016; Karasu *et al.*, 2015; Ertek and Kara, 2013; Bozkurt *et al.*, 2006; Cakir, 2004. They showed that applying the most irrigation resulted in the highest values of vegetative growth and yield attributes. Furthermore, it is evident that foliar sprays of citric acid greatly enhanced vegetative growth and production characteristics, particularly when treated with 300 and 400 ppm of citric acid. Furthermore, in both seasons, the citric acid 0 ppm treatment had the lowest significant values in this regard. Citric acid's direct effects on controlling osmotic potential and the Krebs cycle may be the cause of the notable results of its foliar application. Additionally, it increases the uptake of water and nutrients and improves the synthesis of phytohormones under stress as a natural chelating agent (Miri *et al.*, 2015). However, citric acid lowers pH, acidifies the environment, and stops ethylene from forming, which limits the activity of the synthetase enzyme (Eidyan *et al.*, 2014). Additionally, using citric acid topically lowered the pH of the leaf extract, activating the leaf iron and promoting the production of chlorophyll. Furthermore, by lowering optical oxidation and preserving the integrity of photosynthetic membranes, citric acid stopped the deterioration of pigments under stress. A prior study found that applying citric acid to Thymus vulgaris L. increased the amount of carotenoid and total chlorophyll (Miri *et al.*, 2015). Because citric acid may have stimulated the signaling pathways of secondary metabolism in plants, foliar application of the acid boosted the flavonoid content of plants (Salas-Pérez *et al.*, 2018), therefore playing a useful part in raising the concentrations of these substances. Because citric acid has antioxidant qualities, it also reduced pH and acidified the medium, protecting cell membranes and cellular contents, including vitamin C. As a result, it stopped the synthesis of ethylene and the decrease of vitamin C by inhibiting ACC synthetase activity (Soroori *et al.*, 2021a). Citric acid applied topically decreased MDA, H_2O_2, and O_2 levels while shielding cells from stress-related harm. The use of citric acid lessens this damage by eliminating free radicals, which are typically produced during plant metabolism and cause lipid oxidation, permeability loss, and cell death (Hu *et al.*, 2016). Data from our study clearly demonstrate that applying 50% ETc in conjunction with foliar applications of 300 and 400 ppm of citric acid had the same significant affection as 100% ETc in conjunction with foliar applications of 0 ppm of citric acid (control) with regard to the effect of the interaction between irrigation levels and foliar applications of citric acid on the vegetative growth and yield characteristics of maize.

Table 6. Effect of water stress and foliar application with citric acid concentrations on leaf pigments and proline of maize plants (2022-2023 seasons).

Treatments	Chlorophyll a (mg/100g F.W)	Chlorophyll b (mg/100g F.W)	Total Carotenoids (mg/100g F.W)	Proline (μm/F.W.g)
		First season (2022)		
ETc-100% (control)	151.67A	83.79A	15.56C	84.57C
ETc-75%	147.66B	80.84B	16.17B	97.69B
ETc-50%	131.91C	73.86C	18.11A	146.92A
C.A.0-ppm	122.01D	68.85D	18.96A	173.04A
C.A.100-ppm	130.88C	74.07C	18.06A	146.68B
C.A.200-ppm	146.21B	80.98B	16.50B	103.37C
C.A.300-ppm	159.38A	86.54A	14.79C	63.84D
C.A.400-ppm	160.23A	87.04A	14.74C	61.71D
ETc-100% X C.A.0-ppm	126.34f	71.90d	18.42b	152.37d
ETc-100% X C.A.10-ppm	138.14e	78.03c	17.33c	124.82g
ETc-100% X C.A.200-ppm	155.43c	84.98c	15.53e	81.14i
ETc-100% X C.A.300-ppm	169.31a	91.88a	13.26g	32.69k
ETc-100% X C.A.400-ppm	169.13a	92.13a	13.25g	31.81k
ETc-75% X C.A.0-ppm	122.81f	69.04d	18.79b	168.27c
ETc-75% X C.A.100-ppm	134.01e	75.89d	17.67c	131.68f
ETc-75% X C.A.200-ppm	152.13c	83.84c	16.00d	87.42i
ETc-75% X C.A.300-ppm	165.00b	87.77b	14.09f	49.27j
ETc-75% X C.A.400-ppm	164.34b	87.69b	14.27f	51.81j
ETc-50% X C.A.0-ppm	116.89g	65.62e	19.68a	198.47a
ETc-50% X C.A.100-ppm	120.51f	68.30d	19.16a	183.54b
ETc-50% X C.A.200-ppm	131.08e	74.11d	17.97c	141.55e
ETc-50% X C.A.300-ppm	143.84d	79.96c	17.02c	109.55h
ETc-50% X C.A.400-ppm	147.22d	81.29c	16.71d	101.52h
		Second season (2023)		
ETc-100% (control)	149.95A	83.30A	15.40C	86.94C
ETc-75%	146.14B	80.79B	16.00B	101.62B
ETc-50%	130.16C	73.50C	17.82A	149.54A
C.A.0-ppm	120.65D	68.94D	18.97A	173.73A
C.A.100-ppm	128.67C	73.70C	17.91B	147.17B
C.A.200-ppm	144.25B	80.25B	16.08C	112.87C
C.A.300-ppm	157.73A	86.27A	14.60D	65.63D
C.A.400-ppm	159.11A	86.82A	14.49D	64.08D
ETc-100% X C.A.0-ppm	124.65f	71.98f	18.16b	155.18d
ETc-100% X C.A.10-ppm	135.53e	76.96e	16.98d	129.72g
ETc-100% X C.A.200-ppm	153.02c	84.38c	15.06e	91.29i
ETc-100% X C.A.300-ppm	167.82a	91.26a	13.42g	29.13k
ETc-100% X C.A.400-ppm	168.75a	91.90a	13.40g	29.37k
ETc-75% X C.A.0-ppm	121.32f	69.27f	18.90b	168.85c
ETc-75% X C.A.100-ppm	131.67e	75.84e	17.45c	139.04f
ETc-75% X C.A.200-ppm	150.42c	82.57d	15.40e	99.37i
ETc-75% X C.A.300-ppm	163.92b	88.10b	14.14f	50.13j
ETc-75% X C.A.400-ppm	163.35b	88.17b	14.13f	50.70j
ETc-50% X C.A.0-ppm	115.98f	65.57g	19.84a	197.18a
ETc-50% X C.A.100-ppm	118.81f	68.30f	19.32a	172.76b
ETc-50% X C.A.200-ppm	129.32e	73.81e	17.78c	147.95e
ETc-50% X C.A.300-ppm	141.46d	79.46d	16.24d	117.62h
ETc-50% X C.A.400-ppm	145.24d	80.38d	15.93e	112.18h

ETc = evapotranspiration and C.A.= Citric acid.
Mean followed by the same letter\s within each column are not significantly different from each other at 0.5% level.

Conclusion

In summary, the results clearly show that the highest values for most of parameters was always for a water supply level of 100% ETc and that when citric acid was used, the best results were in favor of 300 and 400 ppm without any statistical differences between the two concentrations. As for the interaction between the two factors, we find that the highest results were in favor of the interaction between the irrigation level of 100% ETc with spraying at 400 ppm, but we recommend using 300 ppm of citric acid with a water supply level of 75% ETc because it led to increased corn growth and increased its productivity higher than the comparison treatment (100% ETc with spraying at 0 ppm), which may save 25% of irrigation water while achieving a higher yield and quality than the control treatment.

Consent for publication

All authors declare their consent for publication.

Author contribution

The manuscript was edited and revised by all authors.

Conflicts of Interest

The author declares no conflict of interest.

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