Journal of Innovations in Pharmaceutical and Biological Sciences (JIPBS)
ISSN: 2349-2759
Available online at https://jipbs.com/index.php/journal

Research article

Application of fulvic acid and potassium fertilization to reduce the harmful effect of salt water stress on growth, productivity and nutritional status of tomato plants

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Received on: 04/03/2024, Revised on: 09/05/2024, Accepted on: 29/05/2024, Published on: 30/06/2024.

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Keywords: Fulvic acid, Potassium fertilization, Tomato plants, Growth, Yield, Nutrients uptake**.**

Vol. 11 (2): 01-09, Apr-Jun, 2024.

DOI: http://doi.org/10.56511/JIPBS.2024.11201

Abstract

Water is a key resource for sustainable agricultural development in Egypt. The scarcity of fresh water resources in Egypt has led to the use of salt water for irrigation. Therefore, the aim of the research was to study the effect of potassium fertilization and spraying with fulvic acid on tomato plants irrigated with salt water and grown in sandy soil during two successive growing seasons. Different rates of the potassium fertilization combined with different concentrations of fulvic acid foliar application. The rates of K fertilization were 150, 200 and 300 Kg K_2O per hectare of the recommended fertilizer unit (300 kg K_2O ha^{-1}). While, the concentrations of fulvic acid were 500, 1000 and 2000 mgl^{-1}. Increasing the spraying concentration of fulvic acid from 500 to 2000 ppm resulted in a significant improvement in the parameters of growth, quantity and quality yield of tomato plants with an increase in potassium fertilization rates from 150 to 300 K_2O kg ha^{-1} with the use of saline irrigation water. Increasing the concentration of fulvic acid spraying led to the uptake of nitrogen, phosphorus and potassium in tomato leaves increased with an increase in potassium fertilization rates. Therefore, it can be said that spraying fulvic acid with the use of potassium fertilization is one of the successful solutions in reducing the effect of irrigation with salt water on the growth and yield of tomato plants.

Introduction

In desert regions, the salinity of soil and water is constantly increasing. Secondary salinization has affected more than 770,000 square kilometers of land worldwide (20% of irrigated areas and 2% of agricultural land) [1]. Salinity is the main abiotic factor limiting plant growth and fruit yield [2]. They cause osmotic and toxic effects and cause physiological, morphological and biochemical changes. They exert osmotic and toxic effects and cause physiological, morphological, and biochemical changes. This results in stunted growth, reduced production, reduced photosynthesis and respiration, nutrient deficiencies, and inhibition of protein synthesis [3]. These phenomena have been observed in agricultural and horticultural crops such as tomatoes [4].

Potassium plays an important role in tomato fruit quality through its involvement in metabolic processes such as enzyme activation, protein synthesis, and membrane transport processes [5]. Potassium is an essential element required for plant growth and physiological function. Potassium is not only a component of plant structure, but also plays a regulatory role in many biochemical processes related to protein synthesis, carbohydrate metabolism, and enzyme activation [6]. Malkuti *et al.*, [7] reported that potassium alleviates water, salinity and drought stress, thereby reducing water requirements of crops. This is because K plays an important role in opening and closing the stomata, allowing water to leave the leaf and carbon dioxide to enter the leaf. Wang *et al.*, [8] reported importance of maintaining optimal nutritional potassium status for plants to cope with biotic and abiotic stresses. Effective use of balanced fertilizers and potassium as well as other nutrients not only promotes sustainable growth, productivity and crop quality, but also affects plant health and reduces environmental risks.

Fulvic acid is a plant bio-stimulant and is mainly formed through the biodegradation of plant organic matter, including lignin [9]. The fulvic acid fraction contains many complex compounds. Therefore, the exact chemical composition is unknown. Several models of fulvic acids are presented in (Figure 1) [10 &11]. When applied to plants, fulvic acid affects cell membranes, increases mineral transport, improves protein synthesis, phytohormone-like activity, enhances photosynthesis, changes enzyme activity, and solubilizes trace and macro-elements. Reduce toxic substances and increase microbial populations [12]. The effect of foliar application of fulvic acid on plants production, increasing the fulvic acid concentrations increased the seed and straw yield of faba bean [13], the productivity and quality of onions [12], as well as increased the marketable yield of tomato [14] and cucumber [15]. Fulvic acid is one of two naturally occurring acidic organic polymers that can be extracted from humus found in sediments, soils, or aquatic environments and represents a small portion of soil organic matter [16]. Furthermore, fulvic acid is considered to be a microbial metabolite and plays a stimulating role in protecting crops from salt stress. Although fulvic acid is not produced as a source of carbon or energy, it plays an important role in protecting crops from salt stress [17].

Tomato (*Solanum lycopersicum*) is considered one of the most important vegetable crops in Egypt. It is considered one of the industrial crops that greatly contributes to Egypt's national agricultural income [18]. Tomato is a rich source of minerals and vitamins and its unique nutritional properties play an important role in reducing the risk of heart and related diseases due to its activity in regulating disease pathways [19].

The current study was conducted to use potassium fertilization rates and fulvic acid concentration to decrease negative effect of saline water stress on growth, productivity and nutritional status of tomato plants.

Material and methods

Site description and plant material

The trials were conducted during the 2021/2022 and 2022/2023 consecutive winter seasons at the National Research Centre Experimental Station in the Nubaria Region of Bihera Governorat (30°30°N Latitude and 30°20°E Longitude). Physical and chemical properties of El-Nubaria soil samples were determined well as particle size distributions and soil moisture were determined as described by Blackmore *et al.,* [20]. Soil pH, EC, cations and anions, organic matter, $CaCO_3$, available N, P, K, Fe, Zn and Mn were run according to Black, C.A. *et al.,* [21]. Soil of the experiment was newly reclaimed sandy in texture; physical and chemical analysis of the experiment soil is described in table 1.

Irrigation water salinity

Irrigation water analysis is shown in table 2.

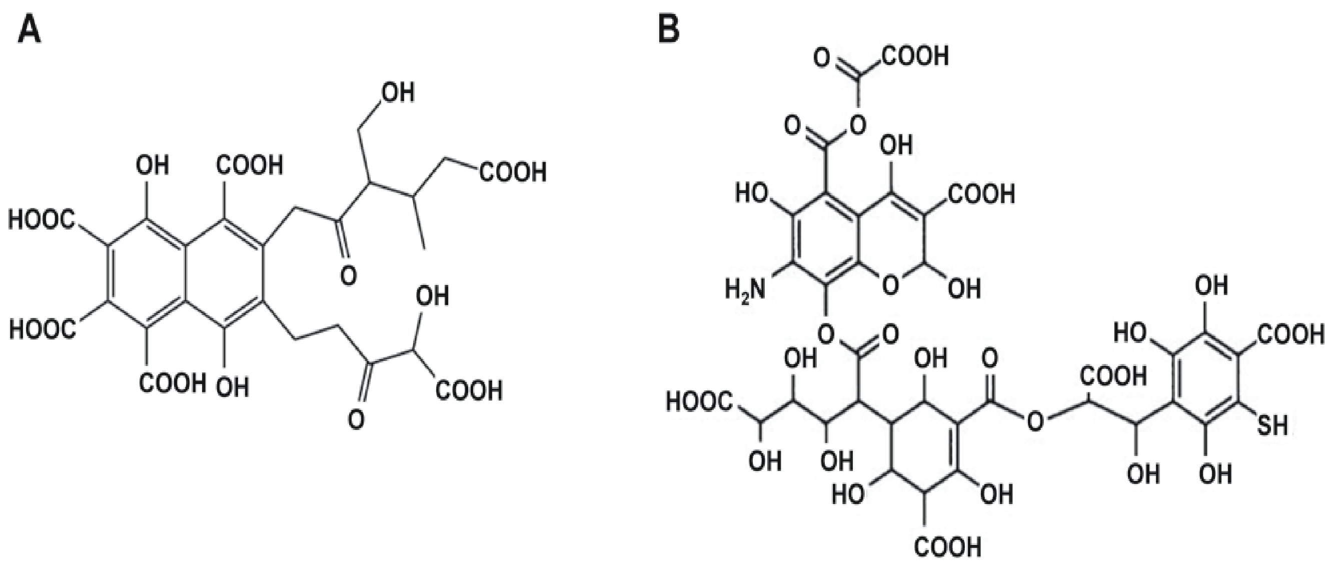


Figure 1. Proposed models of fulvic acid by Buffle (1988, A) and Alvarez-Puebla *et al.* (2006, B) [10-11].

Table 1. Some physical and chemical properties of the experimental soil at the beginning of the experiment.

Soil properties		**First season**	**Second season**
Particle size distribution (%)	Sand	93.32	94.0
	Silt	4.68	3.56
	Clay	2.00	2.44
	Texture	Sandy soil	Sandy soil
$CaCO_3$ (%)		2.21	2.24
pH$_{(1:2.5 \text{ soil suspension})}$		8.21	8.20
EC (dS m^{-1})		1.98	1.80
Soluble cations (mmol L^{-1})	Ca^{++}	8.02	7.96
	Mg^{++}	2.88	3.16
	Na^{+}	5.95	5.20
	K^{+}	2.95	1.68
Soluble anions (mmol L^{-1})	CO_3^{--}	-	-
	HCO_3^{-}	1.52	1.52
	Cl^{-}	8.30	7.82
	SO_4^{--}	9.98	8.66
Available nutrients mg kg^{-1}	N	24.2	26.5
	P	2.05	2.00
	K	68.6	59.5
	Fe	4.11	3.95
	Mn	0.97	1.01
	Zn	1.20	0.99

Table 2. Some chemical analyses of irrigation water.

pH	EC dS m^{-1}	Soluble cations				Soluble anions			
		meq. L^{-1}							
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}
7.10	2.69	7.45	3.81	15.2	0.44	nd.	5.20	14.6	7.10

Experimental treatments

The proposed treatment consists in applying different doses of potassium fertilizer and spraying the leaves with different concentrations of fulvic acid. Potassium application rates were 150, 200, and 300 kg K_2O per hectare of recommended fertilizer units (300 kg K_2O ha^{-1}). Fulvic acid concentrations were 500, 1000, and 2000 mg^{-1}. The first fulvic acid application was performed when the seedlings reached the 6 leaf stage (approximately 2 weeks after transplanting). The second through fourth sprays should be applied every three weeks after the previous spray. The total number of foliar applications was 4 times.

Experimental design

The experiment was performed in a split-site design with three replications. Potassium levels were separated in the main plots and fulvic acid in the sub-plots. The area of the experimental plot was 22.5 m^2 consisted of one row with 15 m length and 1.5 m width and the plants were transplanted 50 cm spaced in the rows.

Experimental site preparation and cultivation

Tomato seedlings "hybrid Marwa" were used in these experiments. Seedlings were transplanted on 5th and 7th of November in the first and second seasons, respectively when plants were 40 days old. The recommended fertilizer rates were added for each of the nitrogen and phosphate fertilizers, where nitrogen fertilizer was added in the form of ammonium sulphate (20.5 % N) at 200 kg N, phosphorus fertilizer was added in the form calcium superphosphate (15.5% P_2O_5) at 37 kg P_2O_5 were applied in equal dose during the growing season. All agriculture practices were performed as recommended by Egyptian Ministry of Agriculture and Land Reclamation for tomato cultivation under open field conditions.

Measurements of crop parameters

Vegetative growth

Samples of three plants were chosen at random from every plot after were recorded in the end of the growing season and directly transferred to the Laboratory. The following data were recorded.

Plant length (cm): Plant length was measured from soil surface to the longest leaf.

Number of leaves: Total number of leaves of the three selected plants was counted and their mean was recorded as the number of leaves per plant.

Number of branches.

Leaves fresh weight (g).

Dry weight per plant (g).

Tomato yield and yield components

When calculating the yield, the following was estimated
Average weight of fruit (g).
Weight of fruits in total yield was recorded from each replicate.

Yield quality

Fruit samples were taken from the 3rd harvest at red ripe stage from each experimental plot to determine fruit quality parameters, *i.e.,* total soluble solids (TSS) using hand held Brix meter, and ascorbic acid [22].

Nutritional status

Leaves were taken from the fourth upper of tomato stem of eight randomly collected plants after 90 days from transplanting, washed with distilled water, dried with paper towels, then dried at 70 ^{0}C and wet digested [23] for the determination of N, P and K [22].

Statistical analysis

Data of the experiment was statistically analyzed using Mstatic (M.S.) software. The comparison among means of the different treatments was determined as illustrated by Snedecor *et al.*, [24].

Results and discussion

The results obtained in are shown in table 3, which showed the effect of spraying different concentrations of fulvic acid with different rates of potassium fertilization on the growth coordinates (plant height, number of leaves, leaf area, dry weight of leaves and number of branches) of tomato plants grown in sandy soil and irrigated by saline water, and that during two growth consecutive seasons. Increasing the spraying concentration of fulvic acid from 500 to 2000 ppm resulted in a significant improvement in the growth parameters of tomato plants with an increase in potassium fertilization rates from 150 to 300 K_2O kg ha^{-1} with the use of saline irrigation water. This explains the role played by fulvic acid and potassium fertilization in alleviating the effect of irrigation water salinity on the growth of tomato plants.
Growth coordinates increase significantly as a result of increasing the rates of potassium fertilization with increasing the concentration of spraying with fulvic acid, and in low rates of potassium fertilization, increasing the concentration of spraying fulvic acid greatly improved the growth coordinates, as in the second level of potassium fertilization (120 K_2O kg ha^{-1}) with increasing the concentration of spraying with fulvic acid to the third concentration of it (2000 mg l^{-1}) led to an improvement in the growth coordinates and the closeness of their values with the values obtained for the same coordinates at high potassium fertilization (300 K_2O kg ha^{-1}), which proves the effectiveness of fulvic acid in increasing the efficiency of potassium fertilization and the possibility of reducing The added amount of potassium fertilizer.

Table 3. Effect of different rates of potassium fertilization and different concentrations of fulvic acid on vegetative growth of tomato plants during 2021/2022 and 2022/2023.

Potassium fertilization rate kg ha^{-1}	Fulvic acid conc. mg l^{-1}	Plant height cm	Leaves number /plant	Leaf area cm^2	dry weight/plant g	Branches number /plant
1st season						
	500	61.3	57.2	31.7	22.5	4.33
150	1000	64.7	63.1	34.5	29.8	5.67
	2000	68.2	65.0	38.2	32.2	6.88
	500	65.6	69.2	36.9	36.1	5.66
200	1000	71.2	89.4	46.2	40.2	6.33
	2000	72.8	91.2	52.2	46.6	7.63
	500	68.8	89.8	42.2	37.5	6.89
300	1000	74.5	94.2	54.2	47.1	8.00
	2000	76.3	98.0	60.8	49.1	8.33
$LSD_{0.05}$		2.82	4.88	3.66	6.42	0.11
2nd season						
	500	62.2	58.2	32.0	24.6	4.35
150	1000	65.1	64.6	35.1	30.1	5.66
	2000	68.0	66.4	39.8	34.4	6.90
	500	66.1	70.1	37.5	37.0	5.70
200	1000	71.0	90.1	47.2	40.5	6.33
	2000	72.2	92.2	53.0	46.9	7.63
	500	69.1	90.1	41.8	37.6	6.91
300	1000	73.6	95.2	55.1	46.5	8.02
	2000	75.1	98.0	60.1	49.2	8.42
$LSD_{0.05}$		2.90	4.87	3.70	6.44	0.12

Arancon *et al.*, [25] reported that fulvic acid is involved in plant growth patterns such as leaf development, stem and root elongation, and flowering, and plays a role in several processes such as the production of plant growth-influencing substances as free enzymes. Fulvic acid regulates plant growth by increasing the rate of photosynthesis and decreasing stomatal opening and transpiration rate [26]. Abd El-Baky *et al.*, [27] showed that the addition of fulvic acid at different doses significantly increased all growth parameters compared to the control. The results also showed that the highest vegetative growth rates (plant height, number of leaves and branches, fresh dry weight of leaves and branches) were recorded in okra plants/fed with fulvic acid (3 gl^{-1}). Hossain *et al.*, [28] who found that increasing potassium fertilizer levels increased shoot height, number of leaves per plant and shoot fresh weight. El-Bassiony *et al.*, [29] who found that the highest vegetative parameters of onion and sweet pepper plants were recorded when used potassium fertilization in the highest level as soil application. Fageria *et al.*, [30] reported that the application of high potassium fertilization might enhance the capacity for osmotic adjustment of the tomato plants growing in the saline habitats.

The effect of spraying different concentrations of fulvic acid with the addition of different rates of potassium fertilization on the quantity tomato crop during the two consecutive growing seasons is shown as shown in table 4. The fruit weight, fruit yield per plant and total yield increased significantly as a result of increasing the concentration of fulvic acid from 500 to 2000 mg l^{-1} with increasing the rate of potassium fertilization from 150 to 300 kg fed^{-1}, and the best experimental treatments were to give the highest yield values when adding the high rate of potassium fertilizer (300 kg ha^{-1}) with a high concentration of fulvic acid (2000 mg l^{-1}), as well as the treatment in which the second rate of potassium fertilizer (200 kg ha^{-1}) was added with a higher concentration of fulvic acid (2000 mg l^{-1}). That is, it can be said that with the use of fulvic acid at a concentration of 2000 mg l^{-1}, potassium fertilizer can be reduced by 25%, which contributes to reducing costs and also increasing profitability.

Foliar application of fulvic acid increased vegetative growth, yield and decreased the incidence of blossom end rot in tomato fruits [31]. Positive fruit traits were obtained in plants treated with fulvic acid, whereas negative effects on fruit quality were observed in untreated plants. These results may be related to the positive effects of fulvic acid that increase cell membranes, plant permeability, respiration and photosynthesis [32]. Chogei *et al.*, [33] showed that potassium fertilizers eliminate the harmful effects of salinity on tomato, increase the physiological performance of plants and reduce proline accumulation.

Table 4. Effect of different rates of potassium fertilization and different concentrations of fulvic acid on yield quantity and quality of tomato plants during 2021/2022 and 2022/2023.

Potassium fertilization rate kg ha^{1}	Fulvic acid conc. mg l^{-1}	Fruit weight g	Fruit yield/plant kg	Total yield ton fed^{-1}
1st season				
150	500	71.5	2.67	22.2
	1000	85.0	2.99	24.1
	2000	87.8	4.00	30.0
200	500	75.1	3.48	29.0
	1000	86.5	3.66	30.5
	2000	90.2	4.11	34.2
300	500	76.4	3.51	30.4
	1000	88.3	3.76	31.6
	2000	90.4	4.12	34.4
$LSD_{0.05}$		8.19	0.77	2.03
2nd season				
150	500	72.2	2.68	22.3
	1000	84.6	3.07	24.7
	2000	87.6	4.05	30.8
200	500	74.8	3.53	30.2
	1000	86.9	3.68	31.7
	2000	90.8	4.04	34.7
300	500	77.0	3.53	30.2
	1000	87.6	3.71	31.1
	2000	92.1	4.11	34.5
$LSD_{0.05}$		8.22	0.75	2.01

Likewise, the quality of the tomato crop, which is represented by total soluble solids and ascorbic acid, has improved significantly by increasing the application of fulvic acid and fertilization rate with potassium fertilizers. Also, as in the case of the amount of the crop, the same experimental treatments were given the highest values for the quality of the tomato crop, as shown in the figure 2 and 3.

Potassium plays a crucial role in the energy state of plants, transfer and storage of sorbents and maintenance of tissue hydration rate. Potassium also plays an important role in crop quality, promotes root growth, sugar transport and carbohydrate formation. Potassium also confers resistance to pests, disease, drought and even frost stress [34].

Amjad *et al.*, [35] indicated that the application of potassium increases the yield and quality of tomato fruits in saline soil. Kamel *et al.*, [36] reported that improvement yield quantity and quality of cucumber plants by using the fulvic acid. Suh *et al.*, [37] found that increasing the quality yield of tomato production by using the higher rate of fulvic acid.

From the data presented in table 5, both fulvic acid and potassium fertilizers were found to affect nutrient uptake in tomato leaves under saline water irrigation. Increasing the concentration of fulvic acid spraying led to the uptake of nitrogen, phosphorus and potassium in tomato leaves increased with an increase in potassium fertilization rates. Uptake values for the three elements can be obtained when spraying the highest concentration of fulvic acid (2000 mg l^{-1}) with the highest ground addition of potassium fertilizer (300 kg ha^{1}), during two successive growing seasons.

Foliar application of fulvic acid led to increasing bioavailability and uptake of nutrients and increased crop growth and yield [38]. El- Metwaly [39] reported that using fulvic acid exerted a marked significant effect on N, P and K uptake than untreated potato plants at two seasons. Yildirim and Unay [40] who indicated that foliar application of fulvic acid enhances nutrients uptake of tomato plants. Kadar [41] found that potassium uptake was improved by potassium fertilizer application. The use of potassium increased the absorption of macro elements. K-stimulated nutrient uptake indicates improved water mobility and solvent transport. This finding may be due to the regulatory role of K on xylem tubule membrane potential and osmotic pressure, which are strongly influenced by her K status in the root [42].

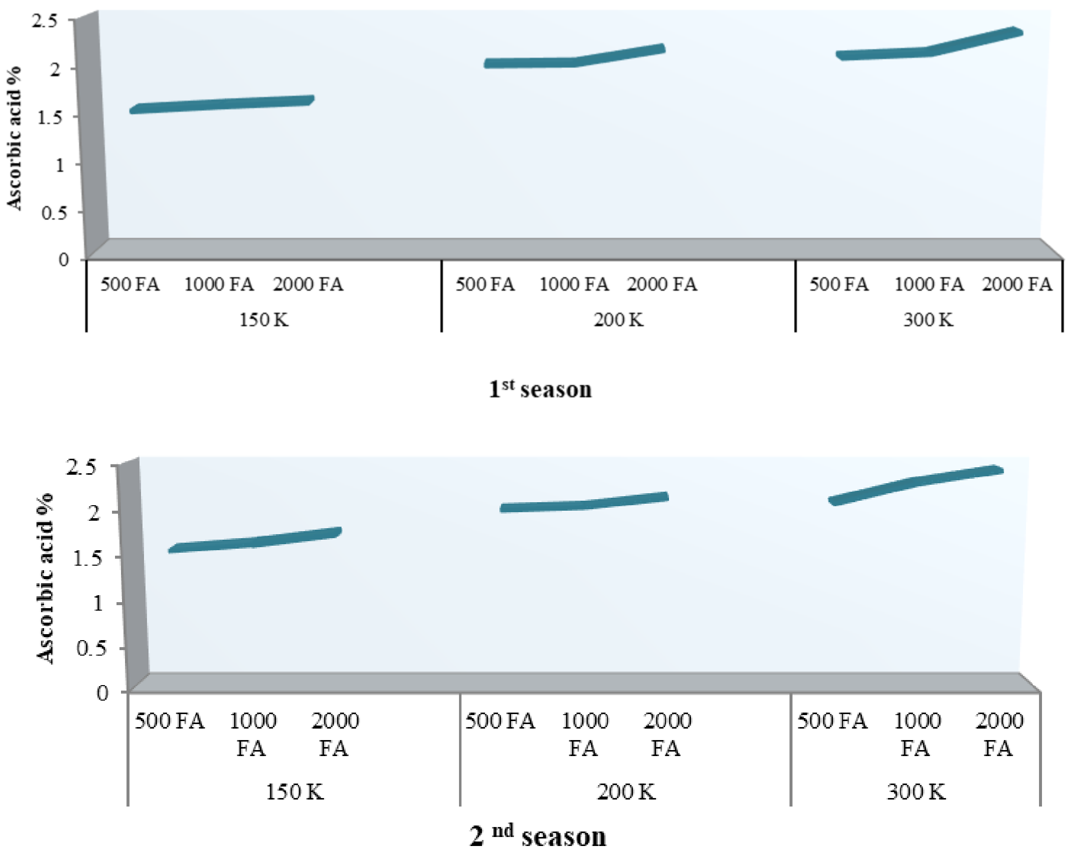
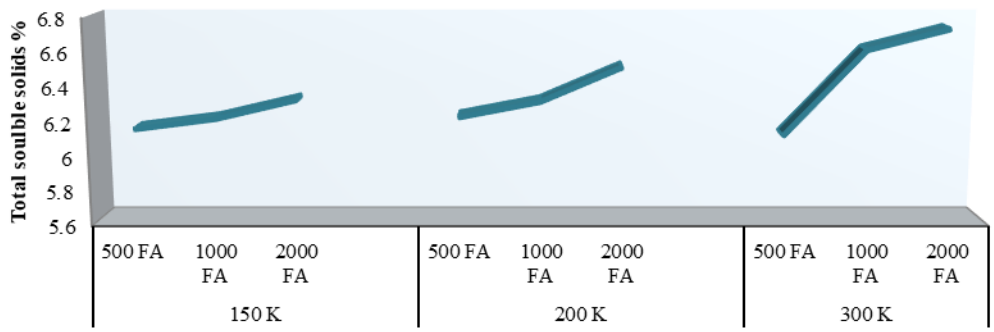
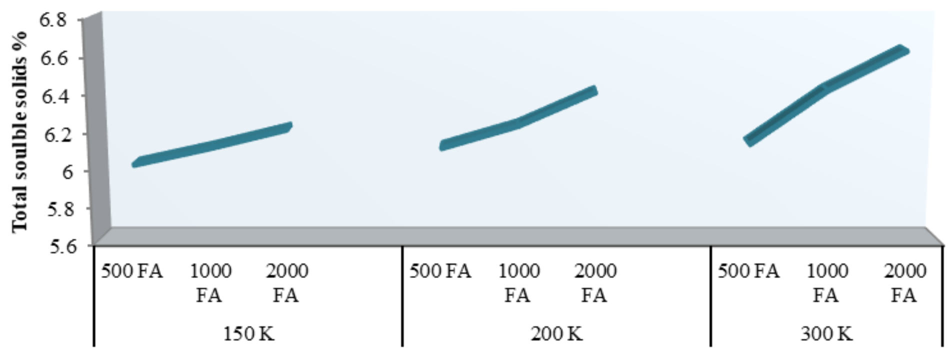


Figure 2. Effect of different of concentrations of fulvic acid (FA) combined with different rates of potassium fertilization (K) treatments on ascorbic acid (%) of tomato.



1st season



2nd season

Figure 3. Effect of different of concentrations of fulvic acid (FA) combined with different rates of potassium fertilization (K) treatments on total soluble solids (%) of tomato.

Table 5. Effect of different rates of potassium fertilization and different concentrations of fulvic acid on nutrients uptake of tomato plants during 2021/2022 and 2022/2023.

Potassium fertilization rate kg ha1	Fulvic acid conc. mg l-1	N	P	K
		mg/Kg		
1st season				
	500	52.1	7.88	38.7
150	1000	55.1	8.44	48.6
	2000	60.3	9.15	52.3
	500	60.2	8.01	51.8
200	1000	82.1	10.8	77.0
	2000	92.1	11.1	84.3
	500	67.3	8.11	63.0
300	1000	88.9	12.3	82.1
	2000	96.1	14.5	88.6
$LSD_{0.05}$		4.01	3.33	5.01
2nd season				
	500	52.4	7.78	39.0
150	1000	55.2	8.34	49.1
	2000	61.3	9.20	53.1
	500	61.1	8.00	52.0
200	1000	84.1	10.6	77.1
	2000	93.1	11.0	84.8
	500	67.4	8.12	63.5
300	1000	89.0	12.4	83.1
	2000	95.2	14.6	89.2
$LSD_{0.05}$		3.28	3.51	5.00

Conclusion

Under salt water irrigation conditions, fulvic acid spraying can be used, taking into account potassium fertilization in the appropriate amount, which allows reducing the effect of salinity on growth and yield, as well as the uptake of nutrients by tomato plants. The best experimental treatments that gave the highest growth and yield values, as well as nutritional status, were when the highest concentration of fulvic acid was sprayed (2000 mg l^{-1}) with the highest rate of potassium fertilization (300 kg ha^{1}).

Acknowledgement

The authors are would like to thank the National Research Centre, Cairo, Egypt for providing the instruments, laboratory equipment and chemicals.

Consent for publication

All authors agreed with the content and that all gave explicit consent to submit and publish.

Competing interests

The authors declare no competing interests.

Ethics approval and consent to participate

As this study does not involve animal and patient experiments, the ethical approval and consent to participate are not applicable.

Funding statement

The author has no relevant financial or non-financial interest to disclose.

Data availability

All data generated or analyzed during this study are included in this published article.

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