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(Original Article)

Mitigating The Negative Impacts of Progressive Salinity and Drought Stresses in Maize Using Various Potassium Fertilizers Sources

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Abstract

With water resources becoming more limited in arid and semi-arid regions, growers use low-quality water for irrigation. An outdoor pot experiment was conducted during the summer season of 2022 in northern Egypt to identify the best irrigation regime with saline water and K fertilizer that boosts maize tolerance for drought and salinity stresses. The salinity of irrigation water used possessed 4.38 dS/m. Irrigation levels were 40, 60, and 80% potential ET, and the types of K salt were 0.0 K(Control), K_2SO_4 (0.05 g kg^{-1} soil), KNO_3 (0.05 g. kg^{-1} soil), and Salwax (0.02 g kg^{-1} soil). Germination percentage, growth parameters, leaves nutrient contents, yield and its attributes, and water use efficiency were monitored. The results showed that the final total soluble salt accumulated in the soil after harvest differed significantly among the three levels of irrigation. K salts had no significant effect on germination percentage and stem diameter, while Salwax significantly increased N, K, Mg, and Ca content in the maize leaves. Obviously, the KNO_3 possessed the greatest growth parameters followed by Salwax in comparison to the control. Irrespective of the irrigation level, both K_2SO_4 and KNO_3 significantly increased the biological yield over the control by 4.5%, while Salwax attained a biological yield similar to the control. All K salts increased the WUE and the biomass-WUE, where the KNO_3 had the highest positive effect. In conclusion, using saline water in irrigation maize crop is possible even at 40% of potential evaporation (ET) level with leaching monthly by 125% ET beside KNO_3 fertilization on three doses after leaching event.

Keywords: *Drought, Progressive salinity, Irrigation, Maize, Potassium.*

Introduction

Increasing water deficit and drought frequency pose a serious threat to agricultural production and its sustainability. Egypt is facing different challenges in crop production such as water scarcity, desertification, climate change, water salinity, and rapid population growth, which affects food- and feed security (Seada *et al*., 2016). Ultimately, water shortage and deterioration of irrigation water quality result in an abiotic stress. These stress factors caused losses yield

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(Cakmak, 2005). Therefore, efficient, and sustainable production methods, and resilience to the ongoing and expected climate change scenarios are no longer optional (Seada *et al*., 2016).

Among all production factors, water is the most important factor for plant growth, development, and productivity. Water availability in adequate quantity and quality is essential for high and economical crop production (Valadabadi *et al*., 2009). The severity of the drought depends on crop type, growth stage, irrigation practices, fertilization management, and type and amount of potassium (K) fertilizers.

Maize (*Zea mays* L.) is the second most important grain crop after wheat in Egypt. However, the gap between the production and consumption of maize is increasing. The effects of drought stress on maize growth and development vary with the timing and severity of stress (Song *et al*. 2010). Several researchers showed massive yield losses due to moisture deficit at the growing stages of maize (Frootan and Yarnia 2015), particularly if drought stress occurs at the flowering stage (Abo-El-Kheir and Mekki, 2007). Therefore, under such conditions, the need for enhancing water conservation, without affecting yield, is a vital management tool for adapting water demand to climate change under growing maize. With the appropriate combination of irrigation and fertilizer management, leaching of fertilizers during agricultural practices may be minimized (Jia *et al*. 2014; Lu *et al*. 2021).

The effects of irrigation regimes, K, and their interaction effects on biological performance could be meaningful. So, K can enhance maize growth, reduce the severity of drought under specific irrigation regimes (below optimum crop water requirement), and/or mitigate the negative impacts during drought waves. Pettigrew (2008) recommended K as a principal plant nutrient underpinning crop yield production and quality determination. There are many criteria for irrigation scheduling that depend on crop type and its growth stage, climatological condition, and soil type. One of the most promising criteria is Romanenko's equation which depends on the air temperature and relative humidity (Xu and Singh 1998). The equation is used to calculate the potential evaporation for irrigation scheduling in the present study.

Due to water shortage in Egypt, growers use low-quality water for irrigation. The use of this sources increases soil salinity and sodicity problems (Feng *et al*. 2017). Moreover, hot weather conditions and intensive agriculture are common factors across Egypt, which also contributed to salinity build-up. Therefore, to maintain sustainable production under these conditions, it became necessary to use leaching fraction and approaches to avoid or delay the saline build-up and to mitigate the negative impacts of salinity and drought stresses. In the present study maize was grown under different irrigation water regimes using moderate water salinity and different types/sources of K fertilizers. The objectives of the present study were to identify the most valuable water regime for enduring the maize to drought stress and to identify the best K fertilizer source that boosts maize tolerance for drought and salt stress. Using different irrigation regimes and different types of K fertilizer may lead to define the most valuable combination of both for maize growth under moderate salinity stress induced by irrigation water.

Materials and Methods

Experimental site

An out-door pots experiment was conducted at Badr region (30.5766°N, 30.7115°E), El-Buhayrah Governorate, Egypt in 2022 season to mitigating the negative impacts of progressive salinity and drought stresses in maize (Pioneer P4444) (*Zea mays* L.) using various potassium sources. The soil and irrigation water characterization used in our study are shown in Table 1.

Table 1. Characterization of the used soil and irrigation water

Soil properties				
Sand (%)		79	Soluble cations (ppm)	
Silt (%)		13	Ca^{2+}	40
Clay (%)		8	Mg^{2+}	24
Texture		Loamy sand	K^{+}	26
EC $_{(1:1)}$	dSm^{-1}	0.327	Na^{+}	39.9
	ppm	209.2	Soluble anions (ppm)	
pH $_{(1:2.5)}$		7.46	SO_4^{2-}	18
OM (%)		0.70	CO_3^{2-}	0
Available N (ppm)		133	HCO_3^{-}	61
Available P (ppm)		0.90	Cl^{-}	71
Irrigation water properties				
EC	dSm^{-1}	4.38	Na^{+} (ppm)	920
	ppm	2809	Cl^{-} (ppm)	1620

Experimental design

The experimental design was randomized complete block in a split-plot arrangement with three replicates. The main plot treatments were three irrigation levels (40, 60 and 80% potential ET). The sub plot treatments were four K salt types (0.0 K (Control), K_2SO_4 (0.05 g kg^{-1}), KNO_3 (0.05 g kg^{-1}) and Salwax (0.02 $g.kg^{-1}$ soil)). For these additions, potassium sulfate (50% K_2O) and potassium nitrate (13% N and 44% K_2O) fertilizers and Salwax (it contains: N, K_2O, CaO, carboxylic acids with 4, 15, 14 and 51.74 %, respectively) were used. The recommended fertilizers doses for maize of NKP were used at rates of 0.2, 0.05, and 0.1088 g/kg soil from mono superphosphate, potassium sulfate, and urea, respectively. All the mount of recommended NK and K salt types were divided into three equal doses (1/3 each), while the mount of recommended P was added with the soil preparation. The 1st dose was applied before sowing the maize seeds on the 3rd of April 2022. The 2nd dose was applied on the 23rd of May 2022 and the 3rd one was applied on June 25th, 2022. A 25 kg of air-dry soil (2% gravimetric water content) was packed in plastic pot (28 cm in diameter and 25 cm in depth). The average bulk density of pot soil is 1.62 $g.cm^{-3}$. The pots were buried in the soil surface. The Romanenko's equation (Xu and Singh 1998) was used for determining the ET.

The leaching requirements were calculated as 125% of ET of irrigation application time. The leaching requirements were 0.841, 0.907, and 1.143 L/pot on 21st of May, June, and July, respectively, with a total of 2.891 L. The leaching requirements were taking place before adding the 2^{nd} and 3^{rd} doses of fertilizer and K salts preventing fertilizer losses by leaching. The total amounts of irrigation water for the whole growing seasons were 30.07, 45.12, and 60.87 L/pot for 40, 60, and 80% ET irrigation levels, respectively. Therefore, the leaching fractions (total leaching requirements/total irrigation water) are 0.096, 0.064, and 0.047 for the irrigation levels 40, 60, and 80% ET irrigation levels, respectively.

Before sowing, the maize seeds (Pioneer P4444) were soaked in the irrigation water for 24 hrs to encourage germination under salinity conditions. Five soaked seeds were sown in each pot on 3rd of April 2022. The soil water content was maintained around the field capacity of soil during the germination stage.

Data collection

The germinated seeds were counted after 10 days from sowing and the germination percentage was calculated (AOSA 1983).

Eleven days after planting, plants were thinned to two plants per pot. The stem height and diameter, and leaves number were recorded. The chlorophyll content index of leaves was nondestructively estimated using the SPAD-502 chlorophyll meter. At the end of experiment (after 125 days from sowing), plants were harvested, and the shoot and ears were separated. The shoot's fresh and dry weights were recorded. The ear length and the number of ears per plant were determined. The weight of 100 grains and the grain yield were recorded at a moisture content of 12-14%. Leaf samples from 4th and 5th leaf on the plant were taken at harvest for N, P, K, Ca, and Mg analysis. The leaf water content as a percentage was obtained by (leaf fresh weight – leaf dry weight)/ leaf fresh weight *100. Dried leaf samples were digested in H_2SO_4 /H_2O_2 mixture according to the method described by Chapman and Pratt (1961). N-content was determined using Kjeldahl method, P was measured using Spectrophotometer according to Watanabe and Olsen (1965), K determined using Flame photometer as outlined by Chapman and Pratt (1961), and Ca and Mg were determined by EDTA according to Derderian (1961). The Electrical conductivity (EC) after the 3rd leaching event on the 21st of July was measured in the soil water extract 1:1 according to Jackson (1958).

The second-degree polynomial equation was used for describing relationship between shoot height or leaf number and time (Burden and Faris 1985).

Biological yield was estimated as the summation of grain yield and biomass yield (Edje and Burris 1970). The water uses efficiency (WUE) ($Kg.m^{-3}$) was expressed as the ratio of grain yield (GY) ($Kg.pot^{-1}$) to the total plant water consumption (WC) ($m^3.pot^{-1}$) as shown by equation 1 (Barker *et al*. 2003). The above-ground biomass-WUE ($Kg.m^{-3}$), was calculated as the ratio of above ground plant dry matter ($Kg.pot^{-1}$) to the total plant water consumption ($m^3.pot^{-1}$) in the same time period as shown by equation 2 (Huang *et al*. 2005; Medrano *et al*. 2010; Tambussi *et al*. 2007).

$$WUE = (GY)/(WC) \quad (1)$$

$$WUE - biomass = (TDW)/(WC) \quad (2)$$

Statistical analysis

The collected data were analyzed with analysis of variance (ANOVA) procedures using COSTAT version 6.311 according to Snedecor and Cochran (1976). The least significant difference (LSD) at 5% level significance was used to compare the treatments means (Steel and Torrie 1980).

Results and Discussion

Salinity accumulation

Results presented in Figure 1 show the total soluble salt in the soil water extract 1:1 after the 3rdleaching event on the 21st of July. The application of water period after the last leaching event was 10 days. The amounts of applied water through this period were 4.752, 3.564, and 2.367 L for the irrigation levels of 80, 60 and 40%, respectively. The corresponding loaded salts were 0.353, 0.265 and 0.176 g kg^{-1} soil. As expected, the more applied salinized water to the soil the more accumulated salt. The mean soluble salt concentrations in soil extract 1:1 were 2.27, 1.90 and 1.78 dS m^{-1} for 80, 60, and 40% irrigation levels, respectively. The total soluble salt differed significantly among the three studied irrigation levels. These concentrations are doubled in the saturated soil paste. Accordingly, the soluble salts at saturation in the present study are over the threshold salinity for maize which is 1.7 dS m^{-1} (Waller and Yitayew 2016). Additionally, maize is classified as moderately sensitive to salinity and has a yield reduction of 12% for each unit (dS m^{-1}) in the soil salinity at saturation (Waller and Yitayew 2016). The total soluble salt in the soil is likely moderate and the maize plant tolerated this concentration of salt especially in the late stage of growth. It is obvious that the soil treated with potassium salt had low soluble salt in comparison to the control treatment (Figure 1). The low salt concentration could be attributed to enhancement in nutrient uptake by maize plants owing to K application. The roles of K are stated by (Xu *et al*. 2020). They suggest that 6 mM K as appropriate K supply was optimal as its enhanced photo assimilate transport from leaves to roots.

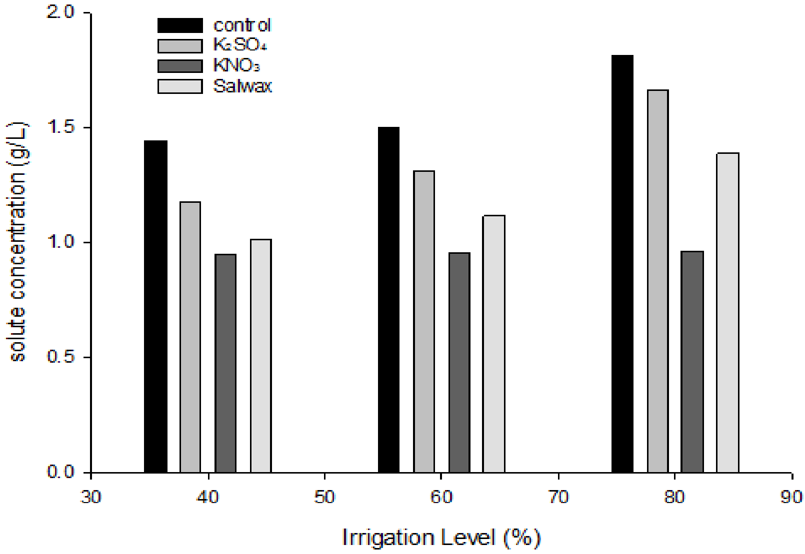

Figure 1. Effect of irrigation levels and K salt types on final total soil solute concentration after harvest.

Germination

Data presented in Table 2 shows the germination of maize as affected by K salt types. The germination percentages were 93.3% for K_2SO_4 treatments and 100% for the rest of treatments. Similarly, Abdelraouf *et al.* (2022) and Adnan (2020) stated that it is likely that K ion does not affect maize seed germination. However, K is one of the most macronutrients required for proper growth.

Growth of Maize Analysis

Results in Table 2 present the diameter of maize stem at 49 days after sowing under three irrigation levels and four K salt types. The stem diameters were 26.05, 27.13, and 27.15 mm for irrigation levels 40, 60, and 80%, respectively. Finally, the stem diameters under the three irrigation levels were not significantly affected. Also, the K salt types were not significant effect on the maize stem diameter (Table 2). The interaction between the irrigation levels and sources of K was not significant too. Song *et al.* (2019) reported that drought stress led to lower biomass.

Table 2 presents the chlorophyll content index at 50 days under different irrigation levels and K salt types. The irrigation levels had a significant effect on the chlorophyll content index where the greatest effect occurred under 40% ET. The K salt types and the interaction between the irrigation levels and sources of K were had no significant effect on chlorophyll contents index of maize plant. Song *et al.* (2019) reported that the leaf chlorophyll content of maize was lower under drought stress. Zhao *et al.* (2016) showed that the chlorophyll content of K-sensitive cultivar was decreased under K deficiency, whereas those of K-tolerant cultivar remained normal.

Table 2. Main effects of irrigation levels and K salt types on the germination, steam diameter and chlorophyll content index of maize

Treatments		Germination %	Stem diameter (mm)*	Chlorophyll content index (SPADvalue)
Irrigation levels				
40 %			26.06	40
60 %			27.13	38.58
80 %			27.15	38.58
$LSD_{0.05}$			NS	0.97
K salt types				
Control		100	26.42	39.33
K_2SO_4		93.33	26.14	38.67
KNO_3		100	27.22	39.11
Salwax		100	27.33	39.11
$LSD_{0.05}$		NS	NS	NS
Interaction				
40 %	Control		25.50	40.00
	K_2SO_4		26.25	40.00
	KNO_3		27.00	40.00
	Salwax		25.50	40.00
60 %	Control		27.92	38.67
	K_2SO_4		27.00	38.00
	KNO_3		26.83	38.67
	Salwax		26.83	39.00
80 %	Control		25.83	39.33
	K_2SO_4		25.17	38.00
	KNO_3		27.83	38.67
	Salwax		29.67	38.33
$LSD_{0.05}$			NS	NS

* Measured at 5-cm height from the soil surface

Figure 2 shows the effect of irrigation levels under the K source types on maize plant height as a function of time. A 2nd polynomial degree was used to describe the plant height vs. time (Abdelraouf *et al*. 2022). The polynomial described the observed values well with a value of determination coefficient (R2) of more than 0.98 (Table 3) for most of the irrigation levels with all K types. The plant height increased linearly till 50 days then it increased with high nonlinearly by further time increases for tall treatments used. The change rates of plant height at 40 and 80 days which described by polynomial equation were differed among the irrigation levels and K salt types. The 80% ET irrigation level had the greatest growth rate in comparison to the other irrigation levels. The mean growth rates after 40 days were 1.948, 1.909, and 1.596 cm day^{-1} for 80, 60, and 40% irrigation levels, respectively. The corresponding rates at 80 days were 2.148, 1.649, and 1.709 $cm.day^{-1}$. So, as the water available is high for plant uptake, the strong of the plant is enhanced. Similar findings by Gomaa et al. (2017), imposition of drought stress decreased the maize plant height. The type of K salt also influences the growth rate. It is concluded that K enhanced growth rates. Where K nutrient is involved in the elongation, regulation of stomatal opening and closing, and other essential physiological processes. There are a lot of research on the effect of K on plant growth (Jin *et al*. 2007; Abdelraouf *et al*. 2022). In general, the change rates after 80 days were consistent with the growth rates at 40 days and followed the same order for K treatment under 80% irrigation levels. The change rates in plant height at 80 days were higher than that at 40 days except the control was low. These rates at 80 were 2.731, 2.290, 1.987 and 1.585 cm.day^{-1} for KNO_3 >Salwax> K_2SO_4 > Control, respectively, under 80% irrigation levels. It may be due to the effective use of K to counteract the passive effect of drought on maize growth. The one of the positive benefits of adequate K is it helps plant roots penetrate to access deeper soil water (Armstrong 1998).

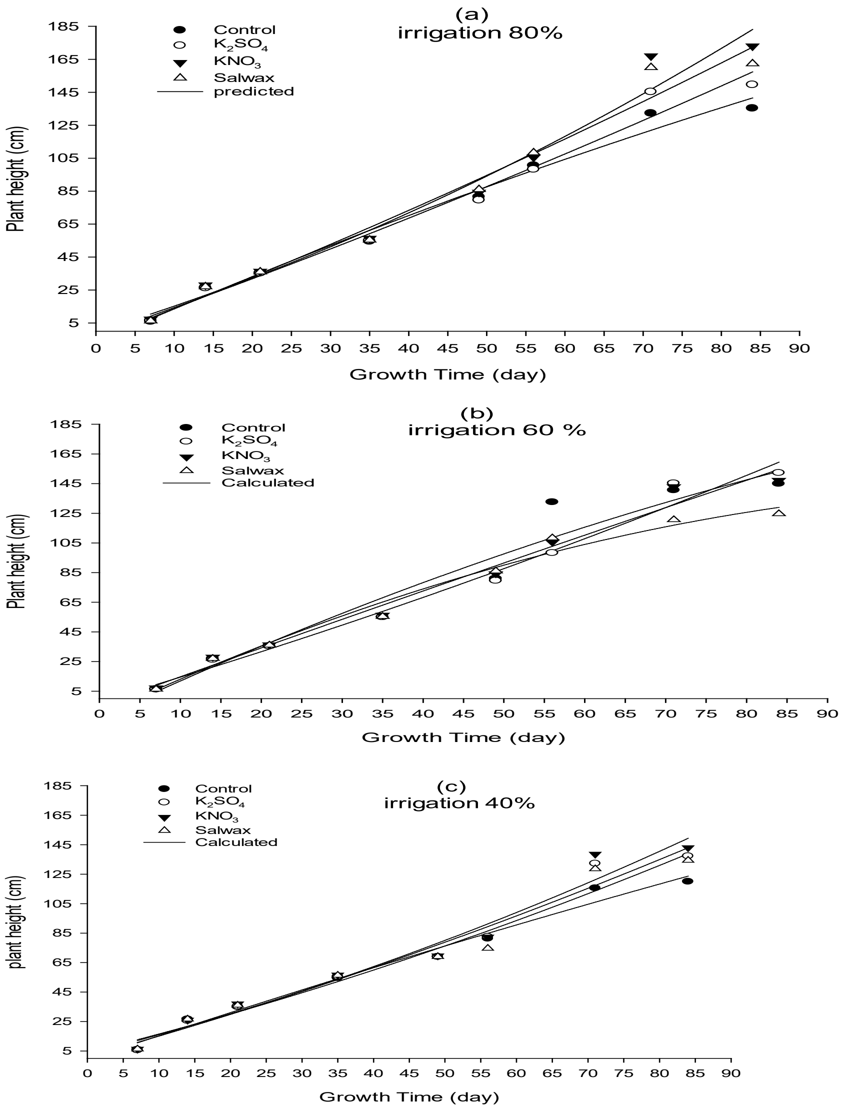

Figure 2. Plant height as a function of time under irrigation levels of 80% (a), 60% (b), and 40% (c) and K salts (symbols), and calculated values (lines)

The leaf numbers with time under the irrigation levels and K types were described well using the 2nd degree polynomial equation as presented in Table 3 and Figure 3. The determination coefficient (R2) ranged from 0.99 to 0.98. The change rate of leaf numbers at 40 days were obviously greater than the values at 80 days. The leaf numbers increased nonlinearly with time. The leaf numbers in the leaching studies behaved similarly to non-leaching studies (Abdelraouf *et al*. 2022). The leaf numbers rates did not coincide with rates of stem height. Comparable results, the mean change rates for 80% irrigation level were 0.202 and 0.122 day^{-1} after 40- and 80-days, respectively. The corresponding rates for 60% irrigation rates were 0.196 and 0.116 day^{-1} and 40% irrigation level were 0.199 and 0.119 day^{-1}. It is clear the high irrigation level gave the highest change rates in comparison to the low irrigation level. It can be concluded that increasing the water availability enhanced water and nutrient uptake that encourages the cell of plant division. Ma *et al*. (2018) reported that leaf and stem moisture content of maize, net photosynthetic rate, leaf area, and biomass-related characteristics were increased nonlinearly as relative soil moisture increased. Also, Song *et al*. (2019) establishes that drought stress on maize during the seedling stage more effective on the growth and development than stress applied during the other stages. Application of K to plant leads to the more strongly it can attract water from the soil and better control its water loss (Armstrong, 1998).

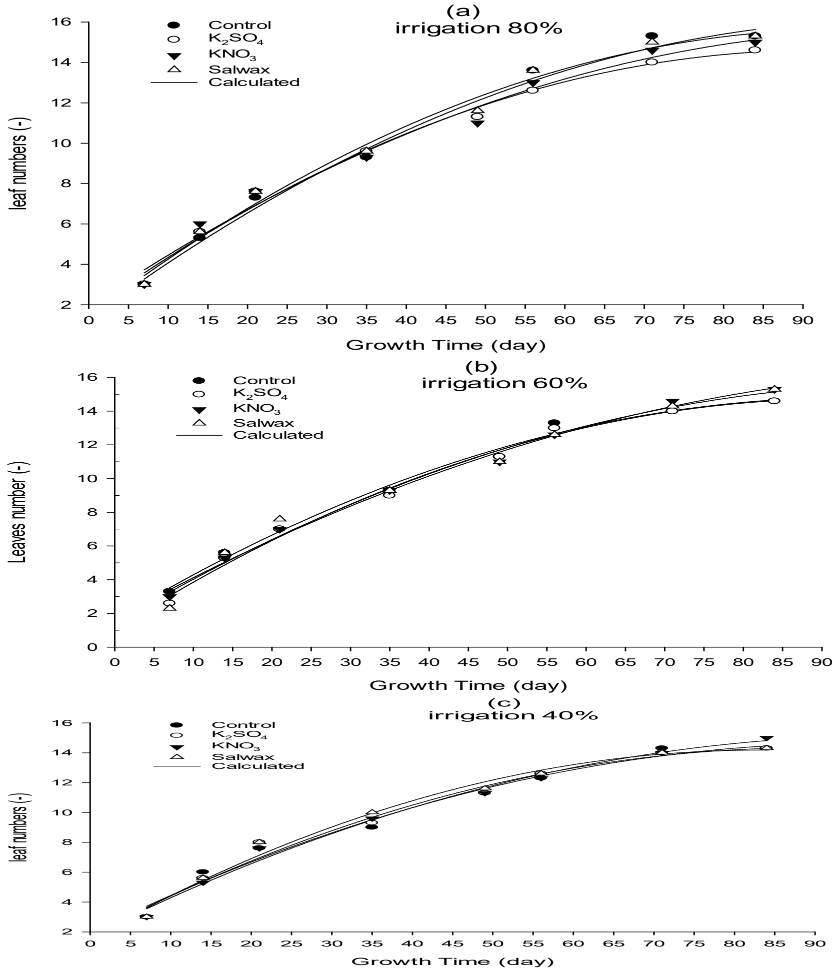

Figure 3. Leaf number with the time under irrigation levels of 80% (a), 60% (b), and 40% (c) and K salt types (symbols), and calculated values (lines).

Table 3. R2 and dy/dx for height and leaf numbers using second-degree polynomial equation.

Type of treatment		Plant height			Leaf numbers		
Irrigation level	K salt type	R^2	dy/dx* (cm d^{-1})	dy/dx** (cm d^{-1})	R^2	dy/dx* (d^{-1})	dy/dx** (d^{-1})
40%	Control	0.982	1.543	0.952	0.981	0.185	0.105
	K_2SO_4	0.972	1.673	1.993	0.983	0.202	0.122
	KNO_3	0.966	1.642	2.042	0.990	0.188	0.108
	Salwax	0.964	1.529	1.849	0.987	0.223	0.143
60%	Control	0.948	2.072	1.592	0.990	0.20	0.12
	K_2SO_4	0.983	1.842	2.082	0.991	0.214	0.134
	KNO_3	0.983	1.970	1.970	0.993	0.177	0.097
	Salwax	0.982	1.752	0.952	0.979	0.194	0.114
80%	Control	0.985	1.825	1.585	0.987	0.209	0.129
	K_2SO_4	0.980	1.827	1.987	0.990	0.20	0.120
	KNO_3	0.976	2.091	2.731	0.981	0.183	0.103
	Salwax	0.976	2.050	2.290	0.989	0.217	0.137

Growth time at 40 * and 80 days **.

Yield and its attributes

Results of yield and yield components of maize treated with different K salts under different irrigation levels are present in Table 4. The results showed that increasing irrigation levels significantly increased shoot fresh and dry weights, grain yield, 100-seed weight, and ear length traits, while significantly decreased the leaves water content and had no significant effect on the ears number. All parameters differed significantly among the K salt types except the ears number. The interaction between the two factors of our study had a significant effect on shoot fresh and dry weights, 100-seed weight, and ear length traits, while they had no significant effect on grain yield, leaves water content and ears number. It is apparent that the using of KNO_3 had the greatest values in most of the traits, but the zero K had the lowest ones. It is concluded that the N in nitrate with K boosted the tolerate of maize under the conditions of the present study. These findings agree with those found by Abdelraouf *et al*. (2022).

Table 4. Main the maize yield measurements affected by irrigation levels and K salt types.

Treatments		Ear length (cm)	No. of ears /plant	100 grains weight (g)	Shoot fresh weight (g/plant) *	Shoot dry weight (g/plant) *	Leaf water content (%) **	Grain yield (kg/pot)
Irrigation levels								
40 %		12.1	1.9	15.1	186.3	63.0	28.2	0.062
60 %		19.6	1.9	18.5	200.9	70.3	26.4	0.084
80 %		24.4	1.9	26.5	213.1	73.6	24.8	0.128
$LSD_{0.05}$		1.6	NS	0.6	6.6	1.8	1.3	0.010
K salt types								
Control		17.3	1.7	17.1	170.3	59.6	31.0	0.074
K_2SO_4		18.0	2.0	18.9	193.3	68.8	28.6	0.093
KNO_3		20.3	2.0	22.8	207.1	70.6	20.8	0.106
Salwax		19.2	1.8	21.2	225.5	76.5	25.4	0.092
$LSD_{0.05}$		1.8	NS	0.7	4.0	1.2	1.6	0.015
Interaction								
40 %	Control	7.6	1.7	11.9	154.0	49.0	34.0	0.047
	K_2SO_4	11.5	2.0	12.5	187.0	64.7	30.0	0.066
	KNO_3	15.6	2.0	18.5	207.7	70.7	21.7	0.077
	Salwax	13.6	2.0	17.3	196.3	67.7	27.0	0.059
60 %	Control	18.8	1.7	15.8	167.3	61.7	29.0	0.054
	K_2SO_4	19.2	2.0	18.2	200.0	71.0	28.3	0.084
	KNO_3	20.3	2.0	20.5	228.7	76.7	22.0	0.104
	Salwax	20.4	2.0	19.5	207.7	71.7	25.3	0.093
80 %	Control	25.7	2.0	23.6	189.7	68.3	29.0	0.122
	K_2SO_4	23.3	2.0	26.2	205.0	71.0	27.3	0.130
	KNO_3	25.0	2.0	29.5	240.3	82.3	18.7	0.136
	Salwax	23.7	1.7	26.8	217.3	72.7	24.0	0.124
$LSD_{0.05}$		3.8	NS	1.2	8.8	2.6	NS	NS

* Weight of plant excluding the ears;

** The water contents of the fourth and fifth leaves at harvesting time.

Data presented in Table 5 indicated that decreasing of irrigation level significantly increased N, K and Mg contents, but had no effect on P and Ca content of maize plants. K salts significantly increased N, K, Mg and Ca content with KNO_3, while they had no significant effect on P content. Similar findings for the correlation between K and Mg were stated by Walker and Raines (1988) in a study of a maize-cultivar × phosphorus × potassium factorial experiment was to assess differential responses of different parameters to phosphorus and potassium soil fertility. Leaf potassium and magnesium were more consistently affected by potassium fertility than other variables studied.

The interaction between the two factors had a significant effect on K and Mg content, while they had no significant effect on N, P, and Ca content. These results of increasing nutrients elements content with decreasing irrigation level may be due to the reduced weight of the maize plant resulting from the lack of available water in the soil, which led up to an increase in the concentration of nutrients in the maize plant. Da Ge *et al*. (2010) referred to that drought stress significantly increased Ca and Mg content but significantly decreased P and K content of maize grains. Abdelraouf *et al*. (2022) reported that there were significant differences of N, P, K, Ca, and Mg content of the maize shoot under the used K salts and irrigation at 40% ET. Bahrun et al. (2002) stated that relative to fully watered controls concentrations of xylem NO3-, NH4+, and H2PO4- decreased by about 50% at 1–5 days after withholding irrigation (DAWI) and K decreased by about 50% at 7–8 DAWI.

Table 5. Effect of irrigation levels and K salt types on chemical composition of above-ground maize biomass

Treatments		N (%)	P (%)	K (%)	Ca (ppm)	Mg (ppm)
Irrigation levels						
40 %		1.79	0.23	0.19	49.8	94.5
60 %		1.62	0.21	0.19	48.8	83.5
80 %		1.38	0.24	0.16	50.3	60.0
$LSD_{0.05}$		0.14	NS	0.01	NS	6.4
K salt types						
Control		1.23	0.22	0.17	50.3	49.0
K_2SO_4		1.28	0.23	0.18	43.0	88.0
KNO_3		1.94	0.24	0.19	42.7	95.0
Salwax		1.93	0.22	0.19	62.3	85.3
$LSD_{0.05}$		0.15	NS	0.01	7.8	10.8
Interaction						
40 %	Control	1.40	0.23	0.17	54	41
	K_2SO_4	1.36	0.23	0.19	41	115
	KNO_3	2.20	0.24	0.20	38	124
	Salwax	2.18	0.22	0.21	66	98
60 %	Control	1.32	0.20	0.16	54	56
	K_2SO_4	1.46	0.20	0.20	40	88
	KNO_3	1.87	0.21	0.21	40	92
	Salwax	1.82	0.22	0.21	61	98
80 %	Control	0.97	0.22	0.16	43	50
	K_2SO_4	1.01	0.25	0.16	48	61
	KNO_3	1.76	0.26	0.17	50	69
	Salwax	1.80	0.22	0.16	60	60
$LSD_{0.05}$		NS	NS	0.02	NS	17.4

Biological Yield and Water Use Efficiency

The effect of biological yield (grain + biomass), water use efficiency (WUE) and biomass-WUE as affected by irrigation levels and the type of K salts is presented in Table 6. Irrespective of the type of the K salt, decreasing the irrigation level showed no effect on the biological yield. However, irrigation regime has significantly affected WUE and biomass-WUE. WUE was significantly affected by irrigation levels in which the 80% level recorded a significantly higher WUE than 60% but statistically similar to 40%. The biomass-WUE followed an opposite trend in which the highest values were recorded at 40% ET, while the 80% ET attained the lowest values that is due the low consumed water for 40 % ET treatment.

Irrespective of the irrigation level, the type of K salts showed a non-significant effect on the biological yield and the biomass-WUE. However, all K salts significantly increased the WUE compared to the control. KNO_3 had the highest positive effect, while Salwax and K_2SO_4 attained similar values of WUE. KNO_3 increased the WUE by 48.3%, while both K_2SO_4 and Salwax increased it by about 28.0% over the control. The interaction between the irrigation levels and the type of K salts was significant at p value of 5% on biological yield and biomass-WUE except WUE. The positive effect of K salts on the WUE can be explained by its positive effect on the grain and biomass yields.

Table 6. The effect of irrigation levels and K salt types on the biological yield, WUE, and biomass-WUE

Treatments		Biological yield ($Kg.pot^{-1}$)	WUE ($Kg.m^{-3}$)	Biomass-WUE ($Kg.m^{-3}$)
Irrigation levels				
40 %		0.62	1.89	18.99
60 %		0.70	1.75	14.68
80 %		0.78	2.01	12.21
$LSD_{0.05}$		0.02	0.13	0.32
K salt types				
Control		0.60	1.49	14.88
K_2SO_4		0.70	1.93	13.76
KNO_3		0.78	2.22	16.39
Salwax		0.72	1.89	16.15
$LSD_{0.05}$		0.02	0.27	0.48
Interaction				
40 %	Control	0.48	1.43	20.76
	K_2SO_4	0.64	1.99	14.56
	KNO_3	0.70	2.35	19.33
	Salwax	0.66	1.79	21.29
60 %	Control	0.60	1.13	12.48
	K_2SO_4	0.71	1.75	14.82
	KNO_3	0.78	2.17	16.28
	Salwax	0.73	1.94	15.14
80 %	Control	0.73	1.91	11.38
	K_2SO_4	0.76	2.04	11.89
	KNO_3	0.86	2.13	13.54
	Salwax	0.77	1.95	12.02
$LSD_{0.05}$		0.04	NS	0.78

Where, the addition of K boosted photosynthesis and metabolism of carbohydrate under water stress (Zahoor *et al*. 2017), by improving the leaf stomatal conductance and leaf internal CO2 concentration which regulates the stomatal opening (Athar and Ashraf 2005; Negin and Moshelion 2016). Zheng *et al*. (2008) indicated that the addition of K mitigated the adverse effects of salinity stress by improving the antioxidant enzymes activities.

Our results agree with those reported by Ul-Allah *et al*. (2020) in which they revealed that K application (KCl) amended yield parameters and WUE of maize under drought conditions. Increasing the grain yield due to K addition in our study might be attributed to increased photosynthesis activity which improves the source-sink relationship resulting in increased grain yield

(Amanullah *et al*. 2016; White et al. 2016). Amanullah *et al*. (2016) indicated that soil and foliar application of K improved the WUE of maize under drought conditions.

Conclusion

The total soluble salt in the soil solution differed significantly among the irrigation levels. K fertilization enhanced maize growth parameters of which KNO_3 possessed the greatest growth parameters followed by Salwax in comparison to the control. Irrespective of the irrigation level, both K_2SO_4 and KNO_3 significantly increased the biological yield over the control by 4.5%, while Salwax attained a biological yield similar to the control. All K salts increased the WUE and the biomass-WUE compared to the control and KNO_3 had the highest positive effect. Accordingly, moderate saline water can be used in irrigation of maize crop using even at 40% ET level with considering leaching fraction monthly and fertilization with K nitrate on three doses after leaching.

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التخفيف من الآثار السلبية للملوحة المتزايدة وإجهاد الجفاف في الذرة باستخدام مصادر أسمدة بوتاسية مختلفة

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الملخص

مع تزايد محدودية الموارد المائية في المناطق الجافة وشبه الجافة، يستخدم المزارعون مياه منخفضة الجودة للري. تم إجراء تجربة أصص خارجية خلال موسم صيف 2022 في شمال مصر لتحديد أفضل نظام ري بالمياه المالحة وسماد البوتاسيوم الذي يعزز تحمل الذرة لضغوط الجفاف والملوحة. بلغت ملوحة مياه الري المستخدمة 4.38 ديسي سيمنز / م. كانت مستويات الري (40، 60، و 80% من البخر- نتح)، وأنواع من ملح البوتاسيوم كانت صفر بوتاسيوم (كنترول)، K_2SO_4 (0.05 جم / كجم تربة)، KNO_3 (0.05 جم / كجم تربة)، و Salwax (0.02 جم / كجم تربة). تم حساب نسبة الإنبات، قياسات النمو، محتويات الأوراق من العناصر الغذائية، صفات محصول الحبوب وسماته وكذلك المحصول البيولوجي، وكفاءة استخدام المياه للذرة. أظهرت النتائج أن إجمالي الملح الذائب النهائي المتراكم في التربة بعد الحصاد اختلف معنويا بين مستويات الري الثلاثة. لم يكن لأملاح البوتاسيوم أي تأثير معنوي على نسبة الإنبات وقطر الساق، بينما ملح Salwax ادي الي زيادة معنوية في محتوى النيتروجين والبوتاسيوم والمغنيسيوم والكالسيوم في أوراق الذرة. كان من الواضح أن KNO_3 يمتلك أكبر قياسات نمو تليها الــ Salwax مقارنةً بالكنترول. بغض النظر عن مستوى الري، أدى كل من K_2SO_4 وKNO_3 إلى زيادة معنوية في المحصول البيولوجي على الكنترول بنسبة 4.5%، بينما حقق الــ Salwax محصولًا بيولوجيًا مشابهًا للكنترول. جميع أملاح البوتاسيوم ادت الي زيادة كفاءة استخدام المياه (WUE) والكتلة الحيوية-WUE، حيث كان لـ KNO_3 أعلى تأثير إيجابي. في الختام، من الممكن استخدام المياه المالحة في محصول الذرة للري حتى عند 40% من مستوى البخر المحتمل (ET) مع الغسيل شهريًا بنسبة 125% ET بجانب التسميد بـ KNO_3 على ثلاث جرعات بعد الغسيل.