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Comparison of Different Fertilization Rates on Yield, Evapotranspiration, and Water Use Efficiency of Sweet Corn Under Drought-Salinity Stresses

Farklı Gübreleme Oranlarının Kuraklık-Tuzluluk Stresi Koşullarında Tatlı Mısırın Verim, Bitki Su Tüketimi ve Su Kullanım Verimliliğinin Karşılaştırılması

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COMPARISON OF DIFFERENT FERTILIZATION RATES ON YIELD, EVAPOTRANSPIRATION, AND WATER USE EFFICIENCY OF SWEET CORN UNDER DROUGHT-SALINITY STRESSES

ABSTRACT

The present study investigated the effects of three fertilization (N-P_2O_5-K_2O) rates (F_1: 240-100-120 kg ha^{-1}, F_2: 192-80-96 kg ha^{-1}, F_3: 154-64-77 kg ha^{-1}) coupled with four irrigation practices (Control: C, irrigated at the 100% field capacity, Drought: D, irrigated 60% of C, Saline: S, irrigated at the 100% field capacity, Drought and saline: D+S, irrigated 60% of S) on sweet corn yield, evapotranspiration (ET), water use efficiency (WUE), and shoot fresh-dry weights. The obtained results depicted that the grain yield at D, S, and D+S treatments decreased by 24.2%, 46.6%, and 62.0%, respectively, relative to the C treatment. Moreover, grain yield at the F_3 condition was reduced by 45.3% compared to the F_1 condition. Additionally, the highest ET (330.7 mm) and yield (74.0 g) was achieved with F_1×C treatment. The F_2 and F_3 treatments reduced WUE by 17.9% and 31.5%, respectively, compared to the F_1 treatment. The highest reduction in yield, ET, WUE, and shoot fresh-dry weights was found at D+S irrigation treatment under all fertilization conditions. The tallest plants were observed in the F1×C treatment, being 24.0%, 33.5%, and 43.2% taller than plants in the F_1×(D+S), F_2×(D+S), and F_3×(D+S) treatments, respectively. Under F_3 conditions, exposing sweet corn plants to single or combined salinity and drought stress remarkably degraded the growth ability of the plants, and therefore, it is not economical and sustainable cultivation for agriculture. Finally, cultivation of sweet corn plants under individual or combined drought-salinity stress is not recommended due to the high reduction in grain yield.

Keywords: Grain Yield, Irrigation, Fertilization, *Zea Mays Var*. Saccharate, Water-Salt Stress.

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FARKLI GÜBRELEME ORANLARININ KURAKLIK-TUZLULUK STRESİ KOŞULLARINDA TATLI MISIRIN VERİM, BİTKİ SU TÜKETİMİ VE SU KULLANIM VERİMLİLİĞİNİN KARŞILAŞTIRILMASI

ÖZ

Bu çalışmada üç gübreleme (N-P_2O5-K_2O) oranı (F_1:240-100-120 kg ha^{-1}, F_2: 192-80-96 kg ha^{-1}, F_3:154-64-77 kg ha^{-1}) ile birlikte dört sulama uygulamasının (Kontrol: C, tarla kapasitesinin %100'ü kadar sulanmıştır, Kuraklık: D, C konusun %60'ı kadar sulanmıştır, Tuzlu: S, tarla kapasitesinin %100'ü kadar sulanmıştır, Kuraklık ve Tuzlu: S konusunun %60'ı kadar sulanmıştır) tatlı mısırın verim, bitki su tüketimi (ET), su kullanım verimliliği (WUE) ve gövde yaş-kuru ağırlıkları üzerine etkileri araştırılmıştır. Elde edilen sonuçlar, D, S ve D+S uygulamalarında tane veriminin C uygulamasına göre sırasıyla %24.2, %46.6 ve %62.2 oranında azaldığını göstermiştir. Ayrıca, F_3 koşulunda tane verimi F1 koşuluna kıyasla %45.3 oranında azalmıştır. Bununla birlikte, en yüksek ET (330.7 mm) ve verim (74.0 g) F_1×C konusundan elde edilmiştir. F_2 ve F_3 uygulamaları, F_1 uygulamasına kıyasla WUE' yi sırasıyla %17.9 ve %31.5 oranında azaltmıştır. Tüm gübreleme koşulları altında verim, ET, WUE ve sürgün taze-kuru ağırlıklarında en yüksek azalma D+S sulama uygulamasında bulunmuştur. En uzun bitkiler F_1×C uygulamasında gözlenmiş olup, F_1×(D+S), F_2×(D+S) ve F_3×(D+S) uygulamalarındaki bitkilerden sırasıyla %24.0, %33.5 ve %43.2 daha uzun olmuştur. F_3 koşullarında, tatlı mısır bitkisinin tek başına veya birlikte tuzluluk ve kuraklık stresine maruz bırakılması, bitkinin büyüme yeteneğini önemli ölçüde bozduğundan, tarımsal açıdan ekonomik ve sürdürülebilir bir yetiştirme yöntemi değildir. Sonuç olarak, tatlı mısır bitkilerinin tek başına veya kombine kuraklık-tuzluluk stresi altında yetiştirilmesi, dane verimindeki yüksek düşüş nedeniyle önerilmemektedir.

Anahtar Kelimeler: Tane Verimi, Sulama, GÜbreleme, *Zea Mays Var*. Saccharate, Su-Tuz Stresi.

1. INTRODUCTION

Water scarcity is a global concern impacting agricultural productivity and food security. Optimizing water use efficiency in crops is crucial as water resources diminish (Yue and Guo, 2021). Drought and salinity stress are major factors affecting plant growth and yield, presenting challenges to sustainable agriculture (Vaughan et al., 2018). Both stresses share similarities in plant structure, function, and biochemistry (Hu and Schmidhalter, 2005). Drought leads to oxidative stress, hampers photosynthesis, limits growth and causes injury (Cao et al., 2023). Salinity stress affects physiological processes like leaf water potential photosynthesis rate and damages photosystem II, hindering plant productivity by specific ion toxicity and disrupting nutrient uptake (Singh, 2022). Managing these stresses is a priority in modern crop production.

Fertilization is crucial for alleviating abiotic stress in plants, enhancing growth, increasing yield, and improving water use efficiency (Abaza et al., 2023). Nitrogen, phosphorus, and potassium (NPK) fertilization notably influences plant growth. Among essential nutrients, nitrogen enhances tolerance in maize and improves tolerance mechanisms under salinity stress (Javed et al., 2024). Potassium, being highly mobile in the phloem, plays a crucial role in distributing photosynthates for plant activities (Sperling et al., 2024). High potassium concentrations support phloem loading by maintaining a high pH and osmotic potential in sieve tubes (Sperling et al., 2024). Phosphorus is crucial for plant metabolism, energy transfer, nucleic acid synthesis, and root development (Guo et al., 2023). Balanced NPK fertilization has been shown to improve plant growth, yield, and stress tolerance by enhancing nutrient uptake, promoting root development, and improving water use efficiency (Ashraf et al., 2008). Recent studies have indicated that the proper application of NPK fertilizers can play a crucial role in alleviating the negative impacts of salinity and drought on plant growth and development (Han et al., 2016; Wang et al., 2019; Yaghoubi Khanghahi et al., 2021). This is achieved by enhancing osmotic adjustment mechanisms within the plants, which helps them maintain proper cellular water balance in challenging environmental conditions (Abaza et al., 2023). Additionally, NPK fertilization has been found to reduce the harmful effects of ion toxicity in plants exposed to high levels of salts in the soil (Acosta-Motos et al., 2017). Overall, these findings highlight the importance of balanced NPK fertilization in enhancing plant resilience and promoting sustainable crop production in saline and drought-prone areas

Sweet corn (*Zea mays var*. saccharate) is a popular and nutritious crop with a high demand for water and nutrients (Osman and Arslan, 2022; Subrata et al., 2022). Understanding how different fertilization management practices affect its yield, evapotranspiration, and water use efficiency under stress conditions is crucial for developing effective cultivation strategies. This study aims to fill this knowledge gap by evaluating the impact of different NPK fertilization rates on sweet corn under drought, salinity, and combined stress conditions. The main objectives of this study are to (1) evaluate the impact of different NPK fertilization rates on evapotranspiration, yield, and water use efficiency in sweet corn plants and (2) assess the effect of drought, salinity and their combined stress on the yield and growth ability of sweet corn plants.

2. MATERIAL AND METHOD

2.1. Experimental Conditions and Plant Material

The pot experiment was conducted at Ondokuz Mayıs University, Faculty of Agriculture, under a rain shelter from June 15, 2022, to September 8, 2022. The daily changes in the air temperature and relative humidity during the growth of sweet corn maize were recorded using a datalogger. The average daily air temperature ranged from 22.0 to 31.5 ^{o}C, and the relative humidity fluctuated between 49.0 and 91.3%, as illustrated in Figure 1.

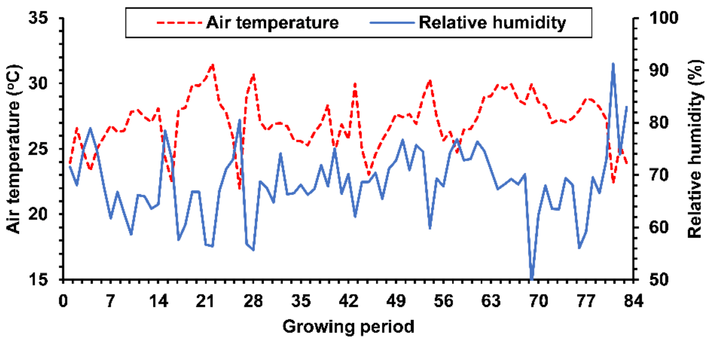

Figure 1. Daily average air temperature and relative humidity changes during growing season of sweet corn.

The soil texture in the research was clay loam, and a comprehensive description of the experimental soil properties is provided in Table 1. The dimensions of the plastic pots used in the experiment were 30 cm high, 28 cm in top diameter, and 26 cm in bottom diameter, respectively. Before filling the pots with soil, the soil was dried in the open air under a rain shelter, then crushed and sifted through a 4 mm sieve. Subsequently, each pot was filled with 1 kg of gravel at the base and 9 kg of sifted experimental soil. Sweet corn (*Zea mays var*. saccharate) cv. Merit F1 seeds were acquired from a local private company, planted on June 15, 2022, and harvested on September 8, 2022.

Table 1. The physical and chemical traits of the study soil.

Soil property	**Value**
Clay	32.1%
Silt	29.9%
Sand	38.0%
Texture	Clay loam
Field capacity	32.4%
Permanent wilting point	15.1%
Saturated EC_e	0.28 dS m^{-1}
Saturated soil pH	7.85
Organic matter content	12.0 g kg^{-1}
Total Nitrogen	23.90 mg kg^{-1}
Available phosphorus	12.65 mg kg^{-1}
Available potassium	15.41 mg kg^{-1}
Calcium carbonate	63.2 g kg^{-1}

2.2. Experimental Design

The pot study was carried out using a randomized complete block design with three replications involving three fertilization applications in the main plots and four irrigation treatments in the subplots. A total of 36 pots were used to carry out the present study. Details of the treatments are provided in Table 1. Three fertilization rates of N-P_2O_5-K_2O (kg ha^{-1}) were applied, representing control, moderate, and severe deficiency levels: F_1 [240-100-120], F_2 [192-80-96], and F_3 [154-64-77]. The F_1 treatment served as the control and followed the recommended rates by Gucdemir (2006). The fertilization rate needed for each treatment was determined and implemented based on the chemical analysis of the soil used in the experiment. In this regard, soil analysis was conducted prior to the commencement of the experiment. The 100% requirement of P and K fertilizer, in the form of triple superphosphate (45% P_2O_5) and potassium sulfate (45% K_2O), was applied at a 10 cm soil depth before sowing for all treatments in soil preparation. Nitrogen fertilizer, with 46% nitrogen content, was applied twice: half post-emergence and the other half at the 3-leaf stage.

Five pots loaded with research soil were saturated with tap water to determine their average field capacity. Plastic covers were used to prevent evaporation, and after 48 hours for drainage, the pots were weighed to establish their field capacity based on the average weight (Özdemir et al., 2009; Kurunc et al., 2011). After that, all pots were first weighted and irrigated to field capacity. Two days later, five sweet corn seeds were planted in each pot and irrigated with equal amounts of tap water (0.18 dS m^{-1}) up to starting various irrigation treatments. Once the sweet corn seedlings reached 2 true leaves, thinning was done, leaving only one seedling per pot. Subsequently, once the sweet corn seedlings had developed 3 true leaves, various irrigation methods were implemented. The control (C) and drought (D) treatments received irrigation with tap water (0.18 dS m^{-1}), while the saline (S) and drought + saline (D+S) treatments were irrigated with saline water (2.5 dS m^{-1}). The saline water was prepared by adding NaCl to tap water. When the usable soil moisture decreased by approximately 35-40% in $F_1 \times C$, $F_2 \times C$, and $F_3 \times C$ treatments, the irrigation water was implemented for the corresponding pots. Before irrigation, pots were weighed and watered according to irrigation practices. The detailed information for irrigation water applications is explained in Table 2.

Table 2. Description of the treatments.

Fertilization Applications	Irrigation Treatments	Abbreviation	Descriptions
F_1	C (Control)	$F_1 \times C$	Irrigated at 100% FC of the pots.
	D (Drought)	$F_1 \times D$	Irrigated at 60% of $F_1 \times C$
	S (Salinity)	$F_1 \times S$	Irrigated at 100% FC of the pots.
	D+S (Drought+salinity)	$F_1 \times (D+S)$	Irrigated at 60% of $F_1 \times S$
F_2	C (Control)	$F_2 \times C$	Irrigated at 100% FC of the pots.
	D (Drought)	$F_2 \times D$	Irrigated at 60% of $F_2 \times C$
	S (Salinity)	$F_2 \times S$	Irrigated at 100% FC of the pots.
	D+S (Drought+salinity)	$F_2 \times (D+S)$	Irrigated at 60% of $F_2 \times S$
F_3	C (Control)	$F_3 \times C$	Irrigated at 100% FC of the pots.
	D (Drought)	$F_3 \times D$	Irrigated at 60% of $F_3 \times C$
	S (Salinity)	$F_3 \times S$	Irrigated at 100% FC of the pots.
	D+S (Drought+salinity)	$F_3 \times (D+S)$	Irrigated at 60% of $F_3 \times S$

2.3. Data Collection

2.3.1. Evapotranspiration and Water use Efficiency

Evapotranspiration (ET) and water use efficiency for each treatment were calculated based on the equations provided by Ünlükara et al. (2015) and Kiremit and Arslan (2018);

$$ET=\frac{\left[\frac{\Delta W}{\tilde{n}_w}\right]+\left[I\text{-}D\right]}{A} \qquad (1)$$

Where, ΔW represent the weights of the pots at n and n+1 days before the irrigation event (in kg), while I and D denote the volumes of irrigation and drainage water. The water bulk density is represented by ρ (1 g cm^{-3}), and A stands for the soil surface area (m^2). Water use efficiency (WUE) is calculated by dividing yield by ET (in mm) and is expressed as g mm^{-1}.

2.3.2. Yield and Growth Traits

After 84 days, when the sweet corn was at the milking stage, the plants were harvested to measure yield and growth from all pots. Ears with cob and bract were picked by hand from each potted plant. The shoot fresh weight was determined by weighing the stem, leaves, and ears, while the shoot dry mass was obtained by oven-drying the stem and leaves at 70°C until a constant weight was reached. Plant height was measured using a tape measure, and the grains were detached from the ears, weighed, and used to calculate the grain yield per plant.

2.4. Data Analysis

Data were analyzed using two-way ANOVA with SPSS 25.0 software to evaluate the effects of fertilization, irrigation, and their interaction. The Duncan multiple range test was used to compare differences between treatments at a 0.05 probability level (Takma et al., 2023). Figures were created with Microsoft Excel [Office 365].

3. RESULTS AND DISCUSSION

3.1. Irrigation Water and Evapotranspiration

As seen in Table 3, the irrigation water amount (IW) was significantly affected by fertilization, irrigation, and their interaction. Besides, the highest IW (283.2 mm) was found in the F_1 treatment, which was 13.6% and 25.9% higher than the F_2 and F_3 treatments, respectively (Table 4). Regarding irrigation treatments, the reduction in IW more obviously occurred at D+S treatment, which was 50.7%, 10.8%, and 64.9% lower than S, D, and C treatments, respectively Table 4. Additionally, the highest and lowest IW values (355.4 mm and 163.1 mm) were observed at F_1×C and F_3×(D+S) treatments, respectively (Table 4). Under all fertilization conditions, the highest IW values were observed at C treatments, while the lowest IW values were seen at D+S treatments (Table 4). Also, the IW values in F_1×(D+S), F_2×(D+S), and F_3×(D+S) treatments reduced by 38.9%, 36.5%, and 43.1%, respectively compared to the F_1×C, F_2×C, and F_3×C treatments (Table 4).

The irrigation, fertilization, and irrigation×fertilization interaction had significantly impacted the evapotranspiration (ET) of sweet corn plants, as depicted in Table 3. The irrigation treatments considerably differed in the ET values of sweet corn plants (Table 4). According to that, the mean ET values for the C, D, S, and D+S treatments were found to be 288.7 mm, 184.3 mm, 263.0 mm, and 165.0 mm, respectively (Table 4). Relative to the C treatment, the ET values decreased by 36.2%, 8.2%, and 42.8% in the D, S, and D+S treatments, respectively (Table 4). Regarding fertilization treatments, a significant decrease in fertilizer

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supply resulted in a notable reduction in ET values of sweet corn plants (Table 4). The F_1 treatment showed the highest ET value (254.4 mm), surpassing the F_2 and F_3 treatments by 14.1% and 28.6%, respectively (Table 4). Considering the interaction between irrigation and fertilization, the highest ET value (330.7 mm) occurred at F_1×C treatment, while reducing the fertilization rates caused more decreases in ET of sweet corn plants at C conditions. For instance, the ET value in F_2×C and F_3×C decreased by 15.5% and 22.6%, respectively, relative to the F_1×C treatment (Table 4). The results clearly indicate that ET and IW were reduced more under S and D+S treatments than under C and D treatments (Table 4). This situation could be mainly related to the inhibition of the water uptake ability of sweet corn plants due to the high osmotic potential in the soil and reduced water accessibility of the plants. Besides, the present findings suggested that sweet corn plants were more sensitive to salinity and combined drought stress than drought stress. This result can be associated with the S or D+S treatments inhibited leaf photosynthesis functions and reduced assimilate accumulation in plants. Angon et al. (2022) explained that osmotic stress induced by salinity disrupts photosynthetic function, leading to a decrease in photosynthesis activity and an increase in chlorophyll degradation. This results in reduced CO_2 intake and ultimately decreases water consumption in plants. In another study, Ye et al. (2022) suggested that optimal NPK fertilization can improve the crop's ability to utilize soil water storage under abiotic stress conditions. Yurtseven et al. (2005) found that tomato plants' water consumption remained unaffected by varying potassium levels but was significantly reduced by salinity stress. Ahanger et al. (2019) found that adequate N supplementation protects essential cellular processes, such as photosynthesis and membrane integrity, enhancing the water uptake capacity of wheat plants under 100 mM NaCl stress. On the other hand, the reduction in ET due to a decrease in NPK fertilization rate may be linked to ion-specific impacts, indicating that plants experiencing drought or salinity stress under inadequate fertilization conditions became more sensitive to stress, ultimately reducing the metabolic functions of the plants.

3.3. Grain Yield

Significant variation and decreasing trends in grain yield were observed with decreasing fertilization rates (Table 4). Accordingly, the grain yield in F_1, F_2, and F_3 treatments was found to be 50.3, 35.9, and 27.6 g plant^{-1}, respectively (Table 4). Regarding irrigation treatments, irrigation practices have caused more inhibition in the grain yield of sweet corn plants (Table 4). The highest yield (56.9 g plant^{-1}) was found at the C treatment, while the lowest (21.4 g plant^{-1}) was observed at the D+S treatment (Table 4). Additionally, the irrigation×fertilization interaction drastically reduced the grain yield of sweet corn plants (Table 4). The reduction in fertilization rates caused more reduction in grain yield, especially the lowest values were observed at F_3×(D+S) treatment. The highest grain yield was observed at F_1×C treatment, which was 134.6%, 237.1%, and 553.1% higher than F_1×(D+S),

F_2×(D+S), and F_3×(D+S) treatments, respectively (Table 4). Moreover, the grain yield of sweet corn showed a linear relation with evapotranspiration (Fig. 2). Increasing evapotranspiration increased the grain yield of sweet corn at all irrigation practices. The greatest increase in yield per unit of water consumption was seen in the drought treatment, with the smallest increase being observed in the salinity treatment (Fig. 2). Considering all, combined salinity and drought (D+S) stress caused a greater reduction in grain yield of sweet corn plants compared to under single stress, confirming past studies (Cao et al., 2023; Chávez-Arias et al., 2021). In our study, under severe fertility conditions (F_3), the lack of essential nutrients limits the plant's ability to cope with drought, salinity, or combined stress, leading to extreme physiological disruption, stunted growth, and minimal grain production. Similarly, Wei et al. (2023) further explained that the significant decrease in rice grain yield under combined drought and salinity stress was strongly linked to the reduction in leaf photosynthesis rate and increased leaf senescence. Javed et al. (2024) found that nitrogen plays a key role in forming amino acids, proteins, and chlorophyll. Ye et al. (2022) explained that providing sufficient nitrogen through fertilization boosts leaf and stem growth, enhancing photosynthesis, leading to improved nutrient absorption, energy generation, and, ultimately, a higher rate of grain filling. Finally, cultivating sweet corn plants under inadequate fertilization conditions, particularly in the presence of drought, salinity, or combined stress, is not advisable as it results in significant reductions in yield due to the adverse effects caused by these stress factors.

Table 3. The results of the two-way ANOVA for the effects of fertilization, irrigation, and their interaction on irrigation water amount, evapotranspiration, grain yield, water use efficiency, and growth traits of sweet corn plants.

Variation Sources	df	Irrigation Water Amount		Evapotranspiration		Grain Yield		Shoot Fresh Weight	
		mm		mm		g plant^{-1}		g	
		F_{value}	P_{value}	F_{value}	P_{value}	F_{value}	P_{value}	F_{value}	P_{value}
Fertilization	2	216.85	<0.01	89.04	<0.01	176.55	<0.01	827.59	<0.01
Irrigation	3	681.67	<0.01	293.14	<0.01	240.73	<0.01	547.74	<0.01
Fert.×Irrig. Int.	6	4.16	<0.01	1.97	<0.05	3.60	<0.05	3.99	<0.01
Variation sources	df	Shoot dry weight		Plant height		Water use efficiency			
		g		cm		g mm^{-1}			
		F_{value}	P_{value}	F_{value}	P_{value}	F_{value}	P_{value}		
Fertilization	2	99.92	<0.01	94.48	<0.01	45.14	<0.01		
Irrigation	3	32.68	<0.01	69.77	<0.01	112.15	<0.01		
Fert.×Irrig. Int.	6	3.48	<0.05	1.39	<0.05	1.87	<0.05		

df: degree of freedom.

Table 4. The effects of different fertilization applications on irrigation water amount, evapotranspiration, grain yield, and the shoot dry and fresh weight of sweet corn under various irrigation practices.

Irrigation treatments	Irrigation water amount (mm)			
	Fertilization treatments			Mean
	F_1	F_2	F_3	
C	355.4 a	307.4 c	286.5 d	316.5 A
D	236.0 f	207.2 g	194.6 h	212.6 C
S	324.3 b	287.6 d	255.8 e	289.2 B
D+S	217.0 g	195.3 h	163.1 i	191.8 D
Mean	283.2 A	249.4 B	225.0 C	
Irrigation treatments	**Evapotranspiration (mm)**			
	Fertilization treatments			Mean
	F_1	F_2	F_3	
C	330.7 a	279.3 bc	256.1 d	288.7 A
D	206.3 f	180.8 gh	165.9 h	184.3 C
S	291.0 b	266.1 cd	232.0 e	263.0 B
D+S	191.8 fg	165.5 h	137.6 i	165.0 D
Mean	254.4 A	222.9 B	197.9 C	
Irrigation treatments	**Grain yield (g plant^{-1})**			
	Fertilization treatments			Mean
	F_1	F_2	F_3	
C	74.0 a	51.6 b	45.1 c	56.9 A
D	55.0 b	42.8 c	31.6 d	43.1 B
S	41.5 c	27.1 de	22.6 ef	30.4 C
D+S	30.8 d	21.9 f	11.3 g	21.4 D
Mean	50.3 A	35.9 B	27.6 C	
Irrigation treatments	**Shoot fresh weight (g plant^{-1})**			
	Fertilization treatments			Mean
	F_1	F_2	F_3	
C	286.0 a	180.0 e	115.3 g	193.8 A
D	263.0 b	162.7 f	104.0 gh	176.6 B
S	236.0 c	154.7 f	99.3 hi	163.3 C
D+S	216.2 d	119.3 g	86.0 i	140.5 D
Mean	250.3 A	154.2 B	101.2 C	
Irrigation treatments	**Shoot dry weight (g plant^{-1})**			
	Fertilization treatments			Mean
	F_1	F_2	F_3	
C	46.7 a	30.9 bc	26.3 cd	34.6 A
D	42.6 a	28.4 bc	20.9 e	30.6 B
S	32.3 b	26.2 cd	19.3 ef	25.9 C
D+S	27.1 cd	23.3 de	14.6 f	21.7 D
Mean	37.2 A	27.2 B	20.2 C	

Distinct capital or lowercase letters in a column or row indicate significant differences at the 5% significance level, based on the Duncan multiple range test. C: Control, D: Drought stress, S: Salinity, D+S:Drought and salinity.

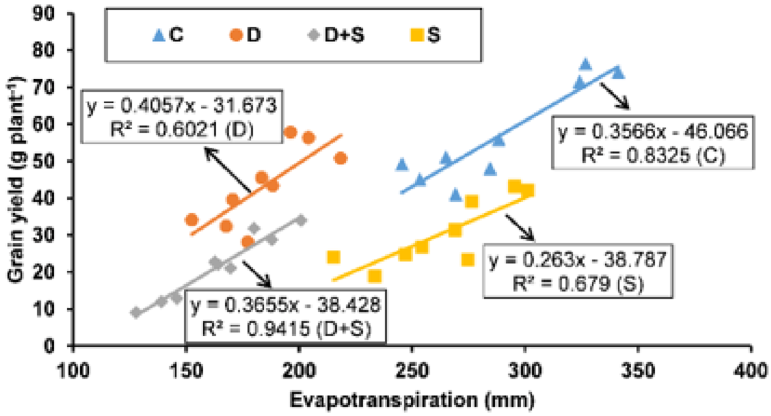

Figure 2. The relation between evapotranspiration and grain yield of sweet corn under various irrigation conditions.

3.4. Shoot Fresh and Dry Weights

As seen in Table 3, both irrigation and fertilization had a significant impact on shoot fresh weight (SFW) and shoot dry weight (SDW). Application of from C to (D+S) irrigation practices gradually decreased SFW and SDW of sweet corn at all fertilization conditions (Table 4). The response of SFW and SDW to irrigation practices was similar under various fertilization rates. According to that, the mean D+S irrigation treatment showed a 27.6% and 37.2% reduction in SFW and SDW as compared to the C treatment (Table 4). Additionally, fertilization practices showed a dramatic reduction in SFW and SDW of grain yield (Table 4). The F_1 treatment showed a maximum SFW (250.3 g plant^{-1}) and SDW (37.2 g plant^{-1}), which was 147.2% and 84.0% higher than the F_3 treatment. In terms of irrigation×fertilization interaction, the greatest shoot fresh weight (286.0 g plant^{-1}) was obtained under the F_1 condition at the C treatment, which was 58.9% and 148.0% higher than F_2 and F_3 fertilization treatment, respectively, at the C treatment (Table 4). Similar to SFW, the lowest fertilization application (F_3) caused significant decreases in SDW in sweet corn plants in comparison to the F_1 treatment. The F_1×C treatment resulted in the maximum SDW, which was statically at par F_1×D treatment (Table 4). Additionally, the lowest SDW was observed at D+S conditions for all fertilization applications, while the lowest SDW was realized at the lowest fertilization condition (F_3). Adequate fertilization can partially mitigate these adverse effects by ensuring that the plants have sufficient nutrients to support metabolic functions and stress responses (Arif et al., 2020; Liu et al., 2023). Wei et al. (2023) showed that combined salinity and drought stress caused more reductions in shoot biomass of rice plants compared to single effects of salinity or drought stress. (Javed et al., 2024) found that salinity stress significantly reduced the fresh biomass of maize.

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They proposed that enhancing nitrogen nutrition in salinity-stressed plants could boost biomass by promoting increased leaf area and vegetative growth. Similar to our findings, Du et al. (2022) indicated that soil salinization negatively affected maize's water and nutrient metabolism, leading to decreased plant biomass. Kaplan et al. (2016) noted that higher irrigation rates improved maize yield but reduced quality, while higher nitrogen rates improved both yield and quality. However, they demonstrated that when soil salinity is below 0.25%, adequate nitrogen application can mitigate the adverse effects of salinity. In our study, the reductions in SDW and SFW are primarily caused by single or combined stresses that impair the protective enzyme systems in plants, leading to compromised leaf photosynthetic functions. This, in turn, results in reduced mineral uptake/transport and accumulation in the plant body, ultimately leading to decreased shoot weights. Furthermore, exposing sweet corn plants to drought or salinity stress under sufficient fertilization (F_1) showed better improvement in shoot weight compared to moderate or lowest fertilization conditions (F_2 and F_3). This highlights the important role of providing essential nutrients to support growth, enhance stress tolerance, and promote healthier plants. In the future, additional research must be conducted to explore various irrigation and fertilization methods in order to gain a more comprehensive understanding of the ideal NPK needs for sweet corn crops.

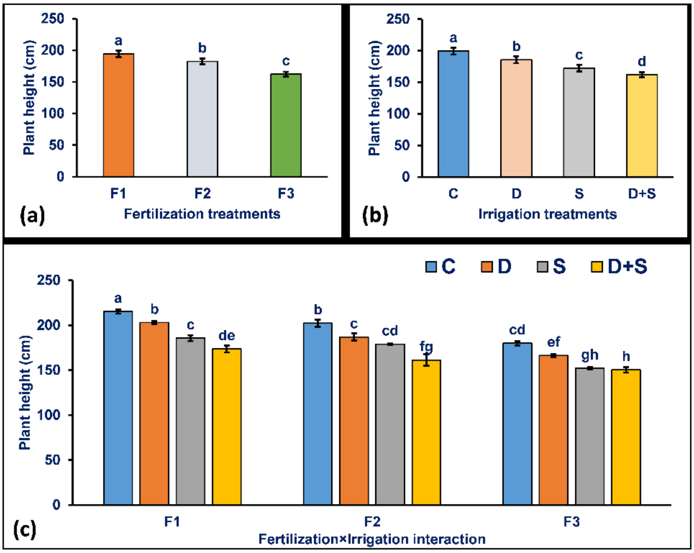

Figure 3. Effects of various irrigation practices on plant height of sweet corn plants under different fertilization conditions. Different letters on the bar graph indicate significant differences at the 5% probability level, according to the Duncan multiple range test. The vertical lines on the bar graphs show the standard error of the three replicates for each treatment. C: Control, D: Drought stress, S: Salinity, D+S: Drought and salinity.

3.5. Plant Height

The height of sweet corn plants was significantly influenced by a two-way interaction between irrigation and fertilization, as shown in Table 3. Plants fertilized under F_1 conditions exhibited greater height compared to those under F_2 and F_3 treatments (Fig. 3a). Moreover, a reduction in irrigation rate had a notable impact on plant height, with plants under condition C being 7.4%, 15.6%, and 23.1% taller than those under D, S, and D+S treatments, respectively (Fig. 3b). The constructive interaction of fertilization and irrigation indicated that lowest fertilization combined with saline deficit irrigation significantly impeded the growth of sweet corn plants, resulting in the smallest plant heights among all treatments (Fig. 3c). Notably, plant heights varied between 215.3 cm and 173.7 cm for F_1, 202.3 cm to 161.3 cm for F_2, and 180.0 cm to 150.3 cm for F_3 (Fig. 3c). The tallest plants (215.3 cm) were observed in the F_1×C treatment, being 24.0%, 33.5%, and 43.2% taller than plants in the F_1×(D+S), F_2×(D+S), and F_3×(D+S) treatments, respectively (Fig. 3c). Du et al. (2019) point out that the leaf anatomical structures of maize are significantly hampered by potassium deficiency, thus reducing the growth ability of the plants. Javed et al. (2024) reported that optimum nitrogen supply improved plant metabolism and increased the growth ability of the maize plants under salinity stress. Therefore, plants must receive adequate nutrients and water in order to support optimal hormone production and sustain healthy growth patterns. Our findings clearly show that low fertilization combined with high osmotic stress leads to a further decrease in cell division and growth, ultimately resulting in reduced plant height. Based on the findings, it could be noted that low fertilization levels in soil caused a significant impact on plant growth, especially when coupled with high osmotic stress. The combination of these factors ultimately leads to a decrease in the production of growth hormones within the sweet corn plants. As a result, the normal processes of cell division and elongation are disrupted, causing a noticeable stunting in overall plant development. Collectively, individual or combined drought-salinity stress disrupted reactive oxygen balance and caused high oxidative damage, reducing the growth ability of sweet corn under low fertilization. It is essential to focus on determining the optimal irrigation and fertilization requirements of plants for sustainable agriculture.

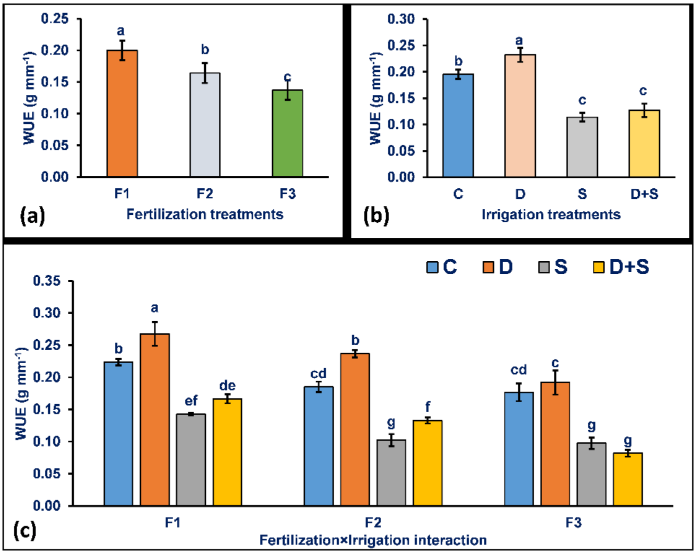

Figure 4. Effects of various irrigation practices on water use efficiency (WUE) of sweet corn plants under different fertilization conditions. Different letters on the bar graph indicate significant differences at the 5% probability level, according to the Duncan multiple range test. The vertical lines on the bar graphs show the standard error of the three replicates for each treatment. C: Control, D: Drought stress, S: Salinity, D+S: Drought and salinity.

3.6. Water use Efficiency

The results from the two-way ANOVA analysis on WUE indicate that the impacts of irrigation, fertilization, and their interaction on WUE were statistically significant (Table 3). As illustrated in Figure 4a, the fertilization treatments had a notable influence on the WUE of sweet corn plants. The F_3 treatment resulted in the lowest WUE of 0.14 g mm^{-1}, which was 19.1% and 46.0% lower than the WUE values of treatments F_2 and F_1, respectively. According to irrigation treatments, the highest WUE of 0.23 g mm^{-1} was observed in the D treatment, while the lowest was found in the S treatment, which did not significantly differ from the D+S treatment (Fig 4b). In terms of interaction, it can obviously be seen in Fig. 4c that the highest WUE values were found at D treatment under all fertilization treatments. The maximum WUE (0.27 g mm^{-1}) was found at F_1×D treatment (Fig. 4c). Additionally, the WUE for the F_1×D treatment was 60.9%, 101.6%, and 226.7% higher than that of the F_1×(D+S), F_2×(D+S), and F_3×(D+S) treatments, respectively (Fig.4c). The highest WUE values were observed at F_1 conditions due to enhanced plant growth from adequate water and nutrient uptake. However, the highest WUE was detected at drought stress (D) conditions. In response to soil drying, roots produce abscisic acid to regulate the stomatal aperture, causing partial closure under deficit irrigation (Wang et al., 2022). This action reduced the transpiration rate, limited shoot growth over time, decreased water consumption and enhanced WUE (Kang and Zhang, 2004). Garcia y Garcia et al. (2009) noted that sweet corn plants had a higher WUE value under deficit irrigation compared to full irrigation. Our results align with Zou et al. (2020) in demonstrating that the WUE of spring maize declines with lower fertilization rates and higher irrigation water application.

Conclusion

The present study concluded that applying saline or deficit saline irrigation to sweet corn plants significantly decreased evapotranspiration, yield, and WUE, especially under medium or high fertilization deficiency. Therefore, more studies are needed to determine the optimal fertilization management of sweet corn under various irrigation strategies to ensure sustainable irrigation and fertilization in harsh environmental conditions. Finally, the findings of this pot trial serve as the baseline data for future experiments in field conditions to verify the results.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethics

This study does not require ethics committee approval.

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