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Impact of Irrigation Regime and Organic Amendments on Soil Physical Properties, Nutrient Availability, and Productivity in Calcareous Soil

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The scarcity of irrigation water in Egypt requires addressing severe water scarcity, such as deficit irrigation and using organic amendments to improve water use efficiency in agriculture. A field experiment was conducted at El-Nubaria Agricultural Research Station in the summer of 2022 for maize and the winter of 2022/2023 for wheat to study the impact of organic amendments and irrigation regime on calcareous soil properties and productivity. The experiment involved a split-plot design with three replicates, irrigation regime was placed in main plots (50% (I_{50}), 75% (I_{75}), and 100% (I_{100}) of ETc) and organic amendments in subplots included five treatments: 1) 9.6 ton ha^{-1} (B_1), 2) 14.4 ton ha^{-1} (B_2) of biochar, 3) potassium humate at the rate of 1.5% (KH_1), 4) 3% (KH_2)

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and 5) compost (12 ton ha^{-1}). The obtained results indicated that compost, followed by B_2 (14.4 ton ha^{-1}), achieved the highest soil organic matter value. Applied I_{100} had the highest soil available NPK and micronutrients, followed by I_{75}. Organic amendments significantly affected the soil availability of N, P, K, Fe, Mn and Zn. The maximum potassium content in grains was achieved using I_{100}, followed by I_{75}. The influence of organic amendments on field capacity and available water took the descending order: B_1> KH_1> compost. Water use efficiency was negatively impacted by increasing the amount of applied irrigation water. Applying I_{100} resulted in a significant increment in wheat and maize grain yields, followed by I_{75}. The influence of organic amendments on wheat grain yield took the descending order: compost > potassium humate > biochar, while the effect on maize grain yield took the descending order: potassium humate > compost > biochar.

Keywords: Cereal crop; calcareous soil; biochar; maize.

1. INTRODUCTION

Considering over 80% of Egypt's water sources are used for agriculture, the availability of water is the greatest obstacle to growing the country's food production. The increase in irrigated areas, however, is increasing the demand for water sources. Since irrigation water resources are scarce, great efforts should be made to rationalize the use of each unit of water. One of the major tactics to save water and improve water use efficiency is irrigating the crops with a water amount less than the optimal requirement, which refers to water deficit. However, the application of a deficit water pattern in irrigating crops is associated with low yields and quality [1]. Physiologically, low water supply, as an abiotic stress, causes critical issues in cell water integrity, stomata performance, plant pigments, and photosynthesis, hence a reduction in productivity is anticipated [2]. Therefore, several practices are required to be applied under water shortage to maintain better plant growth and productivity [3]. Maize (*Zea mays* L.) is an important food and feed crop that ranks third in the world, with multiple uses such as human food, animal feed, and industrial raw materials [4].

Wheat (*Triticum aestivum* L.) is a major cereal crop in Egypt, with a planted area of 1.43 million hectares. The total production was 9.3 million tons, with an average of 6.5 tons per hectare [5]. Another important cereal crop is wheat, whose grains contain a range of protein (6–21%), fats (1.5–2.0%), cellulose (2.0–2.5%), minerals (1.8%), and vitamins (1.8%), according to Malav et al [6]. Egypt is the world's largest importer of wheat, providing 40% of the population's needs, with 10 million tons produced annually from 1.5 million hectares [7]. However, growing wheat in calcareous soils under deficit irrigation resulted in noticeable decreases in yield and quality. In saline or calcareous soils, crop plants are subjected to physiological drought, which negatively alters the physiological status and nutrient balance, suppressing growth. Organic soil amendments enhance soil properties, maintain fertility, increase productivity, preserve the environment, and produce safe organic food [8]. Organic materials improve the chemical and physical properties of sandy soil by retaining moisture and recycling nutrients [9]. Organic additions enhance soil quality and increase carbon storage, potentially aiding in climate change mitigation efforts [10]. Soil amendments, when properly prepared and applied, can enhance plant productivity, and soil stability [11]. They cause increased population sizes and proportions of bacteria associated with nutrient cycling [12].

Compost is a fully decomposed, stabilized, homogeneous substance of animal or plant origin, free from harmful elements that could harm humans, animals, plants, or the environment [13]. It is a humic-rich amendment that enhances soil properties through the controlled biological decomposition of organic resources [14, 15]. Compost can enhance the growth of plants, lower the need for fertilizer, and reduce soil-borne plant diseases [16]. Composting is an environmentally friendly method of converting organic waste into organic nutrients [17].

Biochar is a porous, high-carbon material produced through pyrolysis in a no-oxygen environment, which serves as a storage medium for carbon [18, 19] and raises aromatic structures and essential minerals in clay minerals over time [20]. Biochar is gaining popularity as a soil conditioner due to its carbon storage, soil fertility enhancement, water retention, and increased crop yield [21, 22, and 23]. The biochar use in agricultural soils offers numerous benefits including improved soil health, nutrient retention, efficient transfer, and climate change mitigation. Its high surface area, porosity, and high levels of COO^-, OH^-, P-O-, and R-OH groups contribute to its benefits [24]. Furthermore, biochar enhances soil properties, relocates fertilizers, and sequesters carbon, while maintaining stability is crucial for climate change mitigation [25]. Biochar in alkaline soils was an effective, reasonable, and environmentally friendly approach [26]. Compost and biochar can be used to improve soil quality and productivity by absorbing nutrients, improving nutrient availability, and stimulating the microbial. Biochar-blended compost can act as a partial replacement for mineral fertilizers [27, 28]. Also, Biochar and compost can enhance maize yield and soil quality, with their combined application potentially enhancing the properties of soil [29, 30].

Humic substances (HS) promote plant growth through anatomical and biochemical changes in the root system via chelation [31]. Humic acid, a plant growth regulator, is broken down by living microorganisms, allowing plants with strong chemical and biological activity to easily absorb it [32]. HS comprising 60% of soil organic compounds are crucial for the Agroecosystems and are responsible for various complex chemical reactions [33]. K-humate is more efficient than K-Si and compost due to its high solubility, smaller dose, and ease of field application [34]. HS are commonly used in agriculture due to their hormone-like effects, which promote growth, enhance plant yield, and improve quality [35]. Humates can improve soil structure and water retention capacity to enhance maize quality [36, 37, 38]. Potassium humate, 75% N and 100% Reference evapotranspiration (ETo) improved soil chemical properties, leading to improved wheat yield [39]. Also, foliar applications of potassium humate can mitigate stress-related damage in soybean by promoting antioxidant growth and protecting proteins and chlorophyll [40]. The study found that adding 75% NPK, biochar, and KH to soil improved growth and water efficiency in olive trees under a half-irrigation water regime [41, 42].

The most effective treatment for crop water reduction was 75% full irrigation and 6 tons of biochar, saving 25% of the water needed [43]. Four irrigation treatments had the longest maturity period, while no irrigation treatments had the shortest [44]. The physicochemical and fertility properties of sandy soils were enhanced by optimizing water and nutrients using an 80% water regime with a 45 kg ha^{-1} HA rate [45]. An alternate water-saving method for growing maize is 70% ETc [46]. Apply irrigation with a 4200 m^2 fed level and 4 tons of compost to achieve acceptable maize yield and water utilization [47]. This study aimed to investigate the impact of soil amendments (biochar, potassium humate, and compost) on soil physical properties, nutrient status, growth, and yield of wheat and maize cultivated in calcareous soil under varying irrigation regime.

2. MATERIALS AND METHODS

2.1 Field Experiment Location and Design

The field experiment was conducted at the EL-Nubaria research farm, located in the Behaira Governorate in Egypt. The study examined the impact of soil amendments and irrigation regime on soil physical properties, nutrient status, and productivity of maize and wheat during the 2022 summer and 2022/2023 winter seasons, under the Ministry of Agriculture and Land Reclamation's Agricultural Research Center. The geographical coordinates of the farm are 30° 90 N, 29° 96 E, with an altitude of 25 m above sea level.

The experiment was laid out in a split design with three replicates. The experimental plot area was 10.5 m^2 (3m x 3.5m). Irrigation regime were placed in the main experimental plots, while organic amendments were in the subplots. The treatments were for irrigation water requirements (100%, 75%, and 50% of ETc), and organic amendments included five treatments: 1) biochar 9.6 ton ha^{-1}; 2) biochar 14.4 ton ha^{-1}; 3) potassium humate 1.5% (KH_1); 4) potassium humate 3% (KH_2) and 5) compost (12 ton ha^{-1}).

Some physical and chemical characteristics of the surface soil under investigation, as well as organic amendments, were analyzed before cultivation according to page et al [48], as shown in Tables 1 and 2.

2.2 Plant Materials and Planting

Maize hybrid triple white (Giza 310) was planted on June 1st and wheat (Misr 1) was sown on November 18th obtained from the Field Crops Institute, Agricultural Research Center, Giza, Egypt. Nitrogen fertilizers such as ammonium

Table 1. Physical and chemical properties in soil study

Sand (%)	Silt (%)	Clay (%)	Texture		SP (%)		OM (%)		CaCO$_3$ (%)
53.5	40.0	6.5	Sandy loam		48		0.75		33.65
pH (1: 2.5)	**EC (dSm^{-1})**	**Cations (meq l^{-1})**				**Anions (meq l^{-1})**			
		Ca^{++}	**Mg^{++}**	**Na^{+}**	**K^{+}**	**HCO$_3^-$**	**Cl$^-$**		**SO$_4^{-2}$**
7.96	2.4	7.5	4.50	11.45	0.25	1.5	13.5		8.97
Macronutrients (mg kg^{-1})					**Micronutrients (mg kg^{-1})**				
N	**P**	**K**			**Fe**	**Mn**	**Zn**		
17.8	8.12	224.38			3.01	1.89	1.14		

Table 2. Analysis of organic amendments used in the experiment

Amendments	Bulk density (kg/m^3)	pH	EC (dSm^{-1})	O.C %	O.M %	C/N Ratio	Total (%) N	P	K
Biochar	1060	7.2	2.70	26.5	45.6	35:1	0.76	0.22	0.38
Compost	580	7.6	4.67	15.7	27	16:1	0.97	0.35	0.48
K-humate	ND	8.2	2.50	0.62	1.07	1.2:1	0.53	0.01	4.5

ND: not determined

Table 3. The reference evapotranspiration averages for months during the growing seasons at the experimental site with the applied irrigation water (AIW m^3/ha)

Planting Seasons	ETo mm/day					AIW m^3/ha		
Maize 2022	**June**	**July**	**August**	**September**	**October**	**100% ETc**	**75% ETc**	**50% ETc**
	5.9	5.5	4.4	2.93	1.95	3677.1	2757.8	1838.5
Wheat 2022/2023	**December**	**January**	**February**	**March**	**April**	**100% ETc**	**75% ETc**	**50% ETc**
	1.05	1.2	1.5	2.6	3.67	2218	1663.5	1109

sulfate (20.6%) was added to the soil. Phosphorus fertilizer as superphosphate (15.5% P_2O_5) and potassium fertilizer as potassium sulfate (48% K_2O), micronutrients, weeds, and diseases were added according to the Ministry of Agriculture and Land Reclamation of Egypt's recommendation. Potassium humate treatments were sprayed to coat the leaf surface and drenched the soil around plants at a rate of 1440 L/ha. The plants were sprayed three times at 45, 60 and 90 days after planting.

2.3 Plant-water and Irrigation Water Measurements

The crop evapotranspiration (ETc) value of crops in the Nubaria region was determined using reference evapotranspiration and crop factor. Table 3 showed the average values of standard evapotranspiration. The climatic data from the EL-Nubaria Agricultural Research Station, Ministry of Agriculture and Land Reclamation, Egypt, was used to calculate the ETo using CROPWAT 8 [49]. The crop evapotranspiration was calculated using the following equation [50] ETc = ETo×Kc, where: ETc is crop evapotranspiration (mmd^{-1}), ETo is the reference evapotranspiration (mmd^{-1}) and Kc: crop coefficient.

Applied irrigation water was calculated according to the following equation: AIW= ETc/ Ea (1 - LR) where: AIW: applied irrigation water (mmd^{-1}), ETc evapotranspiration values (mmd^{-1}) and Ea is the irrigation application efficiency. LR is the leaching requirement (assuming that 10% of the calculated applied irrigation water is additionally applied per irrigation during the growing season for leaching purposes).

Drought Tolerance Efficiency (DTE): was calculated using the formula [51]:

$$\text{DTE (\%)} = \frac{\text{Yield under stress}}{\text{Yield under non stress}} \times 100$$

Water utilization efficiency (WUE): was estimated for each crop in according to [52] as follows: $\text{WUE (Kgm}^{-3}) = \frac{\text{Seed Yield (Kg)}}{\text{Water applied (m}^3)}$

2.4 Plant and Soil Sampling and Analysis

At harvest time, maize and wheat plants (after 120 and 150 days from planting, respectively) from each plot were cut and air-dried, and grain yield and straw yield (ton ha^{-1}) were estimated. Also, 1000 grain weights for wheat and 100 grains for maize were weighted. In addition, plant height (cm) and ear weight (gm) of maize were determined as yield components of maize. Oven-dried plant samples were analyzed for nitrogen (N), phosphorus (P), potassium (K), iron (Fe), manganese (Mn) and zinc (Zn) as described by Estefan et al [53].

Soil samples were analyzed for available N, P, K, Fe, Mn and Zn according to methods described by Page et al [48]. Organic carbon was determined by the modified Walkley-Black method [54]. Soil hydraulic conductivity (HC) was determined using undisturbed samples from the cores [55]. Soil moisture retention curves were determined by exposing the completely saturated samples to constant suction levels of 0.1, 0.33, 1.0 and 15 atmospheres using a pressure cooker and membrane [56]. The moisture percentages at each suction level were calculated volumetrically.

2.5 Statistical Analysis

Statistical data analysis was performed using CoStat (version 6.303, CoHort, USA, 1998–2004). The significant differences among means were tested using the least significant differences (L.S.D.) [57].

3. RESULTS AND DISCUSSION

3.1 Organic Matter

Data in Tables 4 and 5 revealed the effect of irrigation treatments and organic amendments on the soil organic matter (O.M) % in calcareous soil under wheat and maize crops. It was observed that the maximum value of O.M% was obtained by compost (12 ton ha^{-1}), followed by B_2 (14.4 ton ha^{-1}). This increment may be due to the high content of organic matter in compost compared to biochar (Table 2). Thus, the soil O.M content resulting from applying soil amendments can be arranged in the following descending order after wheat or maize crops: compost > B_2 > KH_2.

These results are consistent with those obtained by Mahmoud et al. [28] who reported that biochar and compost enhance soil organic matter. Besides, the results achieved by El-Ngar et al [58] showed that compost organic amendments markedly increased soil organic matter compared to control treatments. Additionally, the results achieved by Amin and Eissa [59], who mentioned that biochar application markedly, intensified the values of soil organic matter in calcareous sandy soil.

3.2 Available N, P and K of Calcareous Soil

The results in Tables 4 and 5 indicated the effect of irrigation treatments and organic amendments on the soil availability of N, P and K. It was observed that applying 100% of ETc (I_{100}) significantly affected the soil available N and P, followed by applying 75% of ETc (I_{75}). However, the available K was not significantly affected by irrigation treatments. Applying I_{100} increased soil nitrogen availability possibly due to its effective chelating properties, reducing nutrient loss [39]. The study revealed that organic amendments significantly impacted the availability of N, P, and K in calcareous soil, with compost being the most effective, followed by KH_2 and B_2. Sary and Rashad [34] found that compost significantly increased soil nitrogen (104.4%), followed by K-H, which increased soil available nitrogen by 81.8%. Besides, Yang et al. [60] found that biochar application significantly increased soil available nitrogen. In this respect, biochar and compost enhance soil phosphorus [29]. Moreover, the highest available phosphorus value was found in 100% of irrigation requirements, followed by 80% and 60% WR. Mancy and Sheta [30] achieved a significant increase in soil macronutrient availability by applying high rates of compost and biochar to their soil. Concerning the effect of the interaction between irrigation regime and soil organic amendments on soil macro-nutrient availability, the statistical analysis showed that there is only an interaction between irrigation treatments and soil organic amendments on soil available N under wheat crop. So, applying compost and I_{100} gave the maximum value of soil available N.

3.3 N, P and K Contents of Straw

Data in Tables 4 and 5 revealed that irrigation treatments had a significant effect on the N and K contents of wheat straw, but there was no significant effect of the irrigation regime on the P contents of wheat straw. The highest values of N and K in wheat straw were achieved by applying I_{100}, followed by applying I_{75} (Table 4). While the irrigation regime significantly affected the N, P, and K content of maize straw (Table 5), the lowest NPK contents of maize straw were achieved by applying I_{50}. In this respect, organic amendments significantly affected the NP contents of wheat straw. The maximum values of N and P were obtained by compost, followed by KH_2 (Table 4). On the other hand, the N and K contents of maize straw were significantly affected by organic amendments. KH_1 achieved lower values of N and K compared to compost (Table 5). However, the lowest values of NK were achieved by applying 9.6 ton $ha^{-1}$of biochar (B_1). These results agree with those reported by Sary and Hamed [61] who mentioned that organic materials achieved the highest nitrogen, phosphorus, and potassium contents in wheat straw compared to the control.

3.4 Macro-nutrients Contents of Grains

Data in Tables 4 and 5 revealed that there was no significant effect of irrigation requirements on the N and P contents of grains. However, the K content of the grain is significantly affected by the irrigation regime. The maximum K content of grain was achieved by I_{100}, followed by I_{75}. On the other hand, organic amendments significantly affect the N and K contents of grain. Although the phosphorus content of grain is not significantly affected by organic amendments, the highest values of NK contents of grain were under the wheat crop (Table 4). Additionally, the maximum values of N, P and K contents of maize grains were achieved by applying compost, followed by another attained by applying KH. This increase may be attributed to the high values of available NPK (Table 4). In contrast, the lowest values of NPK in wheat or maize crops were obtained by applying B1 in calcareous soil. These results were in accordance with those obtained by Sary and Rashad [34] who mentioned that compost significantly increased the N content of plants cultivated in calcareous soil compared to KH.

3.5 Available Micro-nutrients of the Calcareous Soil

The results obtained in Tables 6 and 7 showed that the available Fe, Mn, and Zn significantly increased as irrigation requirements increased from 50% to 100% of ETc. Consequently, the highest values of available Fe, Mn, and Zn were obtained with I_{100}. This increase may be attributed to the application of soil organic amendments, which increase the organic matter content of the soil, improving water retention and plant growth [11, 45]. The study also found that compost and potassium humate significantly enhance soil micronutrient availability, with compost providing the highest values of Fe, Mn, and Zn. Potassium humate enhances soil

Table 4. Effect of irrigation water regime and organic amendments on the organic matter, availability of NPK and their content in wheat under calcareous soil

Irrigation water regime	Organic amendments	Soil				Straw			Grain		
		OM (%)	N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
I_{50}	B_1	1.92	18.85	10.27	157.55	0.60	0.08	0.98	1.14	0.27	0.98
	B_2	2.01	21.61	10.74	161.54	0.73	0.10	1.03	1.26	0.31	1.12
	KH_1	1.74	23.72	11.14	169.52	0.90	0.11	1.12	1.54	0.37	1.13
	KH_2	1.82	24.79	12.76	171.51	0.93	0.14	1.16	1.66	0.39	1.15
	Compost	2.17	26.95	13.25	187.46	0.98	0.16	1.23	1.72	0.43	1.18
	Mean	**1.93**	**23.18**	**11.63**	**169.52**	**0.83**	**0.12**	**1.10**	**1.46**	**0.35**	**1.11**
I_{75}	B_1	1.95	21.80	11.59	155.56	0.81	0.14	1.09	1.26	0.29	1.27
	B_2	1.97	24.92	12.84	171.51	0.82	0.16	1.12	1.33	0.34	1.43
	KH_1	1.84	25.93	13.77	191.50	0.88	0.19	1.15	1.47	0.42	1.45
	KH_2	1.89	26.46	14.20	195.44	0.92	0.20	1.19	1.82	0.45	1.54
	Compost	2.09	27.53	15.05	205.41	0.95	0.20	1.26	1.84	0.47	1.66
	Mean	**1.95**	**25.33**	**13.62**	**183.88**	**0.88**	**0.18**	**1.16**	**1.54**	**0.39**	**1.47**
I_{100}	B_1	2.13	23.91	15.40	159.52	0.96	0.14	1.14	1.12	0.30	1.67
	B_2	2.35	27.08	16.10	176.33	1.01	0,16	1.17	1.40	0.33	1.68
	KH_1	1.96	29.11	14.20	195.44	1.02	0.18	1.20	1.55	0.44	1.71
	KH_2	2.21	31.10	15.60	205.42	1.04	0.22	1.23	1.70	0.48	1.75
	Compost	2.67	33.81	16.88	216.72	1.18	0.23	1.28	2.18	0.51	1.77
	Mean	**2.26**	**29.01**	**15.64**	**190.69**	**1.04**	**0.19**	**1.20**	**1.59**	**0.41**	**1.71**
LSD at 0.05	Irrigation	ns	0.97	2.81	ns	0.11	ns	0.07	ns	ns	0.21
	Organic	0.20	0.52	1.13	10.7	0.11	0.04	ns	0.12	ns	0.13
	Interaction	ns	***	ns	ns	ns	ns	ns	ns	ns	ns
Mean of Organic amendments	B_1	1.85	21.52	12.64	157.54	0.79	0.12	1.07	1.17	0.29	1.31
	B_2	1.97	24.25	13.08	169.79	0.85	0.14	1.10	1.33	0.33	1.41
	KH_1	2.00	20.25	13.23	185.49	0.93	0.16	156	1.52	0.41	1.43
	KH_2	2.11	27.45	14.19	190.79	0.96	0.19	1.19	1.72	0.44	1.48
	Compost	2.31	29.43	15.06	203.20	1.04	0.20	1.26	1.91	0.47	1.54

*Note: ** and *** refer to significance level of 5% (p≤0.05) and 1% (p≤0.01), respectively. ns: no-significant*

Table 5. Effect of irrigation water regime and organic amendments on the organic matter, availability of NPK and their content in maize under calcareous soil

Irrigation water regime	Organic amendments	Soil				Straw			Grain		
		OM (%)	N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
I_{50}	B_1	2.24	22.66	11.40	162.11	1.12	0.12	1.04	1.21	0.32	1.51
	B_2	2.39	24.50	12.54	171.65	1.32	0.14	1.05	1.30	0.36	1.64
	KH_1	2.08	26.80	13.49	194.69	1.49	0.17	1.24	1.40	0.43	1.71
	KH_2	2.13	29.77	14.13	209.72	1.55	0.18	1.30	1.59	0.52	1.84
	Compost	2.69	33.70	15.19	223.93	1.74	0.21	1.43	1.68	0.58	1.94
	Mean	**2.31**	**27.49**	**13.35**	**192.42**	**1.44**	**0.16**	**1.21**	**1.44**	**0.44**	**1.71**
I_{75}	B_1	2.29	24.50	11.61	183.77	1.18	0.19	1.15	1.33	0.32	1.65
	B_2	2.45	30.71	12.27	202.40	1.36	0.20	1.16	1.41	0.44	1.74
	KH_1	2.15	31.86	13.69	214.03	1.60	0.21	1.34	1.56	0.48	1.82
	KH_2	2.24	33.70	13.95	225.67	1.78	0.22	1.36	1.31	0.53	1.90
	Compost	2.79	35.42	16.12	232.63	2.05	0.25	1.48	1.77	0.66	2.14
	Mean	**2.38**	**32.14**	**13.53**	**211.50**	**1.60**	**0.21**	**1.30**	**1.48**	**0.49**	**1.85**
I_{100}	B_1	2.52	28.55	13.25	199.20	1.53	0.23	1.38	2.17	0.35	1.73
	B_2	2.72	30.66	14.46	207.03	1.59	0.28	1.41	2.54	0.45	1.80
	KH_1	2.36	34.31	14.94	226.00	1.79	0.25	1.46	2.84	0.56	1.97
	KH_2	2.40	36.23	15.87	245.41	1.86	0.31	1.82	2.74	0.64	2.15
	Compost	3.31	39.95	16.64	260.62	2.59	0.34	1.90	2.97	0.73	2.27
	Mean	**2.66**	**35.04**	**15.03**	**227.65**	**1.87**	**0.28**	**1.59**	**2.65**	**054**	**1.98**
LSD at 0.05	Irrigation	ns	ns	0.85	17.46	0.15	0.03	0 .18	0.11	ns	ns
	Organic	0.25	9.28	0.89	10.61	0.24	ns	0.22	0.12	0.07	0.19
	Interaction	ns	ns	ns	ns	ns	ns	ns	**	ns	ns
Mean of Organic amendments	B_1	2.20	25.42	12.09	181.69	1.28	0.18	1.19	1.57	0.33	1.63
	B_2	2.26	25.62	13.09	193.36	1.43	0.21	1.21	1.75	0.42	1.73
	KH_1	2.35	33.23	14.04	211.57	1.63	0.20	1.35	1.88	0.49	1.83
	KH_2	2.52	36.02	14.65	226.93	1.73	0.24	1.49	1.93	0.56	1.96
	Compost	2.92	37.66	15.98	239.06	2.13	0.27	1.60	2.14	0.66	2.12

*Note: ** and *** refer to significance level of 5% (p≤0.05) and 1% (p≤0.01), respectively. ns: no-significant*

Table 6. Effect of irrigation water regime and organic amendments on the availability of Fe, Zn, Mn and their content in wheat under calcareous soil

Irrigation water regime	Organic amendments	Soil (mg kg^{-1})			Straw (mg kg^{-1})			Grain (mg kg^{-1})		
		Fe	Mn	Zn	Fe	Mn	Zn	Fe	Mn	Zn
I_{50}	B_1	3.22	2.21	1.12	10.60	11.00	10.15	32.40	15.60	15.82
	B_2	3.54	2.30	1.15	14.60	15.16	14.42	33.60	19.17	16.00
	KH_1	3.58	2.38	1.33	15.70	. 16.37	14.65	34.00	23.80	17.68
	KH_2	3.69	2.47	1.37	16.50	16.92	15.40	35.00	36.56	19.45
	Compost	4.18	2.53	1.52	18.30	18.48	17.80	47.40	36.97	25.20
	Mean	**3.64**	**2.38**	**1.30**	**15.14**	**15.59**	**14.48**	**36.48**	**26.39**	**18.83**
I_{75}	B_1	3.26	2.57	1.39	11.20	13.24	13.31	35.60	19.42	14.92
	B_2	3.54	2.62	1.44	12.90	15.61	15.86	39.60	22.30	16.80
	KH_1	3.73	2.66	1.57	16.40	19.34	16.60	41.20	24.35	17.63
	KH_2	3.88	2.77	1.95	17.40	21.40	19.26	43.40	29.14	21.48
	Compost	4.27	3.25	2.38	19.20	22.21	22.20	54.60	35.83	33.40
	Mean	**3.74**	**2.77**	**1.75**	**15.42**	**18.6**	**17.45**	**42.88**	**26.21**	**20.85**
I_{100}	B_1	3.36	3.13	1.48	13.90	13.52	12.20	38.00	21.60	16.32
	B_2	3.75	3.29	1.77	15.60	14.71	12.94	40.60	28.80	18.40
	KH_1	3.89	3.31	2.19	16.80	19.69	16.62	45.40	29.20	27.75
	KH_2	4.03	3.47	2.53	17.80	23.36	19.80	49.40	33.60	29.84
	Compost	4.63	3.58	2.73	21.20	26.72	27.80	57.80	36.90	35.00
	Mean	**3.93**	**2.36**	**2.14**	**17.06**	**19.60**	**17.87**	**46.24**	**30.02**	**25.46**
LSD at 0.05	Irrigation	0.13	0.11	0.30	0.57	0.74	0.70	1.63	0.95	0.77
	Organic	0.06	0.05	0.04	0.27	0.31	0.29	0.73	0.47	0.40
	Interaction	**	***	***	***	***	***	***	***	***
Mean of Organic amendments	B_1	3.28	2.64	1.33	11.9	12.59	11.89	35.33	18.87	15.69
	B_2	3.61	2.74	1.45	14.37	15.16	14.41	37.93	23.42	1.6
	KH_1	3.73	2.78	1.60’	16.30	18.45	15.96	40.20	25.74	21.02
	KH_2	3.87	2.90	1.95	17.23	20.56	18.15	42.60	33.10	23.59
	Compost	4.36	3.12	2.21	19.57	22.47	22.6	53.27	36.57	31.20

*Note: ** and *** refer to significance level of 5% (p≤0.05) and 1% (p≤0.01), respectively.*

Table 7. Effect of irrigation water regime and organic amendments on the availability of Fe, Zn, Mn and their content in maize under calcareous soil

Irrigation water regime	Organic amendments	Soil (mg kg^{-1})			Straw (mg kg^{-1})			Grain (mg kg^{-1})		
		Fe	**Mn**	**Zn**	**Fe**	**Mn**	**Zn**	**Fe**	**Mn**	**Zn**
I_{50}	B_1	3.30	2.25	1.19	24.32	21.66	19.97	39.24	30.80	31.13
	B_2	3.50	2.41	1.24	25.95	23.22	18.36	40.88	32.20	20.37
	KH_1	3.80	2.48	1.46	27.64	25.47	20.13	42.50	34.75	24.28
	KH_2	3.99	2.74	1.52	33.23	26.97	21.18	43.87	35.27	26.76
	Compost	4.72	3.06	1.72	34.22	29.23	29.84	47.30	36.69	39.26
	Mean	**3.86**	**2.60**	**1.43**	**29.07**	**25.31**	**21.90**	**42.76**	**34.97**	**28.36**
I_{75}	B_1	3.37	2.85	1.44	25.94	23.80	15.65	44.51	32.33	18.23
	B_2	3.83	2.96	1.52	28.54	26.26	17.29	45.35	33.38	24.22
	KH_1	4.00	3.03	1.68	32.38	27.52	20.74	48.23	34.40	25.36
	KH_2	4.23	3.22	2.13	35.40	28.38	22.59	51.18	35.05	29.04
	Compost	4.78	3.80	2.69	36.90	31.31	34.67	53.33	39.30	41.75
	Mean	**4.04**	**3.24**	**1.89**	**31.83**	**27.45**	**22.19**	**48.52**	**36.28**	**27.72**
I_{100}	B_1	3.54	3.50	1.53	33.54	24.54	17.19	45.46	33.14	22.99
	B_2	4.06	3.78	1.91	36.66	25.72	19.09	49.26	34.05	27.15
	KH_1	4.24	3.84	2.35	37,12	27.58	28,50	50.90	35.14	36.19
	KH_2	4.47	4.09	2.76	43.83	29.21	30.75	56.49	36.75	40.19
	Compost	5.31	4.37	3.06	44.79	33.05	38.98	60.23	41.34	45.18
	Mean	**4.32**	**3.92**	**2.32**	**39.19**	**28.02**	**26.90**	**52.47**	**33.66**	**34.34**
LSD at 0.05	**Irrigation**	0.15	0.14	0.33	1.90	0.98	1.65	2.28	1.20	2.96
	Organic	0.07	0.15	0.04	2.16	0.49	1.52	1.22	0.62	2.91
	Interaction	***	ns	***	ns	*	***	**	***	***
Mean of Organic amendments	B_1	3.41	2.87	1.39	27.93	23.33	17.60	43.07	32.09	24.12
	B_2	3.80	3.03	1.56	30.38	25.07	18.25	45.16	33.21	23.91
	KH_1	4.01	3.23	1.83	32.38	26.86	23.12	477.21	34.76	28.61
	KH_2	4.23	3.35	2.14	37.49	28.19	24.84	50.51	35.67	31.99
	Compost	4.94	3.74	2.49	38.64	31.20	34.50	53.62	39.11	42.07

*Note: ** and *** refer to significance level of 5% ($p \leq 0.05$) and 1% ($p \leq 0.01$), respectively. ns: no-significant* micronutrient availability by chelating and releasing them [62]. It was observed that the availability of micronutrients affected by applying soil organic materials followed this descending order: compost > potassium humate > biochar. Applying biochar may enhance the soil's capacity to retain nutrients, potentially increasing the availability of micronutrients [63]. Moreover, biochar's porous structure and large surface area enhance soil nutrient availability and reduce leaching [13]. Regarding the interaction between irrigation regime and soil amendments on the availability of micronutrients in the soil, highly significant values of available Fe, Mn, and Zn were obtained by applying compost and I_{100} under wheat and maize crops. On the other hand, the least significant values of soil available Fe, Mn, and Zn were achieved by applying B_1 (9.6 ton ha^{-1}) and I_{50} (50% of ETc).

3.6 Micro-nutrients Contents of Straw

The results in Tables 6 and 7 reveal that the Fe, Mn and Zn contents of straw behaved similarly to those obtained in wheat and maize grains. Thus, the maximum significant increment in Fe, Mn and Zn contents of wheat and maize straw was achieved by applying I_{100}. In this respect, applied compost or KH realized a highly significant increment of Fe, Mn and Zn in wheat and maize crops (Tables 6 and 7). These results were in agreement with previous studies [30, 61], indicating that biochar and compost significantly improved wheat plant straw micronutrient content.

3.7 Micro-nutrient Contents of Grains

Data in Tables 6 and 7 indicated that the Fe, Mn and Zn. contents of grains followed the same trend as soil available Fe, Mn and Zn in the studied calcareous soil. The maximum increment of Fe, Mn and Zn achieved by I_{100}. However, the lowest values of Fe, Mn and Zn were realized by applying I_{50}. Similarly, applied compost attained the highest content of Fe, Mn and Zn in wheat and maize crops, followed by applying KH_2 (3%). This increment in micronutrient concentrations of wheat and maize grains may be due to the increase in soil availability of micronutrients in the studied calcareous soil resulting from the application of compost or potassium humate as soil conditioners. The results were in accordance with previous studies [30, 62 and 63]. The interaction between irrigation regime and organic amendments on the Fe, Mn and Zn contents of wheat and maize grains, as shown in Tables 6 and 7 indicated a highly significant increase in micronutrients was achieved by applying compost and I_{100} followed by those obtained by applying KH_2 and I_{100}. The lowest values of micro-nutrients contents of wheat and maize grains were realized by applying $B_1$and I_{50} (Tables 6 and 7).

3.8 Physical Properties of Calcareous Soil

Data in Table 8 revealed the effect of irrigation regime on the hydraulic conductivity (HC) of the studied calcareous soil. The results indicated that the HC (m/day) values gradually improved as the water requirements increased from I_{50} to I_{100}. So, the maximum values of HC were obtained by applying I_{100}, followed by applying I_{75}. This may be attributed to the increased soil organic matter, which caused an enhancement of soil water retention by applying I_{75} and I_{100} (Tables 4 and 5). These results were in agreement with those obtained by Sharma et al [64]. The obtained results cleared that the effect of organic amendments on HC (m/day) followed this order: compost > biochar > potassium humate. The beneficial effect of biochar on soil moisture retention may be due to the porosity of biochar [25, 65, 66].

The statistical analysis indicated that the combination of irrigation regime and soil organic amendments influenced soil hydraulic conductivity (HC) under wheat and maize crops. The interaction between irrigation regime and organic amendments significantly affected HC, with compost and I_{100} showing the highest impact, followed by B_2 (14.4 ton/ha) and I_{100}. In contrast, applying KH_1 (1.5%) and 50% of ETc had the least significant effect on HC. The results also demonstrated the influence of irrigation treatments and organic materials on soil physical properties such as field capacity (FC %), wilting point (WP %), and available water (AW %) under wheat and maize crops. Soil moisture content at FC% decreased with increasing water requirements, while WP% increased. Available water decreased gradually with increasing water requirements from 50% to 100% of ETc. These findings align with previous studies. [43] found that applying biochar at a rate of 14.4 ton/ha and using 75% of full irrigation saved 25% of water requirements. [45] demonstrated that applying 45 Kg ha^{-1} of humic acid under an 80% water regime improved soil physicochemical and nutrient status in sandy soils. Additionally, Singh et al [46] suggested that utilizing 70% of crop evapotranspiration

(ETc) is an effective water-saving strategy for maize production. Regarding the influence of organic amendments on FC% and AW% of the studied calcareous soil, it can be considered in the following descending order: Biochar (B_1)> potassium humate (KH1)> compost. The increase in soil moisture at FC and AW% resulted from applying biochar, which may be due to biochar becoming a soil conditioner due to its ability to store carbon, improve soil fertility, increase water retention, and increase crop yield [21, 22, and 23]. Biochar has many advantages for agricultural soils, such as its high chemical and physical properties, nutrient retention, improved soil health, and the removal of pollutants. It has a high surface area, porosity, ion exchange, and water-holding capacity [24]. Moreover, compost and biochar can improve soil quality and productivity by enhancing nutrient absorption, cycling, and availability.

Regarding the interaction between irrigation regime and applied organic amendments on F.C.% and AW% of the studied calcareous soil, data in Table 8 revealed that at 50% of ETc, the effect of applied organic amendments on F.C.% and AW% took the following descending order: KH_1> B_1> compost. This increment resulted from the application of potassium humate, which may have enhanced the physicochemical and fertility properties of the studied calcareous soil by optimizing water and nutrients [45]. Meanwhile, at 75% of ETc, the effect of applied organic amendments on the available water of the studied calcareous soil took the following descending order: B_2 > KH_2 > compost (Table 8). However, at 100% ETc, the obtained results in Table 8 showed that both applied compost (12 ton/ha) and B_1 (9.6 ton/ha) maximized the values of field capacity and available water of the studied calcareous soil, followed by the first rate of potassium humate. These results were in accordance with the results obtained by Sánchez-Monedero et al [27] and Mahmoud et al [28], who reported that compost and biochar can improve soil quality and productivity by absorbing nutrients.

Table 8. Effect of irrigation water regime and organic amendments on some physical soil properties under wheat and maize crops

Irrigation water regime	Organic amendments	Maize			Wheat	Maize
		FC (%)	**WP (%)**	**AW (%)**	**HC (m d^{-1})**	**HC (m d^{-1})**
I_{50}	**B_1**	32.31	6.10	26.21	1.62	1.31
	B_2	28.69	5.60	22.79	1.80	1.43
	KH_1	32.60	5.60	27.00	0.85	1.22
	KH_2	27.65	5.60	22.05	0.87	1.29
	Compost	30.40	6.60	23.80	2.24	1.47
	Mean	**30.33**	**5.9**	**24.37**	**1.46**	**1.34**
I_{75}	**B_1**	29.82	5.60	24.22	1.96	1.49
	B_2	30.40	5.60	24.80	2.12	1.57
	KH_1	30.05	6.60	23.45	1.04	1.38
	KH_2	30.15	6.30	23.85	1.12	1.45
	Compost	27.44	6.40	21.04	2.26	1.80
	Mean	**29.57**	**6.1**	**23.47 '**	**1.70**	**1.56**
I_{100}	**B_1**	29.13	6.31	24.23	2.08	1.84
	B_2	28.46	9.64	18.82	2.19	2.11
	KH_1	28.74	7.51	21.23	1.74	1.77
	KH_2	27.80	6.73	21.07	1.44	1.78
	Compost	30.54	6.31	24.23	2.45	2.14
	Mean	**28.93**	**7.29**	**21.92**	**1.98**	**1.93**
LSD at 0.05	**Irrigation**	0.30	0.07	0.30	0.13	0.31
	Organic	0.35	0.09	0.41	0.11	0.04
	Interaction	***	***	***	***	***
Mean of Organic amendments	**B_1**	30.38	6.06	24.77	1.92	1.56
	B_2	29.18	6.95	22.14	2.04	1.70
	KH_1	30.46	6.56	23.89	1.21	1.46
	KH_2	28.53	6.21	22.32	1.14	1.51
	Compost	29.39	6.43	22.93	2.33	1.82

*Note: ** and *** refer to significance level of 5% (p≤0.05) and 1% (p≤0.01), respectively*

3.9 Drought Tolerates Efficiency (DTE)

The results in Fig. 1. illustrated that increasing applied irrigation water had a positive effect on the DTE values, which increased from 75.90% at I_{50} to 85.0% at I_{75}. In addition, increasing the application rate of organic amendments had a positive effect on water stress in the I_{75} treatments, where DTE values were 88.3, 87.4, 82.0, 85.9, and 82.0% for $I_{75}B_1$, $I_{75}B_2$, $I_{75}KH_1$, $I_{75}KH_2$, and I_{75} compost, respectively. Biochar recorded the highest values, at 88.3% for $I_{75}B_1$ and 79.0% at $I_{50}B_1$. The irrigation water regime indicated that I_{75} had high-value drought tolerance efficiency for wheat in Fig. 1. Additionally, results in Fig. 1. illustrate that with maize, the highest value of drought tolerance efficiency was 97.3% at I_{75}, followed by 92.2% at I_{50} for the irrigation water regime. Soil amendments increased by 98.4, 95.3, 96.4, 97.8, and 97.1% for $I_{75}B_1$, $I_{75}B_2$, $I_{75}KH_1$, $I_{75}KH_2$, and I_{75}compost, respectively. Biochar exhibited the highest drought tolerance efficiency at 98.4% due to its ability to retain water and reduce evapotranspiration. These findings align with previous reports [67] that drought tolerance efficiency is influenced by irrigation treatment and calcium-humate. The treatment of I_{75} Ca-H20 (75% of ET along with calcium-humate at rates 20 liter/acre) had the highest drought tolerance efficiency at 96.72%, while the irrigation water regime had 93.07%. The highest drought tolerance efficiency; it was higher in corn than in wheat under the influence of all treatments (Fig. 1).

3.10 Water use Efficiency (WUE)

Results in Fig. 2 for wheat illustrate that the highest water use efficiency value (6.1 kg/m^3) was recorded for I_{50} with compost. Decreasing the amount of applied irrigation water and increasing soil amendment applications have a highly positive effect on water use efficiency. Also, increasing the amount of irrigation water used negatively affects the value of the efficiency of water use, where WUE was better for I_{50} compared to I_{75} and I_{100}, respectively. The best additions for soil amendments were compost, followed by a high rate of potassium humate under an irrigation water regime. Also, the data in Fig. 2 for maize illustrates that the highest value of water use efficiency was I_{50}, followed by I_{75}, then I_{100} of ETc. As for soil amendments, the best additives were compost, followed by potassium humate, and then biochar under an irrigation water regime. Soil amendments are materials added to soil to improve its physical, chemical, or biological properties. They can have various effects on water retention, depending on their composition. For example, organic matter such as compost can improve water retention by increasing soil porosity and enhancing its ability to hold onto moisture. Irrigation water level at I_{50} with compost has significantly impacted water use efficiency, with a maximum value of 6.1 kg m^{-3}. Water use efficiency was higher with maize than with wheat in all treatments under a 50% irrigation water regime (Fig. 2). Using compost and increased potassium rates enhances water storage in the root zone, while potassium humate fertilizer mitigates water stress. Stomata rich in K keep stomata closed, reducing transpiration rate but allowing plant roots to absorb more water without additional water.

3.11 Wheat and Maize Yields

Results in Table 9 showed that applying I_{100} significantly increased wheat and maize yields, followed by I_{75}. This increase may be attributed to improved soil properties such as organic matter and macro- and micronutrient availability, as well as increased soil hydraulic conductivity. These results were obtained by Singh et al [46], who reported that 70% ETc is an alternative water-saving strategy for maize production. Concerning the effect of organic amendments on wheat yield, the data in Table 9 indicates that this effect followed a descending order: applied compost> potassium humate >biochar. However, the effect of organic amendments on maize yield as affected by organic amendments followed a descending order: potassium humate > compost > biochar. The lowest values of wheat and maize grain yields were achieved by applying the first rate of biochar (Table 9). These findings align with previous studies by Abouhussien et al [14] and Mohamed and Rashad [15], who suggest that compost as a humic-rich amendment can enhance soil's chemical, physical, and biological properties. Humic substances, comprising 60% of soil organic compounds, can be utilized as soil conditioners to enhance soil structure and water retention capacity, thereby reducing fertilizer usage and enhancing plant growth. Moreover, potassium humate can also improve maize quality [36-38]. The study revealed that there was no significant difference in wheat grain yield as a result of the interaction between irrigation regime and organic materials. However, the highest maize grain yields were observed when

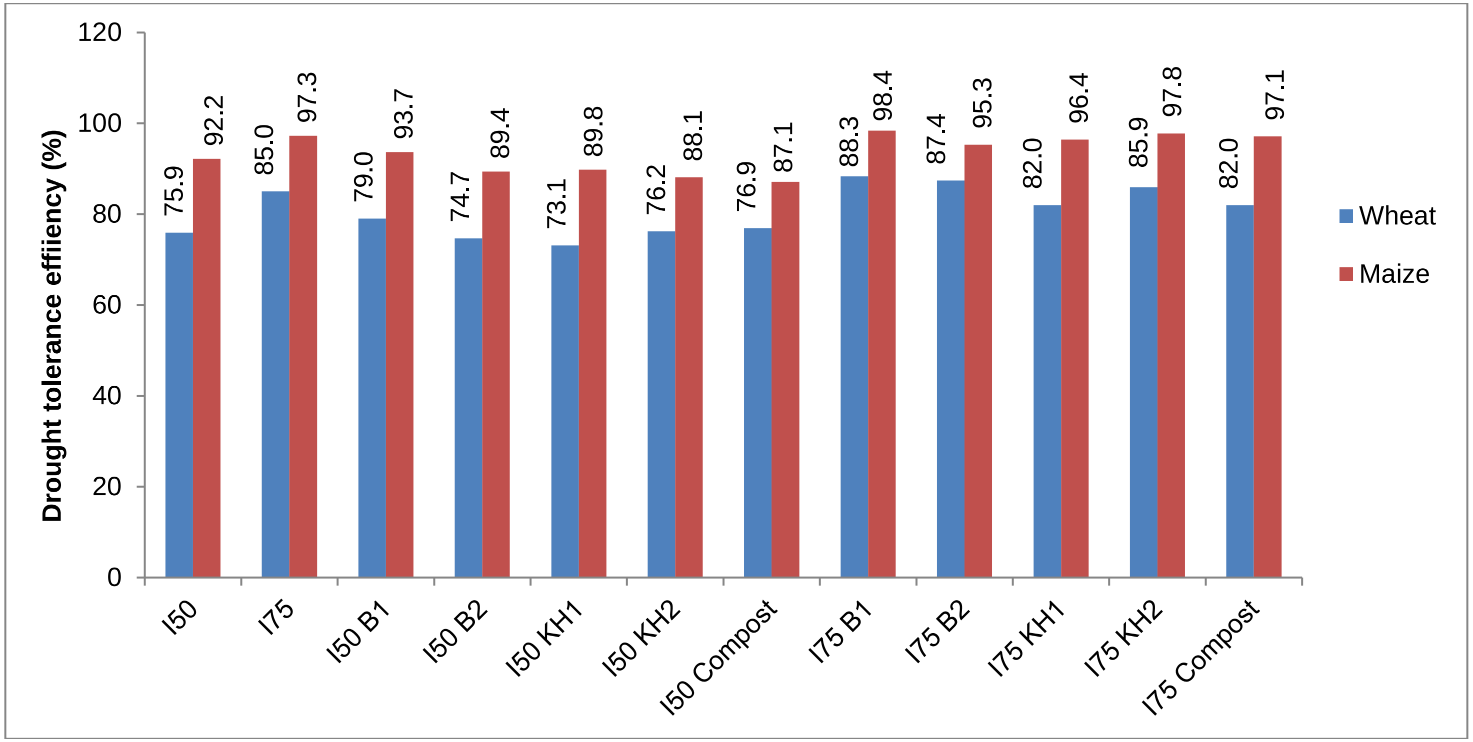

Fig. 1. Drought tolerates efficiency as affected by irrigation water regime and soil amendment of wheat and maize

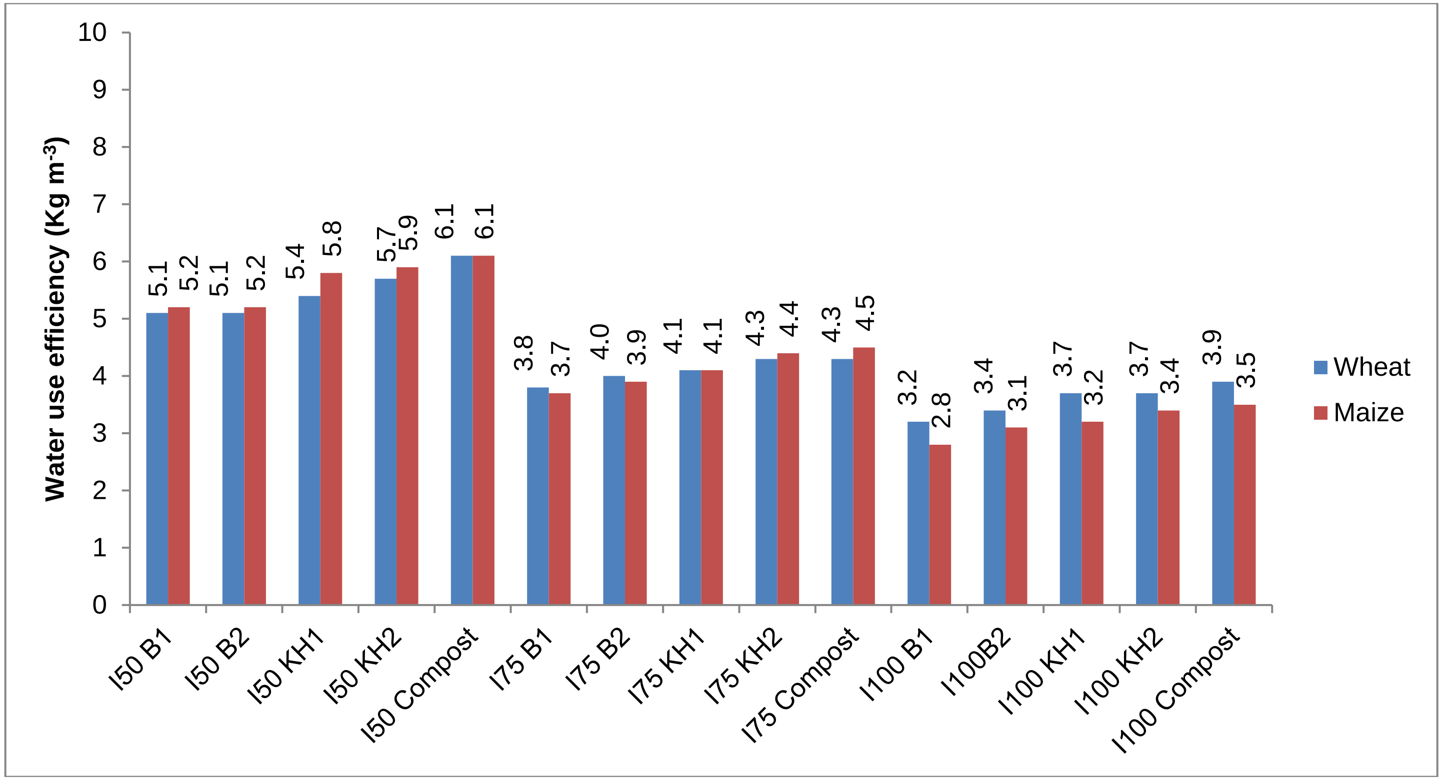

Fig. 2. Water use efficiency as affected by irrigation water regime and soil amendments of wheat and maize

Table 9. Effect of irrigation water regime and organic amendments on yield and its components of wheat and maize under calcareous soil

Irrigation water regime	Organic amendments	Wheat			Maize				
		1000-grain weight (g)	Grain yield (ton ha^{-1})	Straw yield (ton ha^{-1})	Plant height (cm)	Ear weight (g)	Weight of 100 grains (g)	Grain yield (ton ha^{-1})	Straw yield (ton ha^{-1})
I_{50}	B_1	34.07	5.65	10.85	230.90	334.78	38.33	9.63	14.10
	B_2	38.30	5.67	10.63	232.90	373.09	40.00	10.05	14.67
	KH_1	39.80	6.00	9.63	240.97	374.78	42.00	10.59	15.93
	KH_2	39.93	6.28	8.27	245.47	381.55	42.33	10.86	16.42
	Compost	40.20	6.71	10.51	237.00	416.66	43.00	11.19	18.25
	Mean	38.46	6.06	9.98	237.45	376.16	41.13	10.46	15.87
I_{75}	B_1	39.73	6.31	11.78	239.87	349.22	41.00	10.12	14.57
	B_2	40.00	6.63	13.56	240.57	374.78	42.33	10.71	14.69
	KH_1	42.51	6.74	13.70	249.23	410.56	42.67	11.36	15.29
	KH_2	44.55	7.08	12.77	257.77	420.33	44.33	12.06	15.98
	Compost	53.26	7.15	12.20	245.20	436.01	45.00	12.47	16.45
	Mean	44.01	6.78	12.80	246.53	392.01	43.07	11.03	15.39
I_{100}	B_1	42.53	7.15	10.62	228.37	352.56	41.33	10.28	13.71
	B_2	42.67	7.60	10.84	246.90	355.22	42.33	11.24	17.79
	KH_1	55.64	8.19	10.35	249.10	364.00	44.33	11.79	18.01
	KH_2	58.37	8.24	9.67	253.43	423.89	46.33	12.33	18.12
	Compost	57.55	8.72	10.98	248.33	464.33	52.33	12.84	20.01
	Mean	51.35	7.98	10.49	245.23	398.19	45.33	11.34	17.53
LSD at 0.05	Irrigation	3.25	0.13	0.30	3.72	10.07	1.55	0.329	0.389
	Organic	3.01	0.22	0.50	4.93	14.20	0.730	0.263	0.218
	Interaction	**	ns	***	ns	**	***	***	*
Mean of Organic amendments	B_1	38.78	6.37	11.09	233.04	345.52	40.22	10.01	14.13
	B_2	40.32	6.63	11.68	240.12	367.7	41.56	10.67	15.71
	KH_1	45.98	6.98	11.23	246.43	383.11	43.00	11.24	16.41
	KH_2	47.62	7.20	10.24	252.22	408.59	44.33	11.75	16.84
	Compost	50.33	7.53	11.23	243.51	439.00	46.78	11.05	18.24

*Note: ** and *** refer to significance level of 5% ($p \leq 0.05$) and 1% ($p \leq 0.01$). *ns: no-significant*

I_{100} and compost were applied, followed by compost and I_{75}. The lowest yield was achieved with the first rate of biochar (B_1) and I_{50} (Table 9).

3.12 Wheat and Maize Straw Yields

Results in Table 9 showed that the maximum wheat straw yield was achieved with I_{75} irrigation, followed by I_{100}, while maize straw yield was affected in descending order, with 100% irrigation, 50% irrigation, and 75% irrigation resulting in the highest yield. The data in Table 9 revealed that organic amendments impact wheat straw yield in descending order, compost and KH_1 above B_2, and maize straw yield in descending order: compost > potassium humate > biochar. These results were in accordance with previous studies [14, 15].

Concerning the interaction effect presented in Table 9, the first rate of potassium humate and 75% of ETc yielded significantly more wheat straw than the second rate of biochar and 75% of ETc. The study found that the highest wheat straw yield was achieved with the second rate of potassium humate and 50% of ETc, but the maximum significant maize straw yield was achieved with compost and I_{100}, followed by potassium humate and I_{100}. While the minimum value of maize straw yield is achieved by applying the first rate of biochar (B_1) and 50% of ETc.

3.12.1 The weight of 1000 grains of wheat and 100 grains of maize

The results obtained in Table 9 revealed that the irrigation regime had a highly significant effect on the 1000-grain weight of wheat and the weight of 100 maize grains, leading to an increase in both parameters with higher irrigation water requirements. The maximum significant increment in both the 1000-grain weight of wheat and 100-grain weight of maize was observed with the application of I_{100}, followed by 75% of ETc. The increase in the 1000-grain weight of wheat may be attributed to the higher levels of K, Fe, Mn, and Zn in wheat grains (Tables 4 and 6). Similarly, the increase in the weight of 100-grain maize may be due to the increased levels of N, Fe, Mn, and Zn in maize grains, which could enhance plant growth (Tables 5 and 7). The study found that increasing irrigation water requirements led to a significant increase in the weight of wheat and maize grains. Therefore, the application of I_{100} and 75% of ETc resulted in the maximum significant increase in the 1000-grain weight of wheat and 100-grain weight of maize. The increase in grain weight of wheat may be attributed to increased K, Fe, Mn, and Zn contents in wheat grains (Tables 4 and 6). Similarly, the increase in the weight of 100 maize grains may be due to increased N, Fe, Mn, and Zn contents in maize grains, which may reflect on improving plant growth (Tables 5 and 7). Data in Table 9 clarified that the effect of applying organic amendments on 1000-grain weights of wheat and 100-grain weights of maize grains took the following descending order: compost > potassium humate > biochar. This increment in applying compost and potassium humate may be due to an increase in macro- and micronutrient contents in wheat and maize grains, which resulted in improved plant growth (Tables 4, 5, 6, and 7). Soil amendments can improve soil properties, maintain fertility, increase productivity, and preserve the environment [8]. Also, manure and organic fertilizers are appropriate for optimal crop yield and healthy soil [68].

Regarding the effect of the interaction between the irrigation regime and organic amendments on the grain weight of wheat, the results obtained in Table 9 revealed that the highly significant weight of 1000 wheat grains was obtained by applying the second rate of potassium humate (KH_2) and I_{100}. It was followed by applying compost and I_{100}. However, the lowest weight was achieved by applying the first rate of biochar (B_1) and 50% of ETc. The effect of the interaction between the irrigation regime and organic amendments on the weight of 100 maize grains is shown in Table 9. The highly significant value of 100 maize grain weight obtained by compost and I_{100} is followed by applying the second rate of potassium humate and I_{100}. However, the least weight of 100 maize grains was achieved by applying B_2 and 50% of ETc.

3.12.2 Plant height of maize

The results obtained in Table 9 revealed that the effect of the irrigation regime on maize plant height was significantly increased by applying I_{75}, followed by applying I_{100}. Concerning the effect of organic amendments on maize plant height, the data in Table 9 showed that a significant increment in plant height was achieved by applying KH_2, followed by KH_1. However, the lowest height was obtained by applying B_1. The results of this study are consistent with earlier research that demonstrated the combined and single application of biochar or compost additions increased the plant height of two maize varieties. Higher plant heights (206.8 cm) were found in plots irrigated five times compared to the lower irrigation regime [36, 29].

3.12.3 Ear weight of maize

Data in Table 9 indicated that the irrigation regime affected the ear weight of maize. It was observed that an increase in irrigation water requirements from I_{50} to I_{100} caused a highly significant increment in the ear weight of maize. Thus, the maximum value of the ear weight of maize was achieved by applying I_{100}, followed by applying I_{75}. This high value of ear weight in maize may be attributed to improved plant growth under applying I_{100}, which resulted in increasing N, Fe, Mn, and Zn contents in maize grains, as mentioned above (Tables 5, 7). Concerning the effect of organic application on amendments application on ear weight of maize, the obtained results in Table 9 revealed that applying compost resulted in the highest significant increment of ear weight of maize, followed by applying KH_2. Whereas, the lowest one achieved B_1. This increment in ear weight of maize may be due to improving some soil characteristics and maintaining fertility, resulting in the application of soil amendments that increase the macro- and micronutrient contents of the maize grains (Tables 5 and 7). These findings agree with those reported by Al-Dulaimi et al [69] who found that reducing water stress and ensuring moisture during the maize growing season increased ear weight, possibly due to improved photosynthesis and growth. The study found that the maximum significant maize ear weight was achieved with compost with I_{100}, followed by KH_2 with I_{100}, and the least significant value was achieved with B_1 and 50% ETc (Table 9).

4. CONCLUSION

In calcareous soil, applying 100% of ETc for maize (3677.1 m^3 ha^{-1}) combined with compost resulted in the highest maize yield (12.84 ton ha^{-1}). The highest water use efficiency (6.1 kg m^{-3}) was achieved by applying water irrigation at 50% ETc combined with compost. Furthermore, drought tolerance efficiency is influenced by the irrigation water regime and soil amendments. Among the various treatments, $I_{75}B_1$ exhibited the highest drought tolerance efficiency at 98.4%. Therefore, the irrigation water regime indicated that I_{75} had a notable drought tolerance efficiency of 97.3%. Irrigating wheat with 100% ETc (2218 m^3 ha^{-1}) along with compost resulted in the highest yield of 8.72 ton ha^{-1}. The highest water use efficiency of 6.1 kg m^{-3} of applied water was achieved when applying 50% ETc with compost. Drought tolerance efficiency is influenced by the irrigation water regime, with I_{75} showing a high drought tolerance efficiency of 85.0%. The study recommends applying irrigation water at 75% of the ETc to save 25% of the water required for crops in Egypt. Future research should focus on evaluating the effects of biochar, potassium humate, and compost amendments on enhancing salt and drought resilience in soil and plants, considering soil management and cropping systems.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declared that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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