Impact of Organic Amendments and Potassium Silicate on Yield of Different Wheat (*Triticum aestivum* L.) Cultivars and Soil Fertility Under Drought Stress Conditions

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ABSTRACT

Efficient water management is critical in Egypt due to its arid climate and limited water resources, which has a substantial impact on wheat growth and lowers grain production. A field experiment was conducted for two successive winter growing seasons (2021/22–2022/23) to investigate the effects of organic amendments (humic acid, fulvic acid, and compost) and potassium silicate on alleviating drought stress and improving wheat growth and yield under different irrigation regimes (50, 25% Irrigation deficit and full irrigation) across three wheat cultivars (Giza 171, Masr3, and Sakha 95). The results showed that full irrigation significantly enhanced growth parameters, yield, and yield components, particularly the 1000-grain weight, grain yield, and biological yield. Among the cultivars, Sakha 95 demonstrated superior growth and the highest grain yield (4.13 Mg fed^{-1}), while Giza 171 exhibited notable drought tolerance with high 1000-grain weight and competitive grain yield under severe irrigation deficit conditions. Fulvic acid was the most effective fertilizer for increasing spike number and plant growth, whereas potassium silicate had a significant positive impact on both grain and protein yields. The interaction of full irrigation with cultivar selection and organic amendments further enhanced multiple yield traits. Compost was the best amendment for improving soil fertility by increasing soil organic carbon and nutrient content, which is essential for sustainable agriculture. To address climate change challenges and ensure stable wheat production, integrated management practices are recommended, including the application of full irrigation based on water availability, choosing drought-tolerant and high-yielding cultivars, and employing targeted fertilization strategies using organic amendments and potassium silicate. Integrated soil fertility management combines irrigation, targeted cultivar selection and organic amendments such as compost and humate is vital for sustaining agricultural productivity and soil health.

Keywords: Climate change, Abiotic stress, drought stress, Wheat cultivars, Potassium Silicate, Organic fertilizer, Humic, Fulvic acid.

INTRODUCTION

Global warming is caused by greenhouse gas emissions resulting from burning fossil fuels, deforestation, urbanization, and industrialization. With no doubt, human activity has caused global warming, with a global surface temperature rising by 1.1°C between 2011 and 2020 (NOAA, 2024). Seasonal fluctuations and decreased rainfall are primary effects on soil fertility (Regmi and Statistics, 2007). Agriculture is a major source of greenhouse gas emissions, particularly from livestock farming (through enteric fermentation and manure management) and from agricultural soils due to excessive nitrogen fertilizer use and the breakdown of organic matter (Bayu, 2020). Drought is one of the most significant abiotic stresses in agriculture, posing a severe threat to plant growth, development, and yield around the world (Ault, 2020).

Egypt's population is constantly increasing, so that the recent rise in total wheat production is insufficient to meet demand. It became important to rationalize irrigation water management even in old lands because of Egypt's limited water resources. For irrigated crops, water shortages can lead to reduced yields, altered crop quality, or even changes in the types of crops that can be grown. By aligning fertilizer programs with crop needs and expected yields, farmers can lower costs and minimize

Wheat (*Triticum aestivum* L.), is one of the major cereals that are widely grown globally. Expanding wheat areas necessitates searching for cultivars that gave high yields under suitable water regimes, due to the current global water-policy regarding saving irrigation water. Safe irrigation is influenced by a variety of factors, including cultivars and fertilizers, in addition to being closely dependent on the plant growth stage (Ahmed and Ahmed, 2005). Over the past decade, Egypt has experienced a steady increase in wheat production, primarily due to the expansion of high-yielding wheat cultivars. However, despite these gains, the country remains one of the world's largest wheat importers, producing only about half of its annual consumption demand of 20 million tons (Bishaw *et al.*, 2025).

In 2020/2021, wheat growing season, Egypt produced about 9.8 million tons of wheat from 3.4 million feds, with an average yield of 2.88 tons per fed. By 2021/2022, production rose to 10.6 million tons as the cultivated area expanded to 3.65 million feds, while average yield increased slightly to 2.9 tons per fed

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(Weshahey *et al.,* 2022). Egypt has made considerable progress in wheat production, it is vital to focus on improving yields rather than just expanding cultivated land (Sallam *et al.,* 2024). Rising high-yielding, stress-resistant cultivars including Sakha 95 (rust-resistant, heat- and salinity-tolerant), Giza 171 (early-maturing, rust-resistant), and Masr 3 (high-yielding, heat-tolerant) have been introduced by recent developments in Egyptian wheat breeding program (Kishk *et al.,* 2019). Adopting climate-smart practices, improving wheat varieties, and utilizing advanced soil management techniques (such as humic and fulvic acids applications) can help close the supply gap. Although weather conditions cannot be controlled, choosing the right combination of wheat cultivar and fertilizer can significantly enhance outcomes. The best strategy depends on whether farmers prioritize grain yield, seed quality, or long-term soil health. One of the primary goals of wheat breeders is to create high-yielding, promising cultivars of wheat that can withstand drought (Sallam *et al.,* 2024). The process of selection for drought tolerance usually includes assessing cultivars for steady performance under various levels of water stress or high yield potential (Sallam *et al.,* 2024). To find wheat cultivars with superior drought tolerance, researchers have been screening various wheat cultivars (Ahmad *et al.*, 2022). Some research focuses on genetic enhancements, investigating the physiological and biochemical processes that enable wheat to withstand drought (Bapela *et al.*, 2022). In an effort to create high-yielding, drought-resistant cultivars, others look at certain genes associated with drought tolerance (Sallam *et al.*, 2024).

Concern over drought stress is growing due to its effects on crop productivity and its anticipated global expansion. The beneficial impact of silicon (Si) treatment on biomass yield under deficit irrigation is widely acknowledged.

Drought-stricken wheat plants treated with Si retained greater stomatal conductance, relative water content, and water potential compared to untreated plants (Gong *et al.,* 2003). Applying K_2SiO_3 in foliar solution at concentrations ranging from 1 to 2% K_2O at the start of winter wheat's emergence, tillering, and flowering stages may have a beneficial effect on reducing drought stress (El-Shafei *et al.,* 2023). Epstein (1999) has referred to Si as "quasi-essential". These beneficial effects could be due to a change in the physical properties of the soil, the facilitation of the absorption of valuable mineral elements, and the suppression of poisonous compounds uptake from the soil by Si compounds, or the direct uptake and subsequent integration of Si by plants. The application of Si also increases the concentration of P in plants in a P-deficient environment.

In order to alleviate abiotic stressors, compost's organic content is added to help release gradually mineral elements and supplies soluble nutrients. When comparing the application of compost to the control, various physiochemical characteristics of the soil revealed an increase in nutrient content, including organic carbon, nitrogen, available K, and available P. By improving nutrient availability and plant resilience, compost amendments also aid in the mitigation of abiotic stressors**.** Physical properties and fertility of the soil are greatly enhanced by the presence of organic matter, which is a significant source of soil nutrients (AL-Bayati *et al.,* 2019). The combined use of farmyard manure and NP fertilizers supports agricultural sustainability (Bayu, 2020). Using farmyard manure together with mineral fertilizers is more cost-effective than applying only nitrogen and phosphorus fertilizers, helping to sustain agricultural productivity (Bayu, 2020).

Humic acids are essential for plants growth by providing essential elements, which is why they are the core of organic matter (Al-Shater & Al-Balkhi, 2010 and Al-Taey & Al-Musawi, 2022). Apart from their fundamental function in the dynamics of plant nutrients, humic molecules also play a secondary but equally important role in the rhizosphere bio-stimulation of plant physiological and biochemical processes, as well as, in the interactions between microorganisms and plants (Canellas and Olivares, 2017). The combination of humic and fulvic acids with soil minerals results in an enhancement of the soil's physical and chemical properties (AL-Taey and Burhan, 2021). In addition to improving mechanisms involved in plant growth stimulation, cell permeability, and nutrient uptake, humic substances (HS) have numerous positive impacts on soil structure and soil microbial communities (Rahmat *et al.*, 2010).

Therefore, the objectives of this study were

1. Identify high-yielding and climate-resilient wheat cultivars to enhance food security under increasingly unpredictable global warming conditions.
2. Investigate the effects of drought stress on wheat growth, yield, and soil properties.
3. Evaluate the role of potassium silicate, potassium humate, and potassium fulvat (applied as foliar sprays) along with potassium humate and compost (as soil application) in improving drought resilience in wheat cultivars and soil fertility.

MATERIALS AND METHODS

Study Site and Experimental Procedures:

Field experiments were conducted at the Etay El-Baroud Agricultural Research Station in the El-Behera governorate (30º 89'E, 30º 65'N) during the winter growing seasons of 2021/2022 and 2022/2023.

Experimental design: A split split-plot design with three replicates was used. Irrigation regimes were allocated at main plot. Whereas, wheat cultivars and fertilization treatments were assigned to sub and sub-sub plots, respectively.

The treatments studied included

(A) Irrigation regimes (*IrrR*):

- I_1: Two irrigations, one at sowing and another after 21 days (50% water deficit).
- I_2: Three irrigations, one at sowing followed by two more at 21-day intervals (25 % water deficit).
- I_3: The recommended irrigation regime (4 irrigations), starting at sowing and then every 25 days.

(B) Wheat cultivars (*Cul*):

- *Cul₁:* Giza 171
- *Cul₂*: Sakha 95
- *Cul₃*: Masr 3

Grain wheat of selected *Cul* was obtained from Field Crops Res. Inst., Agricultural Research Center (ARC), Giza, Egypt. The Code number, name, pedigree and selection history of the studied bread wheat cultivars as listed before in Abdelaziz *et al.* (2023)

(C) Types of Fertilizer (*FerS*):

- F1: Potassium silicate (Si), applied foliarly twice, at rates of 2 g L^{-1}.
- F2: Potassium fulvat (FA), applied foliarly twice, at rates 2 g L^{-1}.
- F3: Potassium humate (HA), applied as a soil application at rate of 3 g L^{-1}, applied at 65 and then 80 days after sowing.
- F4: Compost, applied at a rate of 5 Mg per fadden (fed) (hectare = 2.4 fed).
- F5: Control (without fertilizers).

Data in Table (1) presents some soil and compost characteristics before planting.

Cultural practices:

Using hand drills, grains were sown on November 15th during both seasons. Seeding rate was 60 kg fed^{-1}. Superphosphate (15.5%) as was applied at 31 kg P_2O_5 fed^{-1} during soil preparation. And as a primary treatment, all seeds were inoculated by (*Azospirillum* spp.). Nitrogen fertilizers was applied as urea (46%) in one dose after 21 days from sowing with the first irrigation regime (I_1) while, in two doses (half after 21 days from sowing and half before the next irrigation) in both the second and third irrigations regimes. During the two growing seasons of study, the second and third irrigation regimes underwent all recommended practices.

Table 1. Some physical and chemical properties of the soil experimental used before planting and compost

		2021/2022	2022/2023	2021/2023	2022/2023
		Soil		Compost	
Physical properties	Sand %	20.30	17.08		
	Silt %	25.10	22.92		
	Clay %	54.60	60.00		
	Texture	Clay	Clay		
Chemical properties	Soil (pH) 1:2.5	8.10	8.11		
	EC (ds m^{-1}) soil paste	2.10	1.20		
	Total $CaCO_3$ (%)	5.60	5.71		
Soil Fertility & Nutrient properties	Total Carbon (%)	1.23	1.37	10.34	9.21
	Organic Matter (%)	2.12	2.37	17.83	16.21
	Total N (%)			1.74	2.10
	C/N			5.94	4.39
	Total (P) %			0.28	0.27
	Total K (%)			1.48	1.50
	NH_4^+-N	56.00	49.00	280.00	178.50
	NO_3^--N	24.50	24.50	2791.25	1452.50
	Mineral N (mg kg^{-1})	80.50	73.50	3071.25	1631.00
	Available P (mg kg^{-1})	11.90	10.09		
	Exchangeable K (mg kg^{-1})	160.5	151.04		
	Fe %			3.56	2.59
	Mn %			1.88	1.09
	Zn %			0.39	0.41

Table 2. Weather data of Etay El Barod-Monthly, El-Behera, Egypt; Temperature (^{0}C) and rainfall during wheat growing period in 2021/2022 and 2022/2023 seasons*

	2021/ 2022				2022/ 2023			
Months	**T_{min}**	**T_{max}**	**TP**	**SD**	**T_{min}**	**T_{max}**	**TP**	**SD**
November	16.69	28.11	29.50	10.6	13.9	21.1	9.9	11.40
December	11.45	20.20	17.50	10.2	12.5	19.4	4.9	10.59
January	7.39	17.05	67.70	10.4	10.5	21.1	28.7	10.40
February	8.09	18.95	13.50	11.1	9.0	19.4	45.2	11.09
March	8.46	19.98	62.10	12.0	11.8	25.2	18.6	12.00
April	13.61	30.95	0.70	13.0	13.7	28.8	14.6	12.95
May	17.05	33.04	5.30	13.7	17.3	32.9	0.5	13.73
Average	**11.82**	**24.04**	**28.04**	**11.57**	**12.67**	**23.97**	**17.49**	**11.79**

Where: T_{max} and T_{min} represent the Maximum and Minimum Air Temperature (°C), TP (Total Precipitation (mm)), SD Sunshine Duration (Hours).
*Egyptian Ministry of Agriculture & Land Reclamation. ARC. Central Lab. for Agricultural Climate.

Sampling and Analysis:

Soil Analysis:

Before planting and after plant harvesting, soil samples (0-30 cm) were collected for the primary physical and chemical analysis. Measurements were made using the hydrometer method to determine the particle size distribution of sand, silt, and clay (FAO, 1970). In 1:2.5 soil–water suspension, the electrical conductivity was measured using a conductivity meter and the pH was measured by a pH meter (Jackson, 1973). The Kjeldahl method was used to determine the available nitrogen in soil, Olsen *et al.* (1954) described extraction of soil-available phosphorus using 0.5 N $NaHCO_3$ pH 8.5, By using the ascorbic acid method, the concentration of P was determined (Olsen and Watanabe, 1965), and Black *et al.* (1965) and Cottenie *et al.* (1982) used a neutral normal NH_4^- acetate solution to extract the amount of available K and measure it using a flame photometer. Organic matter was determined by Walkley- Black method (Black *et al.*, 1965). Total carbonate was measured by calcimeter (Alison and Moodle, 1965). Main physical and chemical properties of the experimental soil and compost, in the two growing seasons, are shown in Table (1).

Plant Analysis:

1- Vegetative growth data collection:

- Days to heading (DH)
- Days to maturity (DM)

At harvest, the following parameters were recorded:

- Plant height (PH, cm)
- Spike length (SL, cm)
- Number of spikes (No. Sp, m^{-2})

2- Yield and yield components:

- 1000-kernel weight (KWt, g)
- Straw yield (Mg fed^{-1}), (Mg= ton)
- Grain yield (GY, Mg fed^{-1})
- Biological yield (BY, Mg fed^{-1})

The harvest index (HI, %) was calculated as:

$$\text{HI} = \left(\frac{\text{Grain Yield (GY)}}{\text{Biological Yield (BY)}}\right) \times 100$$

According to Chapman and Pratt (1961).

3- Plant nutrient analysis

- Total nitrogen was determined using the micro-Kjeldahl method (Bremner and Mulvaney, 1982), and
- The concentration of protein was calculated by multiplying total N by 6.25 as a standard factor.
- Total phosphorus was determined calorimetrically using the Vanado-Molybdate yellow color method according to A.O.A.C. (1995), and
- Total potassium was measured by a flame photometer (Page *et al.*, 1982).

Statistical analysis:

Snedecor and Cochrom's (1990) approach was used the least significant difference test (LSD) was then used to examine the difference between means of treatments.

RESULTS AND DISCUSSION

Differences between seasons did not significantly differ, according to statistical analysis. The homogeneity of error variance was determined using the Bartlett (1937) test, which revealed a substantial difference between the two seasons. Consequently, statistics from both seasons were combined.

1. Vegetative Growth:

The data presented in Table (3) show the effects of irrigation regimes (*IrrR*), wheat cultivars (*Cul*), and types of fertilizer (*FerS*) on the days to maturity (DM), days to heading (DH), and growth parameters.

Table 3. Vegetative growth parameters as affected by irrigation regimes, wheat cultivars, types of fertilizer and their interactions

			DM	DH	PH	SL	No. Sp.
			Days		cm		
IrrR.		I_1	130.04	83.06	107.82	10.85	246.64
		I_2	126.93	87.33	114.12	12.26	287.66
		I_3	127.33	88.66	118.77	11.68	316.77
LSD 0.05			ns	0.35	0.91	0.49	0.71
Wheat Cul		Masr 3	128.06	86.24	109.39	10.94	283.17
		Sakha 95	127.93	**87.55**	**115.88**	10.62	**295.39**
		Giza 171	128.37	85.26	115.44	**12.22**	272.51
LSD 0.05			ns	0.32	0.97	0.28	4.18
FerS		Cont.	124.33	83.33	110.30	10.58	245.59
		Comp.	127.88	87.14	113.57	10.94	279.66
		HA	130.44	87.04	114.47	**11.63**	302.62
		FA	128.51	87.22	114.51	11.54	291.22
		Si	129.44	86.66	114.99	**11.61**	200.37
LSD 0.05			1.25	0.34	0.57	0.14	4.41
IrrR X Cul	I_1	Masr 3	130.06	83.93	104.42	10.26	232.73
		Sakha 95	129.60	84.13	110.40	10.33	256.06
		Giza 171	130.46	81.13	108.65	11.96	251.13
	I_2	Masr 3	126.80	87.13	109.77	12.02	290.73
		Sakha 95	126.73	88.06	115.79	12.50	297.00
		Giza 171	127.26	86.80	116.81	12.26	275.26
	I_3	Masr 3	127.33	87.66	113.98	11.57	326.06
		Sakha 95	127.46	90.46	121.45	11.02	333.13
		Giza 171	127.20	87.86	120.87	12.43	291.13
LSD 0.05			ns	0.54	0.38	0.49	5.92
$IrrR_1$ X FerS		Cont.	126.77	80.11	104.13	10.19	215.00
		Comp.	128.55	83.22	107.60	10.52	248.77
		HA	131.44	**84.44**	108.90	11.30	265.00
		FA	130.00	**84.44**	108.56	11.29	250.55
		Si	**133.44**	83.11	109.93	10.96	253.89
$IrrR_2$ X FerS		Cont.	122.33	83.44	109.65	14.19	241.66
		Comp.	127.66	*88.44*	113.93	11.01	286.33
		HA	129.89	88.44	115.51	11.4	309.66
		FA	127.11	88.44	115.30	**13.05**	296.11
		Si	127.66	87.89	**116.23**	11.62	304.55
$IrrR_3$ X FerS		Cont.	123.88	86.44	117.14	10.72	280.11
		Comp.	127.44	89.77	119.17	11.30	303.89
		HA	**129.66**	89.33	119.01	12.19	333.22
		FA	128.44	88.77	119.68	11.93	327.00
		Si	127.22	88.99	118.83	12.24	339.66
LSD 0.05 IrrR X FerS			2.17	0.59	0.99	0.25	7.64
Cul x FerS	Masr 3	Cont.	124.22	82.33	107.02	9.98	258.77
		Comp.	127.88	87.33	109.59	10.68	279.88
		HA	130.55	87.44	109.67	11.39	300.11
		FA	128.33	87.11	109.92	11.04	273.66
		Si	129.33	87.00	110.74	11.63	303.44
	Sakha 95	Cont.	124.44	85.11	111.49	10.08	243.66
		Comp.	127.88	**88.55**	115.29	10.28	295.66
		HA	129.77	**88.11**	117.41	11.17	**319.22**
		FA	128.11	**88.22**	117.79	11.19	302.55
		Si	129.44	87.77	117.42	10.37	**315.88**
	Giza 171	Cont.	124.33	82.55	112.4	11.70	234.33
		Comp.	127.88	85.55	115.82	11.87	263.44
		HA	131.00	86.66	116.34	12.33	288.55
		FA	129.11	86.33	115.82	12.37	297.44
		Si	129.55	85.22	116.83	**12.82**	278.77
Cul x FerS			ns	0.60	0.99	0.25	7.64
IrrR x Cul x FerS			ns	1.02	1.71	0.44	13.24

Days to Maturity (DM):

The results indicate that main effects of *IrrR* for the wheat types ranged between 126.93-130.04 and have an insignificant effect on DM (Table 3). At the same time the differences among wheat cultivars are insignificant, but Giza 171 cultivar had the highest mean value for DM for 128.37 days after planting. In terms of different fertilizer amendments, the soil application of potassium humate (HA) significantly surpasses the other treatments where DM reached 131.6 for Masr 3 cultivar.

The interaction between *IrrR* and wheat cultivars reveals that the highest DM is achieved with the I_2 *IrrR* alongside the foliar application of silicon (Si), resulting in 133.44 days. According to the data in Table (3) and the findings illustrated in Fig. (1), there is a significant interaction among the various treatments. Under the first irrigation (I_1) regime, Giza 171 with silicon fertilizer shows the highest days to maturity (Fg. 1), while Masr 3 under the I_2 *IrrR* without fertilizers (control) has the shortest days to maturity at 121 days which means low resistance to drought stress.

Days to Heading:

Results demonstrated in Table (3) showed that *IrrR* has a significant effect on days to heading (DH). The full *IrrR* has the highest mean value in all tested parameters, except for days to heading (DH), which gave the lowest mean value (83 days) in both growing seasons. The lowest DH (85.66 days) obtained by Giza 171 *Cul*, control FerS (83.33 days). Also, data showed that the longest DH was obtained by the interaction between full *IrrR* (I_3) and Sakha 95 *Cul* or combined with compost fertilizer (90.46 and 89.77 days, respectively), also by the interaction between Sakha 95 *Cul* and compost application (88.55 days), and the interaction between I3, Sakha 95 *Cul*, and compost fertilizer has the highest DH, while I_1 with Giza 171 and foliar application of Si has the lowest value (92 and 79 days, respectively), (Fig 2).

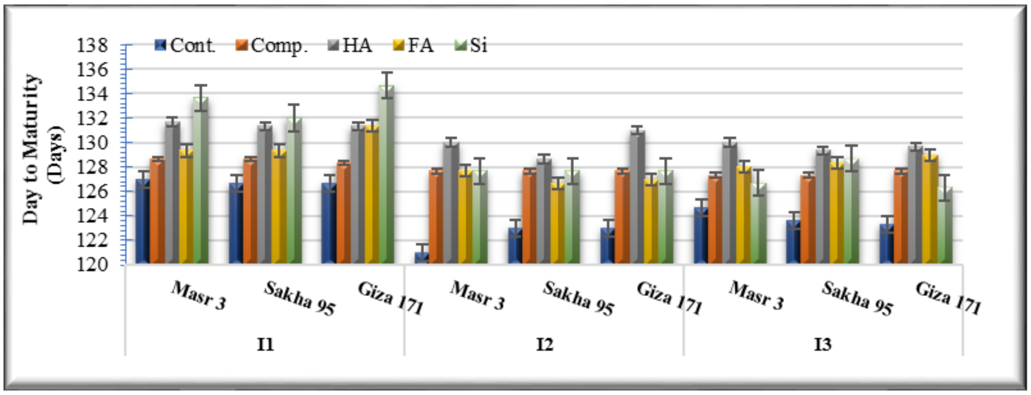


Fig. 1. Days to maturity (DM) as affected by the interaction among irrigation regimes, wheat cultivars and types of fertilizer

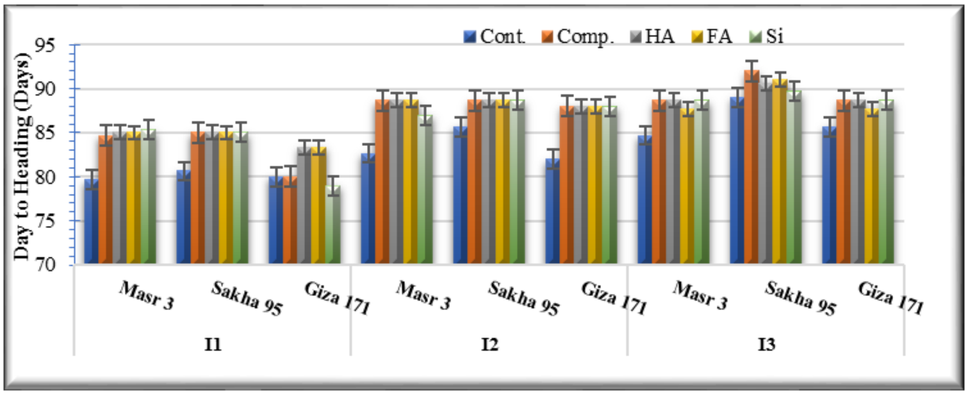


Fig. 2. Days to heading (DH) as affected by the interaction among irrigation regimes, wheat cultivars and types of fertilizer

Plant height (PH):

Plant height is a simple yet powerful indicator of vigor, stress, and productivity. The data in Table (5) showed that plant height was reduced by 10.15% and 4.07% due to decreased irrigation water (I_1, I_2) compared to full irrigation (*IrrR*). Among the cultivars, Mars 3 was the shortest, measuring 109.39 cm. In terms of fertilizer treatments (*FerS*), the potassium fulvat fertilizer yielded the highest values for all tested parameters. The interaction between the highest irrigation level (I_3) and the Sakha 95 cultivar, as well as I_3 with silicon fertilizer, resulted in the tallest plants, measuring 121.45 cm and 116.23 cm, respectively. Additionally, the combination of Sakha 95 with potassium fulvat (FA) achieved a height of 117.79 cm. Notably, the interaction of I_3 on Sakha 95 with FA produced the tallest plants at 124.34 cm (Fig. 3).

Spike length (SL):

Wheat Giza 171 exhibited the highest mean spike length at 12.22 cm (Table 3). Among the fertilizer treatments, both humic acid (HA) and silicon (Si) resulted in the best values with no significant differences with FA. The interaction between irrigation treatment I_2 and foliar application of FA or Sakha 95 cultivar significantly increased spike length to 15.45 cm (Fig. 4). Moreover, the combination of Giza 171 and silicon (Si) fertilizer resulted in the highest mean spike length of 12.82 cm.

Number of Spikes m^{-2} (Sp no.):

Full *IrrR* (I_3), Sakha 95 *Cul*, and FA recorded the highest spike numbers per square meter (Sp no.), measuring 316.77, 295.4, and 302.62, respectively. The most significant spike numbers were achieved through the interactions between I_3 and Sakha 95, which yielded a Sp no. of 333.13, and I_3 combined with Si fertilizer at 339.66. Additionally, Sakha 95 *Cul* with HA produced a Sp no. of 319.22 over all irrigation treatments. The interaction of I_3 with Sakha 95 and I_3 with Si fertilizer both reported higher Sp numbers of 333.13 and 339.66, respectively. Furthermore, the combination of Sakha 95 with HA achieved a Sp no. of 319.22. Notably, the interaction of I_3 on Sakha 95 with HA resulted in the highest Sp no. of 371.66, as shown in Fig. (5).

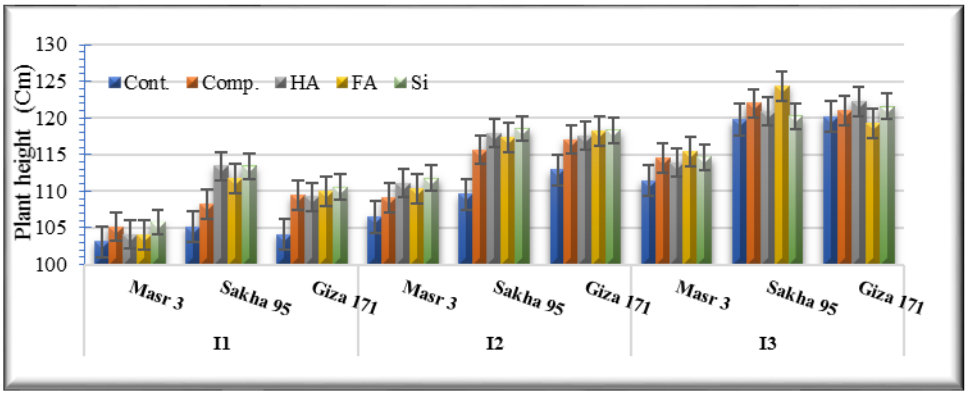


Fig. 3. Plant height (PH), cm as affected by the interaction among irrigation regimes, wheat cultivars and types of fertilizer

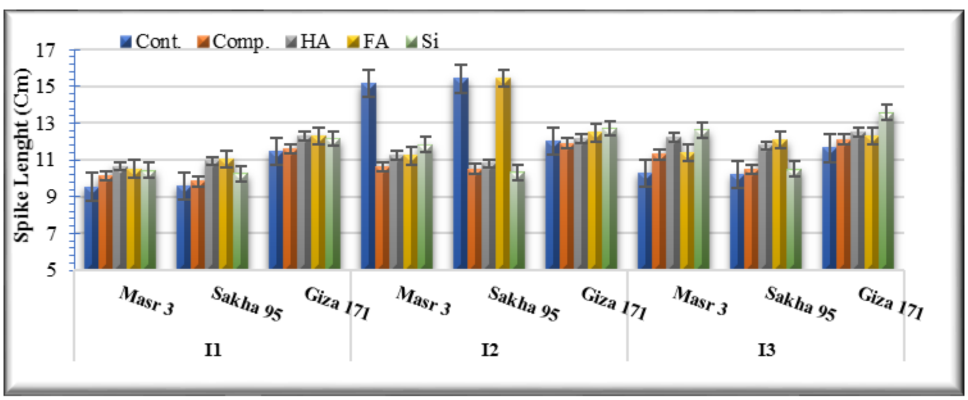


Fig. 4. Spike length (SL), cm as affected by the interaction among irrigation regimes, wheat cultivars and types of fertilizer and their interactions

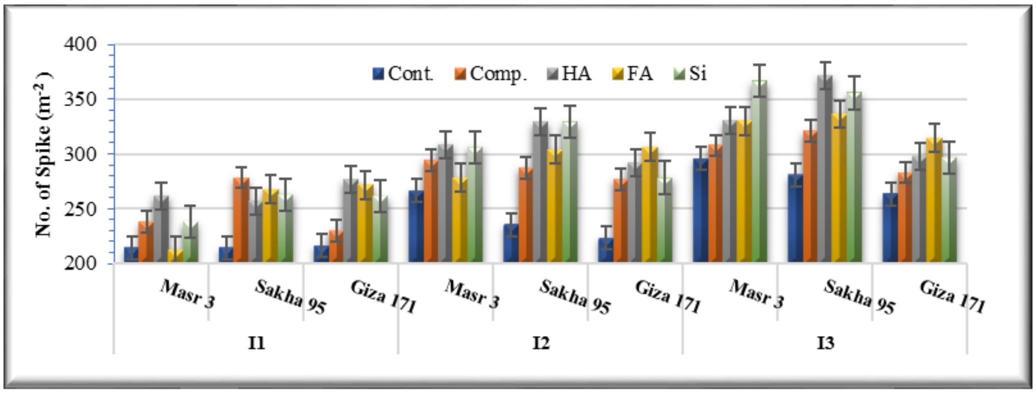


Fig. 5.Number of Spikes m^{-2} (Sp no.) as affected by the interaction among irrigation regimes, wheat cultivars and types of fertilizer

The data align with the findings of Abdelaziz *et al.* (2023) and Nyaupane *et al.* (2023), indicating that water stress generally reduces the height of wheat plants and the length of spikes. This reduction can be attributed to the dehydration of protoplasm, decreased cell division and expansion, and loss of cell turgidity, all of which hinder vertical growth. However, the extent of these reductions in plant height and spike length due to water stress varies among different wheat cultivars (Abdelaziz *et al.*, 2023).

In wheat, water stress often leads to a decrease in the number of spikes per square meter, particularly during the early growth stages (Abdelaziz *et al.*, 2023). This limitation occurs because tillering and spike production, which are crucial for achieving the final spike density, are negatively affected by water deficiency during these phases.

Additionally, water stress reduces the number of days to heading and maturity, especially during the vegetative or reproductive stages (Abdelaziz *et al.*, 2023). This phenomenon may occur because plants expedite their growth as a survival strategy under stress, causing them to head and mature earlier. The decrease in growth metrics is typically more pronounced in sensitive cultivars and under extreme or early-applied stress conditions.

Moreover, silicon can help reduce the need for irrigation, which may decrease salinization in crop fields, as it enhances plants' resistance to drought. Silicon fertilizer is also considered an excellent option for promoting environmentally friendly agriculture since it is non-toxic and pollution-free (Zhu and Gong, 2014).

Yield and yield component:

Egypt is one of the major producers of wheat in the Middle East and Africa; production is expected to be around 8.7 million metric tons in 2023, a modest down from prior years. Government initiatives including increased procurement costs, encouragement of modern machinery, and seed subsidies have pushed farmers to increase wheat production and implement yield-enhancing techniques (FAO, 2025).

1000-grain yield (g):

Data presented in Table (4) demonstrate the effects of various treatments and their interactions on the 1000-grain weight (g). The full *IrrR* resulted in the highest mean value of 54.66 g, reflecting a relative increase of 6.99%. During the two growing seasons, the cultivars (*Cul*) were tested under both normal and drought conditions. Giza 171 exhibited the highest 1000-grain weight at 56.27 g, followed by Sakha 95 *Cul* with 51.52 g, while Masr 3 recorded the lowest grain weight with 49.54 g. The application of compost as a soil amendment yielded the highest 1000-grain weight of 54.06 g, whereas the control treatment produced the lowest mean value of 50.46 g. Regarding the interaction between the irrigation regime and the wheat cultivars, the full *IrrR* combined with Giza 171 resulted in a 5.90% increase compared to the one *IrrR* regime. The combination of full *IrrR* and compost led to the highest 1000-grain weight of 55.96 g. Furthermore, the interaction between Giza 171 and the compost amendment produced the highest 1000-grain weight at 57.25 g. Under the full *IrrR* condition, Giza 171 fertilized with compost achieved the highest mean value for 1000-grain weight, exceeding the control by 7.25% and surpassing the 50 and 25% water deficit *IrrR* by 10.70% and 4.81%, respectively.

Table 4.1000-grain weight (g) as affected by irrigation regimes, wheat cultivars, types of fertilizer and their interaction

IrrR.	***Wheat Cul***	**Cont.**	**Comp.**	**HA**	**FA**	**Si**	**Mean**	**IrrR**
	Masr 3	48.93	49.6	47.46	49.25	49.2	48.89	
I_1	Sakha 95	44.37	51.03	50.58	50.74	50.6	49.46	
	Giza 171	53.04	55.48	55.68	55.99	54.37	54.91	
IrrR₁ X FerS		48.78-	52.03	51.24	51.99	51.39		51.09
	Masr 3	46.29	50.59	46.19	49.23	47.63	47.99	
I_2	Sakha 95	45.71	55.23	52.18	51.66	50.41	51.04	
	Giza 171	54.52	56.77	57.28	56.35	53.86	55.76	
IrrR₂ X FerS		48.84	54.20	51.88	52.41	50.63		51.59
	Masr 3	49.96	51.4	53.24	51.29	52.91	51.76	
I_3	Sakha 95	53.77	56.98	52.46	53.88	53.28	54.07	
	Giza 171	57.53	59.5	58.37	58.73	56.61	58.15	
IrrR₃ X FerS		53.75	55.96	54.69	54.63	54.27		54.66
FerS Mean		50.46	54.06	52.06	53.01	52.10		Cul Mean
	Masr 3	48.39	50.53	48.97	49.92	49.91		49.54
Cul	Sakha 95	47.95	54.41	51.74	52.09	51.43		51.52
	Giza 171	55.03	57.25	57.11	57.02	54.95		56.27

LSD 0.05 *IrrR: = 0.36* *Cul = 0.11* *FerS = 0.19*
IrrR X Cul = 0.20 *Cul X FerS= 0. 34* *IrrR X FerS = 0.34*
IrrR X Cul X FerS = 0.60

Grain yield (Mg fed^{-1}):

Table (5) presents data on the effects of different treatments on wheat grain yield (measured in Mg per fed) and their interactions. The findings show that the full *IrrR* (irrigation regime) resulted in the highest average grain yield of 4.41 Mg fed^{-1}. During two growing seasons, the Sakha 95 *Cul* demonstrated the highest grain yield of 4.13 Mg fed^{-1} averaged under both normal and drought conditions. Additionally, applying potassium silicate as a foliar treatment led to a significant grain yield of 4.32 Mg fed^{-1}.

Moreover, the combination of full *IrrR* with the Sakha 95 cultivar produced the highest mean grain yield at 4.59 Mg fed^{-1}, which is 19.84% more than the single irrigation treatment. This was followed by the Masr 3 cultivar, yielding 4.43 Mg fed^{-1} (an increase of 30.29%), and Giza 171 at 4.20 Mg fed^{-1} (19.32%) over the I_1 irrigation treatment.

The interaction between *IrrR* and fertilizer type showed that the full *IrrR* combined with potassium silicate (K_2SiO_3) foliar application yielded the highest grain yield of 4.70 Mg fed^{-1}. Additionally, using full *IrrR* along with fulvic acid (FA) improved the grain yield to 4.55 Mg fed^{-1}. The data in Table 9 also indicate that when the *IrrR* was increased to fulfill the full irrigation needs of the Sakha 95 cultivar, the mean grain yield reached 5.00 Mg fed^{-1}, which included a 14.16% increase due to potassium silicate foliar application.

Overall, the information presented in Table (5) and Fig. (6) highlights that using high-yielding cultivars and optimizing fertilizer application resulted in grain yields that exceeded the average productivity of the Behara Governorate (2.88, 2.90 Mg fed^{-1}), in both growing seasons, respectively.

Table 5.Grain yield (Mg fed^{-1}) as affected by irrigation regimes, wheat cultivars, types of fertilizer and their interaction

IrrR.	*Wheat Cul*	*Cont.*	*Comp.*	*HA*	*FA*	*Si*	*IrrR X Cul*	*IrrR*
	Masr 3	3.15	3.55	3.11	3.64	3.56	3.40	
I_1	Sakha 95	3.31	3.54	4.00	3.92	4.38	3.83	
	Giza 171	3.36	3.82	3.05	3.61	3.75	3.52	
IrrR₁ X FerS		***3.27***	***3.64***	***3.39***	***3.72***	***3.90***		***3.58***
	Masr 3	3.51	3.91	3.72	4.46	4.16	3.95	
I_2	Sakha 95	3.89	3.96	3.96	3.83	4.26	3.98	
	Giza 171	3.33	3.99	3.33	3.67	4.70	3.80	
IrrR₂ X FerS		***3.58***	***3.95***	***3.67***	***3.99***	***4.37***		***3.91***
	Masr 3	4.01	4.48	4.39	4.67	4.59	4.43	
I_3	Sakha 95	3.98	4.24	4.97	4.78	5.00	4.59	
	Giza 171	3.98	4.30	4.10	4.12	4.52	4.20	
IrrR₃ X FerS		***3.99***	***4.34***	***4.49***	***4.52***	***4.70***		***4.41***
FerS Mean		***3.61***	***3.97***	***3.85***	***4.08***	***4.32***		***Cul***
	Masr 3	3.55	3.98	3.74	4.26	4.10		3.93
Cul	Sakha 95	3.73	3.91	4.31	4.18	**4.55**		**4.13**
	Giza 171	3.56	4.03	3.49	3.80	4.32		3.84
LSD 0.05	*IrrR*:	0.02		*Cul*		**0.06**	*FerS*	**0.06**
	IrrR X Cul	**0.11**		*Cul X FerS*		**0.11**		
	IrrR X FerS	**0.11**		*IrrR X Cul X FerS*		**0.19**		

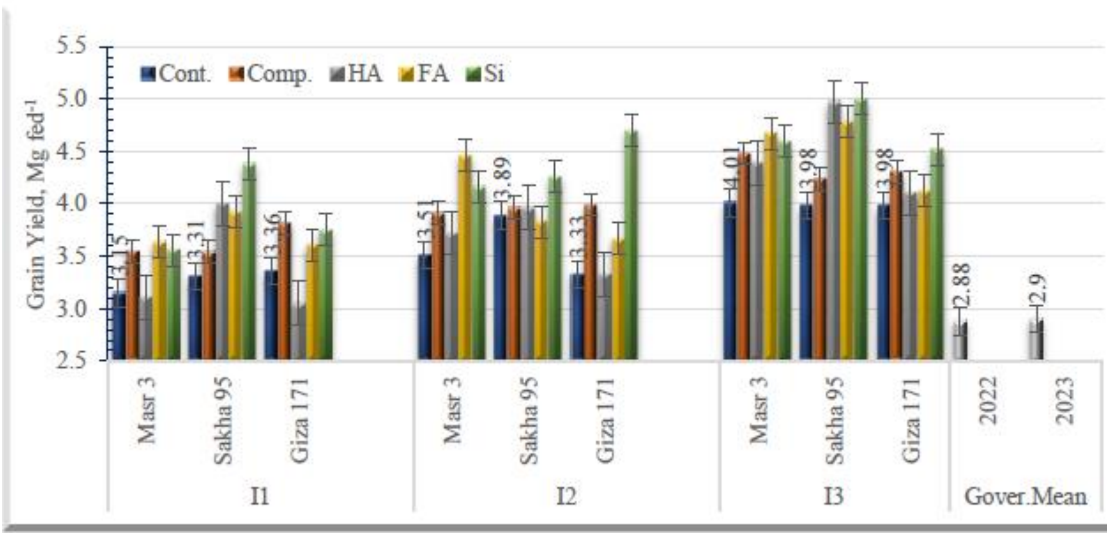


Fig. 6. Grain yield production (Mg fed^{-1}) as affected by the interaction among irrigation regimes, wheat cultivars and types of fertilizer compared with Governate mean grain yield production in 2022, 23

Biological yield (Mg fed^{-1}):

One important measure of wheat's vegetative vigor and resource efficiency is biological yield. Sustainable grain yields depend on striking a balance between biomass production and a high harvest index, even though contemporary breeding and agronomic techniques have increased biomass production to 18 Mg ha^{-1} under ideal circumstances. To maximize both biomass and grain yield, farmers and researchers must tailor their approaches to local conditions and cultivar genetics.

Data presented in Table (6) revealed that the full *IrrR* resulted in the highest biological yield at 20.94 Mg fed^{-1}. The Masr 3 cultivar achieved a biological yield of 20.13 Mg fed^{-1}. The highest mean values for biological yield—20.66 Mg fed^{-1} and 20.81 Mg fed^{-1} were observed with potassium humate and potassium silicate, respectively.

Furthermore, the interaction between *IrrR* and wheat *Cul* demonstrated that biological yield increased with higher irrigation levels across all cultivars, with Masr 3 showing the highest mean yield of 21.31 Mg fed^{-1}, representing an increase of 11.75% over the control. The combination of full *IrrR* and humate enhanced biological yield by 0.68% compared to the control. Notably, Giza 171 combined with potassium silicate exceeded the control by 27.13%.

The overall interaction among all treatments revealed that the full irrigation regime applied to Sakha 53, along with foliar application of potassium humate, resulted in the highest mean biological yield of 23.12 Mg fed^{-1}.

Harvest index (HI, %):

The harvest index (HI) is a key indicator of a crop's reproductive efficiency and is essential for initiatives aimed at boosting agricultural production. Several factors, including crop management techniques, environmental conditions, and genetics, influence the HI.

Data from Table (7) reveals that the highest mean values for HI percentages were 21.10%, 21.19%, and 20.81%, achieved through full *IrrR*, the Sakha 53 *Cul*, and potassium silicate application, respectively. Additionally, the combination of full irrigation with the Sakha 95 *Cul* resulted in the highest mean harvest index of 22.41%. The use of full irrigation along with K_2SiO_3 foliar application yielded a mean HI value of 21.97%. Furthermore, the Sakha 95 *Cul*, when treated with potassium silicate foliar application, reached an impressive harvest index of 22.77%. The highest overall harvest index recorded was 24.23%, achieved through the interaction of I_3 irrigation with the Sakha 95 *Cul* and the foliar application of potassium silicate.

The impact of soil amendments on yield and its components, including grain yield, biological yield, and 1,000-grain weight, is significant. The use of organic amendments has a profound effect on all traits investigated. Specifically, the application of organic amendments, such as compost, showed a marked improvement compared to the control group. By enhancing the physical and chemical properties of the soil, these organic additions create an ideal germination environment and promote plant growth, ultimately benefiting yield and its components. Moreover, farmyard manure (FYM) is recognized as an essential source of humus and carriers of macro and microelements, while also fostering the activity of beneficial microorganisms (Niel, 2021). Delfine *et al.* (2005) noted that the application of humic acid positively influenced the growth and yield of durum wheat.

Table 6. Biological yield (Mg fed^{-1}) as affected irrigation regimes, wheat cultivars, types of fertilizer and their interaction

IrrR.	*Wheat Cul*	Cont.	Comp.	HA	FA	Si	*IrrR X Cul*	IrrR
I_1	Masr 3	17.42	19.42	19.00	19.92	19.57	19.07	
	Sakha 95	17.47	18.29	19.20	19.05	19.15	18.63	
	Giza 171	16.39	17.54	16.83	19.50	19.72	18.00	
$IrrR_1$ X FerS		17.09	18.42	18.34	19.49	19.48		18.56
I_2	Masr 3	19.09	20.28	18.63	21.21	20.78	20.00	
	Sakha 95	17.69	18.81	19.74	20.48	20.14	19.37	
	Giza 171	17.37	18.98	19.92	21.67	23.50	20.29	
$IrrR_2$ X FerS		18.05	19.36	19.43	21.12	21.47		19.89
I_3	Masr 3	19.77	21.18	22.62	22.18	20.82	21.31	
	Sakha 95	18.57	18.96	**23.12**	21.25	20.65	20.51	
	Giza 171	18.34	21.23	21.76	20.68	23.00	21.00	
$IrrR_3$ X FerS		18.89	20.46	**22.50**	21.37	21.49		20.94
Mean FerS		18.01	19.41	20.09	20.66	20.81		Cul
Cul	Masr 3	18.76	20.29	20.09	21.1	20.39		20.13
	Sakha 95	17.91	18.68	20.69	20.26	19.98		19.50
	Giza 171	17.36	19.25	19.5	20.61	**22.07**		19.76
LSD 0.05	*IrrR*	*0.325*		*Cul*		*0.172*	*FerS*	*0.291*
	IrrR X Cul	*0.299*		*Cul X FerS*		*0.503*		
	IrrR X FerS	*0.503*		*IrrR X Cul X FerS*		*0.872*		

Table 7. Harvest index (HI, %) as affected by irrigation regimes, wheat cultivars, types of fertilizer and their interaction

				H I, %				
IrrR.	***Wheat Cul***	***Cont.***	***Comp.***	***HA***	***FA***	***Si***	***IrrR X Cul***	***IrrR***
I_1	Masr 3	18.11	18.30	16.37	18.28	18.21	17.85	
	Sakha 95	18.98	19.38	20.83	20.63	**22.91**	20.55	
	Giza 171	20.55	21.78	18.11	18.50	19.06	19.60	
$IrrR_1$ X FerS		19.21	19.82	18.44	19.14	20.06		19.33
I_2	Masr 3	18.39	19.30	20.00	21.05	20.05	19.76	
	Sakha 95	21.99	21.06	20.10	18.72	21.18	20.61	
	Giza 171	19.16	21.05	16.79	17.02	20.02	18.81	
$IrrR_2$ X FerS		*19.85*	*20.47*	*18.96*	*18.93*	*20.42*		*19.73*
I_3	Masr 3	20.30	21.18	19.43	21.07	22.05	20.81	
	Sakha 95	21.47	22.35	21.52	22.48	24.23	22.41	
	Giza 171	21.72	20.26	18.88	19.96	19.64	20.09	
$IrrR_3$ X FerS		*21.16*	*21.26*	*19.94*	*21.17*	*21.97*		*21.10*
FerS Mean		*20.08*	*20.52*	*19.11*	*19.75*	*20.81*		*Cul*
Cul	Masr 3	18.93	19.60	18.60	20.13	20.10		19.47
	Sakha 95	20.82	20.93	20.82	20.61	**22.77**		**21.19**
	Giza 171	20.48	21.03	17.92	18.49	19.57		19.50
LSD 0.05	***IrrR***	**0.40**		***Cul***		**0.30**	***FerS***	**0.32**
	IrrR X Cul	0.44		*Cul X FerS*		0.56		
	IrrR X FerS	0.56		*IrrR X Cul X FerS*		0.97		

These results align with the findings of Abdelaziz *et al.* (2023), who reported significant increases in 1,000-grain weight (53.67 g) and biological yield (17.46 Mg fed^{-1}) with increased irrigation water. Compared to the full irrigation treatment (full *IrrR* I_3), the I_1 irrigation treatment (50% water deficit) decreased grain yield by 0.67 Mg fed^{-1}, while I_3 resulted in the highest grain yield of 3.66 Mg fed^{-1}. This supports the observations made by Hochman (1982) and Amir *et al.* (2005), who indicated that water stress at any growth stage can significantly reduce wheat grain output. The wheat crop is particularly sensitive to heat and drought stressors during the flowering and grain development stages, which adversely affect both production and grain quality, leading to lower 1,000-grain weight and variations in protein quality.

Additionally, it has been demonstrated that incorporating compost with nitrogen and phosphorus fertilizers significantly enhances wheat yield by improving plant height, spike length, and grain weight (Kabato *et al.*, 2022).

3. Climatic Change and Wheat Productivity:

Data in Table (2), Fig. (7), showed the change in temperature and precipitation nowadays and ten years ago, and cleared that the summation of minimum temperature was increased, while maximum temperature and total rainfall decreased.

Over the past two decays, Egypt's wheat production has generally increased, due to the increase in areas of high-yielding varieties Fig. (8). Despite producing only roughly half of the 20 million tons of wheat it consumes each year, the nation continues to be one of the biggest importers of wheat worldwide.

From all the above, the results clearly demonstrate that optimizing irrigation regimes, cultivar selection, and foliar fertilizer application significantly enhances wheat grain yield. The full irrigation regime (*IrrR*) consistently produced the highest yields, especially when combined with the high-yielding Sakha 95 cultivar and potassium silicate foliar treatment, pushing grain yields up to 5.00 Mg fed^{-1} in some cases. These yields notably exceed the average productivity of the Behara Governorate (2.90 Mg fed^{-1}), indicating that adopting such integrated management practices can substantially improve wheat production. Thus, improving water management alongside the use of superior cultivars and tailored fertilizer applications represents an effective strategy to boost wheat yield in the region across varying climatic conditions**.**

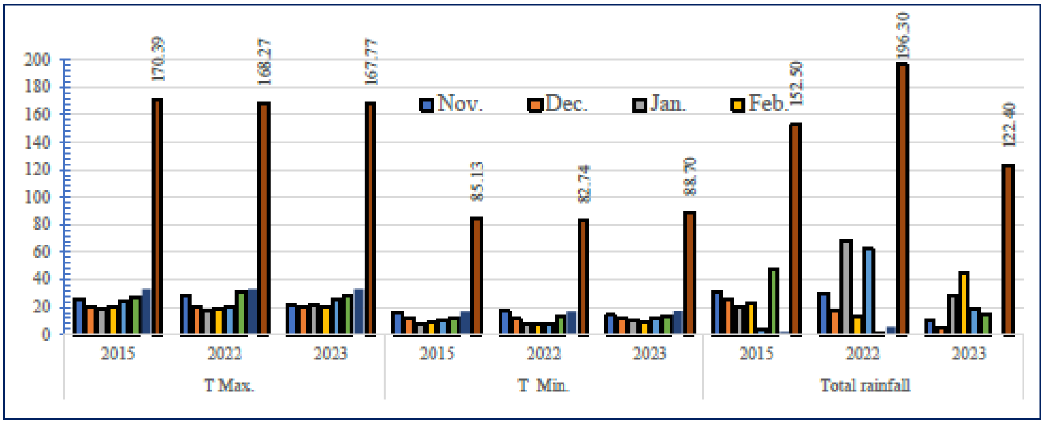


Fig. 7. Maximum, minimum temperature and precipitation

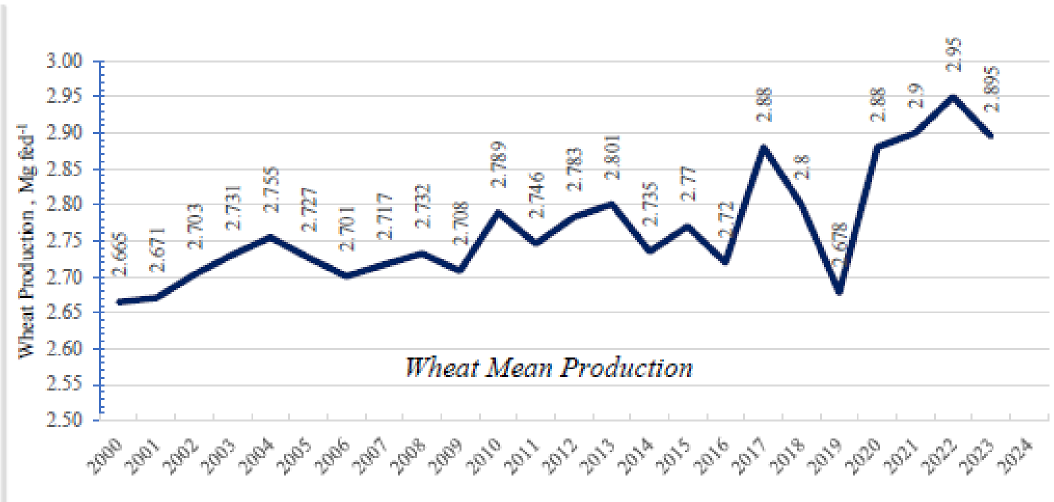


Fig. 8.Wheat means productivity (Mg fed^{-1}) in Egypt

Yield quality:

Seed Macro – Micronutrient and Protein

Seed protein (%):

The protein content in wheat grain is a key quality trait that influences dough strength, elasticity, and bread-making characteristics (Table 8). However, seed protein was found to be insignificantly affected by *IrrR*. Among the varieties studied, Sakha 95 exhibited the highest mean protein value at 12.01%. The control treatment, which did not receive fertilizer, showed a protein percentage of 11.91%. When considering the interaction between I_3 or I_1 *IrrR* and Sakha 95, the highest protein values were observed at 12.23% and 12.14%, respectively. The control treatment yielded the highest mean protein values across all irrigation rates. Sakha 95 cultivated with foliar application (FA) of fertilizer, followed by the control treatment, demonstrated the highest mean protein values. In contrast, the lowest protein percentage of 8.85% resulted from the interaction between the first irrigation rate (I_1), Masr 3, and the foliar application of FA.

Table 8.Seed protein, % as affected by irrigation regimes, wheat cultivars, types of fertilizer and their interaction

IrrR.	*Wheat Cul*	**Cont.**	**Comp.**	**HA**	**FA**	**Si**	**IrrR X Cul**	**IrrR**
	Masr 3	9.98	8.86	9.66	**8.85**	9.66	**9.40**	
I_1	Sakha 95	12.88	12.07	13.2	12.88	9.66	**12.14**	
	Giza 171	11.27	9.38	12.88	8.86	9.66	**10.41**	
$IrrR_1$ X FerS		**11.38**	10.10	11.91	10.20	9.66		**10.65**
	Masr 3	8.05	9.66	9.98	8.37	10.47	**9.31**	
I_2	Sakha 95	12.88	11.27	10.47	**13.68**	9.98	**11.66**	
	Giza 171	**13.84**	10.47	13.2	8.05	9.66	**11.04**	
$IrrR_2$ X FerS		**11.59**	10.47	11.22	10.03	10.04		**10.67**
	Masr 3	12.08	11.27	11.27	11.75	11.27	**11.53**	
I_3	Sakha 95	13.36	12.07	11.27	13.2	11.27	**12.23**	
	Giza 171	12.88	10.95	7.73	10.46	12.88	**10.98**	
$IrrR_3$ X FerS		**12.77**	11.43	10.09	11.80	11.81		**11.58**
FerS Mean		**11.91**	10.66	11.07	10.68	10.5		**Cul Mean**
	Masr 3	10.03	9.93	10.30	9.66	10.46		10.08
Cul	Sakha 95	**13.04**	11.8	11 64	**13.25**	10.30		**12.01**
	Giza 171	**12.66**	10.26	11.27	9.12	10.73		10.81
LSD 0.05	*IrrR:*		*ns*	*Cul*		*0.50*	*FerS*	*0.71*
	IrrR X Cul		*0.88*	*Cul X FerS*		*1.23*		
	IrrR X FerS		*1.23*	*IrrR X Cul X FerS*		*2.14*		

During the growing season, drought stress often leads to an increase in grain protein concentrations compared to well-watered conditions. This occurs because water stress reduces starch accumulation more significantly than it affects protein production, thereby concentrating protein in the grain.

Seed total N, P and K (%):

Data listed in Table (9) and Fig. (9) demonstrates that wheat cultivars exhibit distinct responses to varying irrigation regimes and fertilization levels. Increasing irrigation levels from I_1 to I_3 positively influenced the measured traits, seed nitrogen content. Sakha 95 generally showing superior performance across treatments. The interaction effects between *IrrR*, *Cul*, and *FerS* were significant. These findings showed the importance of optimizing both water management and nutrient supply tailored to specific cultivars to maximize wheat growth and productivity.

Also, data in Table (14), showed that there was insignificant different among the *IrrR* on TP. Giza 171 *Cul* has highest P percentage. Concerning, fertilizer sources, compost amendment results in high P percentage. Also, data cleared that the highest Seed TP obtained by the application of compost with $I_{1,}$ also by Giza 171 with either compost or FA. Also, Giza 171 *Cul* with I_2 water regime resulted in highest seed TP mean value. The interaction among the different treatments explained that the interaction between Giza 171*Cul* under I_1 and compost fertilizer lead to the highest seed TP percentage.

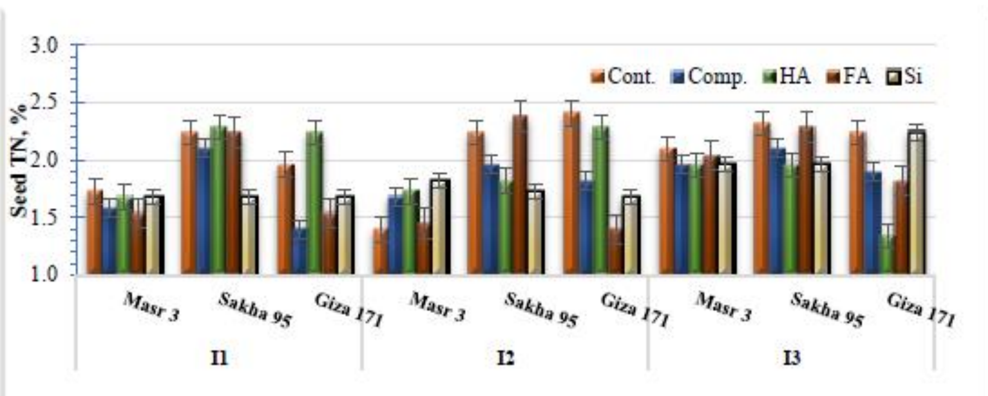
Nonetheless, I_1 and I_2 *IrrR* has highest mean value of seed total K. However, wheat *Cul* and *FerS*. have significant effect on TK and protein content, Giza 171 has lowest TK value and FA gave the highest TK. Concerning, fertilizer sources, compost amendment results in high K percentage. The interaction between - I_1 and compost fertilizer, - Giza 171 *Cul* and I_2 – also, - Giza 171 with either HA, FA or Si application, resulted in highest S TK percentage. The interaction between I_1 on Giza 171 *Cul* under compost fertilizer has highest S TK (0.40 %). Seed TK content as affect by different interactions between diverse treatments.

Seed total Fe, Mn and Zn (mg kg^{-1}):

Seed micronutrient concentrations varied significantly across different treatments as listed in Table (10). The highest mean value for total seed iron (Fe) was found under full *IrrR*, particularly in plots amended with compost, reaching 2.94 mg kg^{-1}. This finding is consistent with the interaction analysis, which showed that the Masr 3 *Cul* combined with compost (*FerS*) yielded the highest Fe content at 3.83 mg kg^{-1}. Similarly, full *IrrR* with compost significantly enhanced Fe levels to 3.12 mg kg^{-1}, indicating that both optimal water availability and organic amendments work together to improve Fe uptake.

Table 9. Seed macronutrients, % as affected by irrigation regimes, wheat cultivars, types of fertilizer and their interaction

Treatmeants		N	P	K			N	P	K
IrrR.	I1	1.84	0.21	0.333	*Cul*	Masr 3	1.75	0.19	0.322
	I2	1.85	0.20	0.335		Sakha 95	2.08	0.20	0.326
	I3	2.01	0.21	0.325		Giza 171	1.86	0.22	0.345
LSD 0.05		***0.15***	***ns***	***0.003***	***LSD 0.05***		***0.09***	***0.01***	***0.005***
FerS					I1	Masr 3	1.64	0.20	0.328
	Cont.	11.91	0.18	0.320		Sakha 95	2.11	0.20	0.322
	Comp.	10.66	0.23	**0.338**		Giza 171	1.76	0.22	0.350
					I2	Masr 3	1.62	0.19	0.328
	HA	11.07	0.20	0.331		Sakha 95	2.03	0.19	0.322
						Giza 171	1.92	0.23	0.354
	FA	10.68	0.22	0.340	I3	Masr 3	2.00	0.19	0.310
						Sakha 95	2.13	0.22	0.334
	Si	10.50	0.20	0.332		Giza 171	1.91	0.21	0.332
LSD 0.05		***0.13***	***0.005***	***0.003***	***LSD 0.05***		***0.17***	***0.02***	***0.002***
IrrR1 X FerS	Cont.	1.97	0.17	0.307	*Masr 3*	Cont.	1.74	0.18	0.300
	Comp.	1.68	0.24	0.360		Comp.	1.72	0.21	0.333
	HA	2.07	0.20	0.333		HA	1.79	0.18	0.313
	FA	1.77	0.23	0.343		FA	1.68	0.20	0.323
	Si	1.68	0.20	0.323		Si	1.82	0.20	0.340
IrrR2 X FerS	Cont.	11.59	0.18	0.327	*Sakha 95*	Cont.	2.26	0.17	0.310
	Comp.	10.47	0.23	0.333		Comp.	2.05	**0.24**	0.343
	HA	11.22	0.22	0.347		HA	2.02	0.22	0.33
	FA	10.03	0.19	0.337		FA	2.30	0.20	0.336
	Si	10.04	0.20	0.330		Si	1.79	0.19	0.310
IrrR3 X FerS	Cont.	**2.22**	**0.19**	0.313	*Giza 171*	Cont.	2.20	0.19	0.336
	Comp.	1.98	**0.22**	0.323		Comp.	1.70	**0.25**	0.34
	HA	1.75	**0.20**	0.313		HA	1.96	0.21	**0.350**
	FA	**2.05**	**0.23**	0.333		FA	1.58	**0.25**	**0.353**
	Si	**2.05**	**0.21**	0.343		Si	1.86	0.22	**0.346**
LSD 0.05		***0.22***	***0.009***	***0.009***			***0.39***	***0.01***	***0.009***
IrrR X Cul X FerS		***0.39***	***0.016***	***0.016***					



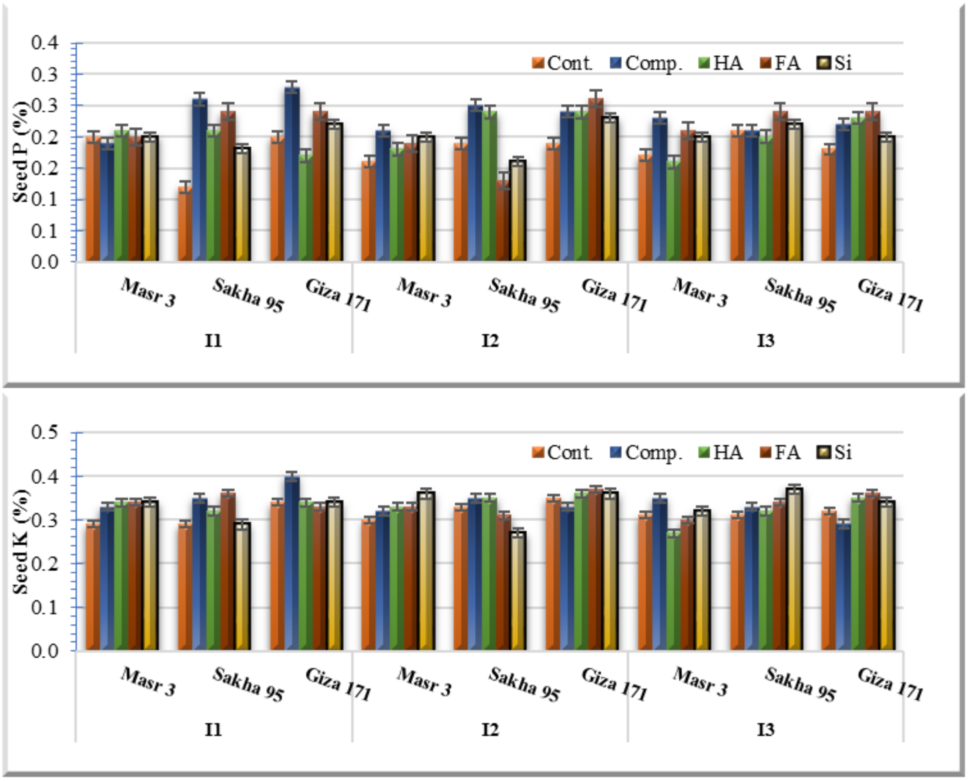


Fig. 9. Seed macronutrient concentrations as affected by the interaction among the irrigation regimes, wheat cultivars and types of fertilizer

Table 10. Seed micronutrients, mg kg^{-1} as affected by irrigation regimes, wheat cultivars, types of fertilizer and their interactions

	Fe	Mn	Zn		Fe	Mn	Zn
	IrrR				***Wheat Cul***		
I_1	27.8	41.41	11.28	Masr 3	**32.90**	41.00	**15.58**
I_2	25.8	41.41	11.08	Sakh 95	25.10	42.00	10.04
I_3	**29.4**	**42.42**	**14.47**	Giza 171	25.00	41.00	12.21
LSD 0.05	***1.47***	***1.7***	***0.25***		***3.40***	***3.47***	***0.004***
	FerS						
Cont.	23.7	41.00	10.09	*IrrR X Cul*	0.42	0.34	0.003
Comp.	**31.2**	**42.00**	14.42	*IrrR X FerS*	1.16	0.22	0.0022
Fulvat	29.7	41.00	13.34	Cul X FerS	0.42	0.21	0.0023
Humate	29.2	**42.00**	**15.52**	IrrRXCulX	0.44	0.32	0.0032
K_2SiO_3	24.6	0.41	1.02				
LSD 0.05	2.99	1.23	0.0007				

For zinc (Zn) and manganese (Mn), the highest concentrations were observed in specific cultivar-fertilizer combinations. The interaction of Sakha 95 with fulvate (FA) produced the highest Zn content at 45.45 mg kg^{-1}, while the combination of Masr 3 with humate (HA) maximized Mn levels at 17.76 mg kg^{-1}. Notably, full *IrrR* combined with FA further boosted Zn uptake to 43.43 mg kg^{-1} and Mn uptake to 20.00 mg kg^{-1}. In contrast, full *IrrR* alone produced the highest mean seed values for Mn and Zn, measuring 14.47 mg kg^{-1} and 42.42 mg kg^{-1}, respectively. These trends were supported by Fig. 10, which showed that I_1 (moderate drought) combined with Masr 3 maximized Fe levels at 34.40%. Additionally, full *IrrR* with Sakha 93 enhanced Zn levels to 45.00 mg kg^{-1}, and full *IrrR* with Masr 3 elevated Mn levels to 1.69%. Figure (10) further illustrated treatment interactions, revealing peak micronutrient levels under full *IrrR*: Fe at 39.70 mg kg^{-1}

with Masr 3 and compost, Zn at 49.00 mg kg^{-1} with Sakha 95 and compost, and Mn at 25.90 mg kg^{-1} with FA.

Contextualizing these findings with existing literature, while compost generally promotes the uptake of Fe, Zn, and Mn, some studies (Wang *et al.*, 2016) suggest it may reduce the availability of copper (Cu) and Mn, potentially due to nutrient immobilization or shifts in pH. Conversely, humate (HA) has been shown to enhance dry mass production (Delfine *et al.*, 2005) and significantly increase the uptake of Mg, Fe, Mn, and other macro and micronutrients (N, P, K, Ca, Cu, Zn). This supports our observations that organic acids (HA/FA) and compost improve nutrient mobilization, particularly under adequate irrigation.

Seed N uptake (Kg fed^{-1}):

Additionally, the highest N uptake was observed in Giza 171 under I_2, as illustrated in Table (11). The interaction between I_3 and Si resulted in the highest seed N uptake, while the lowest value recorded was (61.30 kg fed^{-1}) due to the interaction between I_1 and compost application.

Data presented in Table (11) clarified that Sakha 95 under full *IrrR* with FA fertilizer exhibited the highest SN uptake value.

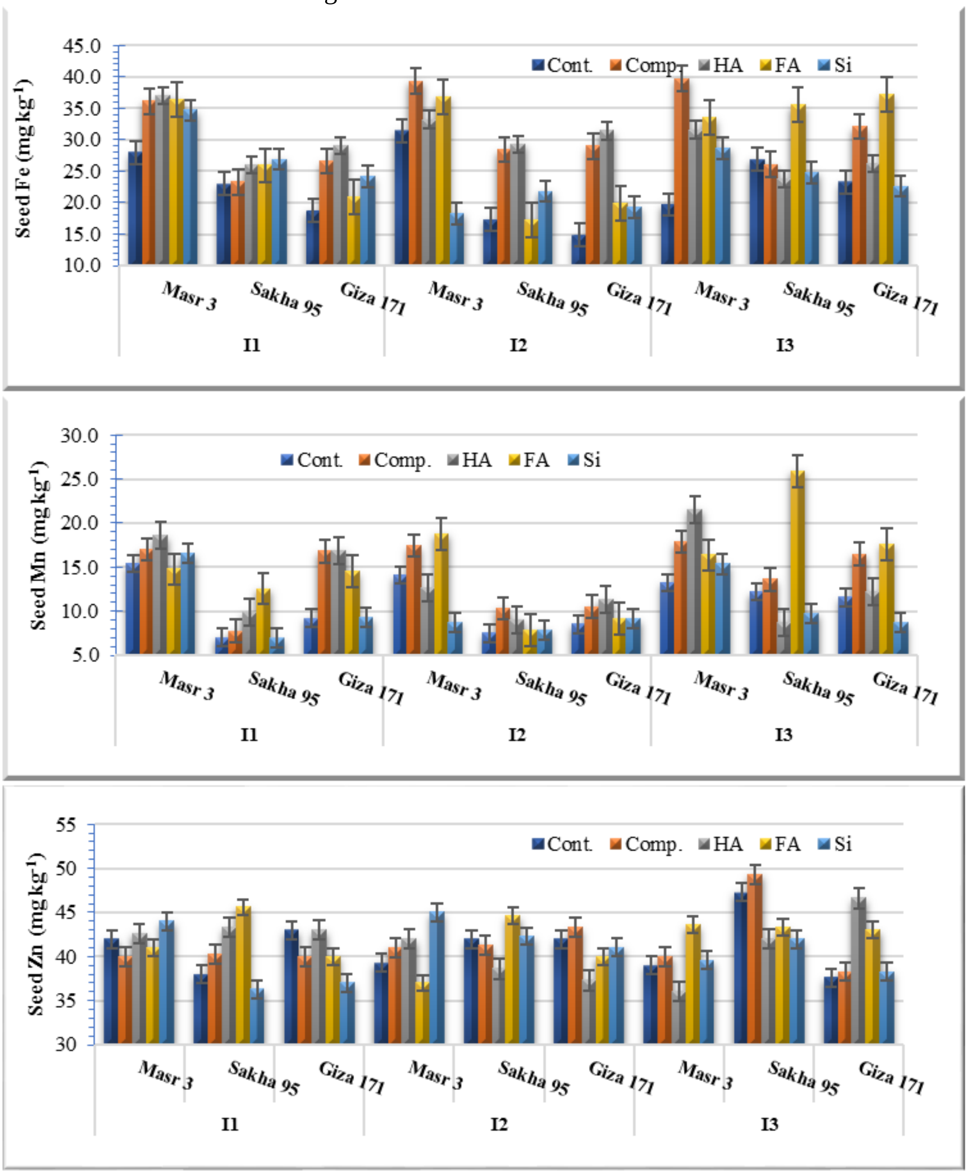


Fig. 10. The interaction among the irrigation regimes, wheat cultivars and types of fertilizer on seed micronutrients

Table 11.Seed N uptake, kg fed^{-1} as affected by irrigation regimes, wheat cultivars, types of fertilizer and their interaction

IrrR.	*Wheat Cul*	*Cont.*	*Comp.*	*HA*	*FA*	*Si*	*IrrR X Cul*	*IrrR*
I_1	Masr 3	54.50	56.09	52.25	56.06	59.81	**55.74**	
	Sakha 95	74.14	74.34	91.60	87.81	73.58	**80.30**	
	Giza 171	65.86	53.48	68.32	55.59	63.00	**61.25**	
Mean $IrrR_1$ X FerS		64.83	**61.30**	70.72	66.49	65.46		**65.76**
I_2	Masr 3	49.14	65.69	64.36	64.67	75.71	**63.91**	
	Sakha 95	87.14	77.62	72.07	91.15	73.70	**80.34**	
	Giza 171	80.25	72.62	76.26	51.38	78.96	**71.89**	
Mean $IrrR_2$ X FerS		72.18	71.97	70.90	69.07	76.12		**72.05**
I_3	Masr 3	84.21	87.81	86.04	95.27	89.96	**88.66**	
	Sakha 95	92.34	89.04	97.41	109.46	98.00	**97.25**	
	Giza 171	89.15	81.70	54.94	74.98	101.25	**80.40**	
Mean $IrrR_3$ X FerS		88.57	86.18	79.47	93.24	96.40		**88.77**
FerS Mean								***Cul Mean***
Cul	Masr 3	61.77	68.46	66.95	71.57	74.62		**68.67**
	Sakha 95	84.30	80.16	87.06	96.14	81.45		**85.82**
	Giza 171	78.32	68.51	**68.40**	60.04	80.35		**71.13**
LSD 0.05	*IrrR*		*0.60*	*Cul*		*0.30*	*FerS*	*ns*
	IrrR X Cul		*0.70*	*Cul X FerS*		*0.90*		
	IrrR X FerS		*0.90*	*IrrR X Cul X FerS*		*1.60*		

Strow Macronutrient and Protein

Strow TN (%), TP (mg Kg^{-1}) and TK (%):

Concerning to strow distinguishing, data in Table (12) and Fig. (11) showed that there was insignificant different among the *IrrR* in strow total nitrogen. Also, *Cul* and *FerS* has no effect on Strow TN. The highest St N obtained by the interaction between Giza 171 *Cul* at I_1 and compost application. Also, data reflected that I_1 *IrrR* with Giza 171 *Cul* has the highest mean value (0.30 %) and Giza 171 *Cul* without applied fertilizer was (0.37 %). Data also reflected that one *IrrR* with Giza 171 *Cul* without applied fertilizer has the highest mean value (0.42 %).

Data in Table (12), cleared that neither *IrrR* nor wheat *Cul* or *FerS* has significant effect on St. TP. However, the lowest St. Tp was due to the interaction between I_2 and Sakha 53 (131.51 mg kg^{-1}). The highest St. TP (237.68 mg kg^{-1}) was as result to the interaction between I_1 and compost amendment, and the interaction between Sakha 95 and HA fertilizer (206.11 mg kg^{-1}). Regarding, the interaction among I_2, Masr 3 and without fertilization has lowest P (95.45 mg kg^{-1}).

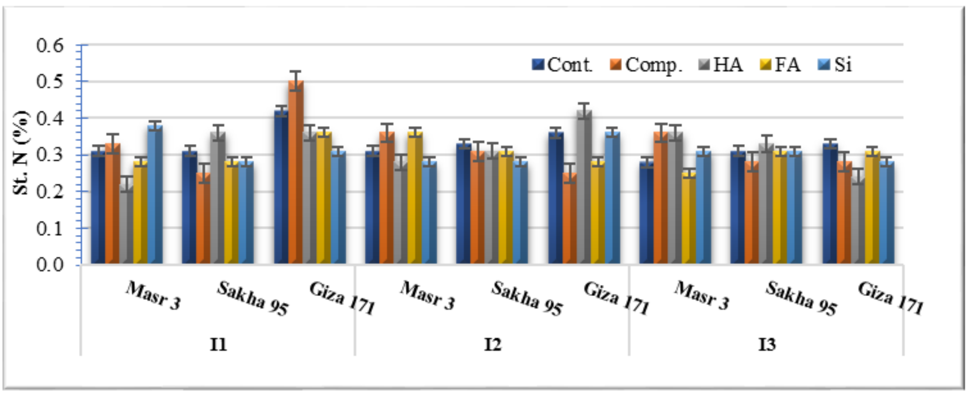
Data in Table (12), cleared that under the *IrrR* treatment, St. TK showed a significant and gradual decline as irrigation water decreased, the *Cul* Sakha 53 and Masr 3 has highest St. TK (1.61 %), while HA > FA > Si amendments but was insignificantly different and has highest TK (1.64, 160 and 1.58 %) respectively. The interaction between full *IrrR* and Sakha 95 *Cul* gave the highest TK (1.82 %).

Biological N uptake (kg fed^{-1}):

Regarding the highest biological N uptake, the *IrrR* I_3, *Cul* Sakha 53 has highest biological N uptake (1.39 and 1.32 kg fed^{-1}) respectively, while *FerS* treatments was insignificant different. Concerning the interactions among various treatments, indicates that the highest Bio N uptake resulted from the interaction between full *IrrR* and Sakha 95 *Cul*, as well as the interaction between Sakha 95 *Cul* and either HA or FA. The interaction among the different treatments, as shown in Table (13), revealed that the highest Bio N uptake was achieved by I_3 with Sakha 95 and foliar application of FA.

Table 12. Strow macronutrients as affected by irrigation regimes, wheat cultivars, types of fertilizer and their interaction

Treatments		N	P	K			N	P	K
		g kg^{-1}	mg kg^{-1}	g kg^{-1}			g kg^{-1}	mg kg^{-1}	g kg^{-1}
IrrR.	I_1	0.33	179.85	1.48	***Cul***	Masr 3	0.31	157.50	1.61
	I_2	0.32	139.22	1.54		Sakha 95	0.30	167.22	1.61
	I_3	0.30	156.45	1.64		Giza 171	0.33	150.79	1.43
LSD 0.05		***ns***	***ns***	***0.15***	***LSD 0.05***		***ns***	***ns***	***0.13***
FerS	Cont.	0.33	149.20	1.40	I_1	Masr 3	0.30	193.64	1.55
						Sakha 95	0.30	185.88	1.44
	Comp.	0.32	186.89	1.54		Giza 171	0.39	160.04	1.47
					I_2	Masr 3	0.32	139.77	1.63
	HA	0.32	166.96	1.64		Sakha 95	0.31	131.51	1.59
						Giza 171	0.33	146.36	1.39
	FA	0.30	140.00	1.60	I_3	Masr 3	0.31	139.09	1.66
						Sakha 95	0.31	184.27	1.82
	Si	0.31	149.48	1.58		Giza 171	0.29	145.97	1.43
LSD 0.05		***ns***	***ns***	***0.15***	***LSD 0.05***		***0.04***	***53.26***	***0.20***
$IrrR_1$ X FerS	Cont.	0.35	211.99	1.25	*Masr 3*	Cont.	0.30	135.71	1.38
	Comp.	0.36	237.68	1.47		Comp.	0.35	193.38	1.55
	HA	0.31	152.52	1.67		HA	0.28	143.16	1.75
	FA	0.31	143.43	1.54		FA	0.29	141.62	1.69
	Si	0.32	153.64	1.49		Si	0.32	173.64	1.69
$IrrR_2$ X FerS	Cont.	0.33	113.38	1.49	*Sakha 95*	Cont.	0.31	163.99	1.42
	Comp.	0.31	180.56	1.51		Comp.	0.28	187.47	1.68
	HA	0.34	142.05	1.52		HA	0.33	206.11	1.66
	FA	0.32	120.71	1.56		FA	0.30	131.56	1.7
	Si	0.31	139.39	1.60		Si	0.29	146.97	1.62
$IrrR_3$ X FerS	Cont.	0.31	122.22	1.46	*Giza 171*	Cont.	**0.37**	147.90	1.39
	Comp.	0.31	142.42	1.65		Comp.	0.34	179.80	1.40
	HA	0.31	206.31	1.73		HA	0.34	151.62	1.51
	FA	0.29	155.86	1.71		FA	0.31	146.82	1.42
	Si	0.30	155.41	1.64		Si	0.31	127.83	1.42
LSD 0.05		***ns***	***68.76***	***0.26***			***ns***	***68.76***	***0.26***
IrrR X Cul X FerS		***0.06***	***119.10***	***0.44***					



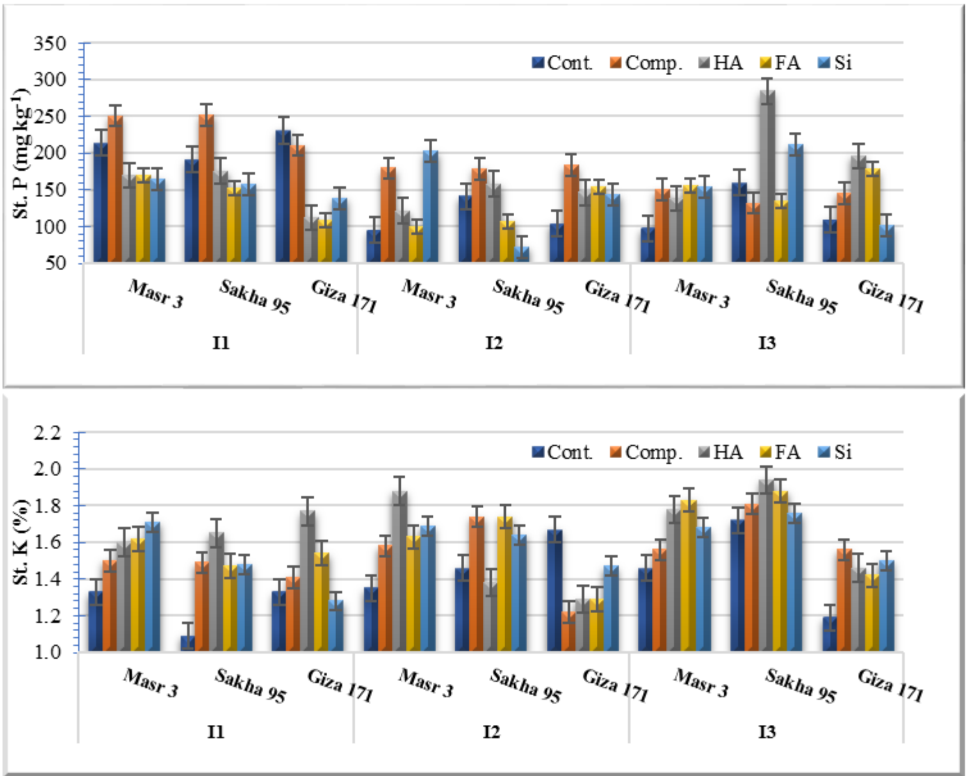


Fig. 11. The interaction among the irrigation regimes, wheat cultivars and types of fertilizer on straw micronutrients

Table 13. Biological N uptake, Kg fed^{-1} as affected by irrigation regimes, wheat cultivars, types of fertilizer and their interaction

IrrR.	*Wheat Cul*	*Cont.*	*Comp.*	*HA*	*FA*	*Si*	*IRR X Cul*	*IrrR*
	Masr 3	1.00	1.07	0.87	1.03	1.07	**1.01**	
I₁	***Sakh 95***	1.17	1.10	1.50	1.30	1.13	**1.24**	
	Giza 171	1.20	1.23	1.20	1.17	1.13	**1.19**	
Mean IrrR₁ X FerS		***1.12***	***1.13***	***1.19***	***1.17***	***1.11***		***1.144***
	Masr 3	1.00	1.27	1.07	1.27	1.20	**1.16**	
I₂	***Sakh 95***	1.33	1.20	1.17	1.43	1.20	**1.27**	
	Giza 171	1.30	1.13	1.47	1.03	1.50	**1.29**	
Mean IrrR₂ X FerS		***1.21***	***1.20***	***1.23***	***1.24***	***1.30***		***1.238***
	Masr 3	1.30	1.47	1.50	1.40	1.40	**1.41**	
I₃	***Sakh 95***	1.37	1.27	1.57	1.60	1.47	**1.45**	
	Giza 171	1.37	1.30	1.00	1.27	1.53	**1.29**	
Mean IrrR₃ X FerS		***1.34***	***1.34***	***1.36***	***1.42***	***1.47***		***1.387***
FerS Mean		1.23	1.23	1.26	1.28	1.29		**Cul Mean**
	Masr 3	1.10	1.27	1.14	1.23	1.22		**1.19**
Cul	***Sakh 95***	1.29	1.19	1.41	1.44	1.27		**1.32**
	Giza 171	1.29	1.22	1.22	1.16	1.39		**1.26**
LSD 0.05	*IrrR:*	*0.110*		*Cul*		*0.070*	*FerS*	*ns*
	IrrR X Cul	*0.800*		*Cul X FerS*		*0.110*		
	IrrR X FerS	*ns*		*IrrR X Cul X FerS*		*0.190*		

There is growing interest in how Si affects plant concentrations of carbon, N and P**.** Although the N concentration in wetland plants shown negative correlations with the concentration of Si (Schaller *et al.*, 2016), the application of Si improves N concentration in non-leguminous plants exposed to N-deficient grasslands**.**

Soil fertility characteristics:

Maintaining soil fertility and appropriate fertilization are essential for achieving food security and sustaining crop productivity growth. Soil fertility declining and unbalanced fertilization is one of the bottlenecks to sustainable agricultural production. Data in Table (14).

Soil Organic Matter (g kg^{-1}):

Data in Table (14) cleared that the *IrrR* have insignificant effect on soil organic matter, Masr 3 *Cul* resulted in the highest mean value of soil organic matter (2.23 g kg^{-1}). The different fertilizer amendments showed compost application has the highest mean values (2.53 g kg^{-1}) for SOM. Also, there were significant effect on all interaction treatment on SOM. The interaction between *IrrR* and wheat *Cul*, resulted in the highest mean values obtained by I_2 with Giza 171, Masr 3, respectively. Moreover, the two *IrrR* with compost amendment gave the highest SOM value (2.92 g kg^{-1}), even though, Masr 3 with compost has the highest mean value (2.86 g kg^{-1}). The interaction among *IrrR*, wheat Cul and different soil fertilizer on SOM (Fig. 12) cleared that the highest mean value (3.74 g kg^{-1}) was due to the interaction among I_2 *IrrR*, Giza 171 cultivar and compost fertilizer.

Table 14. Some soil fertility parameter as affected by irrigation regimes, wheat cultivars, types of fertilizer and their interactions

		SOM	Min.N	Av. P	Exch. K
		g kg^{-1}	*mg kg^{-1}*		
IrrR.	I_1	**2.06**	**98.20**	10.39	245.06
	I_2	**2.21**	90.07	10.72	263.32
	I_3	**2.13**	**84.59**	12.44	271.20
LSD 0.05 IrrR		***ns***	***1.58***	***0.75***	***5.79***
FerS	Cont.	**1.88**	82.55	10.39	253.35
	Comp.	**2.53**	93.31	13.27	**276.63**
	HA	**2.15**	93.65	11.39	265.96
	FA	**2.01**	95.02	10.95	243.91
	Si	**2.09**	90.23	9.90	259.43
LSD 0.05		***0.12***	***4.08***	***1.14***	***7.79***
$IrrR_1$ X FerS	Cont.	1.93	86.11	8.84	237.46
	Comp.	2.39	96.22	12.14	270.00
	HA	1.89	102.06	9.98	263.44
	FA	2.08	107.78	10.77	255.39
	Si	2.03	98.81	10.20	271.33
$IrrR_2$ X FerS	Cont.	2.01	83.72	9.71	267.37
	Comp.	2.92	90.83	13.26	287.56
	HA	2.27	93.33	12.21	300.70
	FA	1.93	91.50	10.16	259.07
	Si	1.94	90.94	8.26	257.80
$IrrR_3$ X FerS	Cont.	1.71	77.81	12.64	255.22
	Comp.	2.29	92.89	14.43	272.33
	HA	2.31	85.56	11.98	233.73
	FA	2.03	85.78	11.91	217.57
	Si	2.29	80.94	11.22	249.14
LSD 0.05		***0.21***	***7.06***	***1.97***	***13.48***
IrrR X Cul X FerS		***0.37***	***12.24***	***3.42***	***23.25***

		SOM	Min.N	Av. P	Ex. K
		g kg^{-1}	*mg kg^{-1}*		
Cul	Masr 3	**2.23**	**90.35**	10.51	259.52
	Sakha 95	**2.13**	**86.74**	10.98	274.50
	Giza 171	**2.04**	**95.77**	12.05	245.60
LSD 0.05		***0.12***	***4.53***	***0.72***	***7.00***
I_1	Masr 3	**2.25**	90.67	9.60	241.18
	Sakha 95	**2.25**	100.29	10.96	267.93
	Giza 171	**1.70**	103.63	10.60	226.05
I_2	Masr 3	**2.34**	89.97	10.97	265.41
	Sakha 95	**1.95**	86.73	10.23	272.97
	Giza 171	**2.36**	93.50	10.96	251.57
I_3	Masr 3	**2.10**	90.42	10.97	271.98
	Sakha 95	**2.20**	73.20	11.75	282.44
	Giza 171	2.08	90.17	14.59	259.17
LSD 0.05		***0.16***	***5.47***	***1.53***	***ns***
Masr 3	Cont.	1.80	78.86	9.58	219.24
	Comp.	2.86	93.61	11.90	269.20
	HA	2.39	97.83	11.16	283.20
	FA	1.99	94.67	10.46	212.68
	Si	2.09	86.78	9.45	240.95
Sakha 95	Cont.	1.82	83.22	10.01	261.30
	Comp.	2.26	88.61	12.76	280.34
	HA	2.24	88.33	11.35	262.71
	FA	2.20	87.5	10.97	239.34
	Si	2.15	86.03	9.81	272.91
Giza 171	Cont.	2.04	85.56	11.59	279.53
	Comp.	2.47	97.72	15.16	280.36
	HA	1.83	94.78	11.66	251.96
	FA	1.84	102.89	11.41	279.72
	Si	2.03	97.89	10.42	264.42
LSD 0.05 Cul X FerS		***0.21***	***7.06***	***1.97***	***13.48***

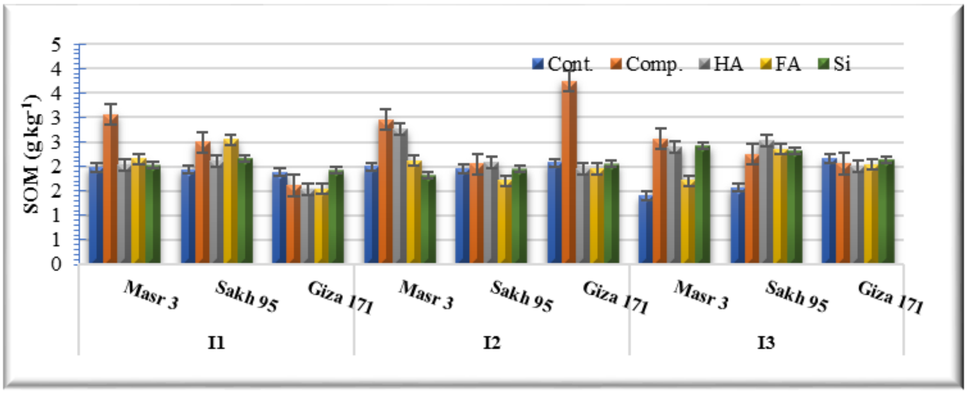


Fig. 12. The interaction among the irrigation regimes, wheat cultivars and types of fertilizer on soil organic matter, g kg^{-1}

Soil Mineral Nitrogen (mg Kg^{-1}):

Irrigation regimes showed significant effect on S Min. N, and cleared that I_1 has the highest mean value, and the lowest value by I_3. Giza 171 *Cul* resulted in the highest mean value (95.77 mg kg^{-1}). Fulvic fertilizer has the highest value (95.02 mg kg^{-1}). The interaction between I_1 and Giza 171 has the highest Min. N. The interaction between I_1 and Fulvic acid foliar application has the highest mean soil Min. N value by 25.16 % over control. The interact between Giza 171 and FA resulted in highest soil N value. The combined treatment I_1, Giza 171 with FA resulted in relative increment 39.54 % compared by control (Fig. 13).

Soil Available Phosphorus (mg Kg^{-1}):

There was significant effect on soil available P due to various treatment and their interaction (Table 14 and Fig. 14). The full *IrrR* has the highest value of available P, however, the first *IrrR* treatment gave the lowest mean value (10.39 mg kg^{-1}), Giza 171 *Cul* has the highest value among the different tested cultivars. Though highest mean value in (13.27 mg kg^{-1}) given by compost fertilizer. The highest Av P obtained by the interaction between full *IrrR* and Giza 171 and between I_3 and compost fertilizer (14.59, 14.43 mg kg^{-1}) respectively. The highest Av-P has been detected by the interaction between Giza171 *Cul* and compost. The highest mean value obtained by the combination between full *IrrR* on Giza171 and compost fertilization (17.82 mg kg^{-1}).

Soil Exchangeable Potassium (mg Kg^{-1}):

The highest soil exchangeable K was due to full *IrrR* (271.20 mg kg^{-1}), nevertheless, Sakha 95 led to the highest available K mean value (274.50 mg kg^{-1}). The different fertilizer treatments showed compost application has the highest mean values (276.60 mg kg^{-1}) for ex. K (Table 14). The highest mean value of ex. K (296.20 mg kg^{-1}) as result of interaction between one *IrrR* treatment and compost. Ex. K (300.70 mg kg^{-1}) highest mean value by Sakha 53 and potassium humate. However, ex. K. obtained by one *IrrR* treatment on Sakha 53 and foliar application of potassium humate has the highest mean value (355.22 mg kg^{-1}), with raising by 195.12, 100 mg kg^{-1} of the soil before planting and control, respectively (Fig. 15).

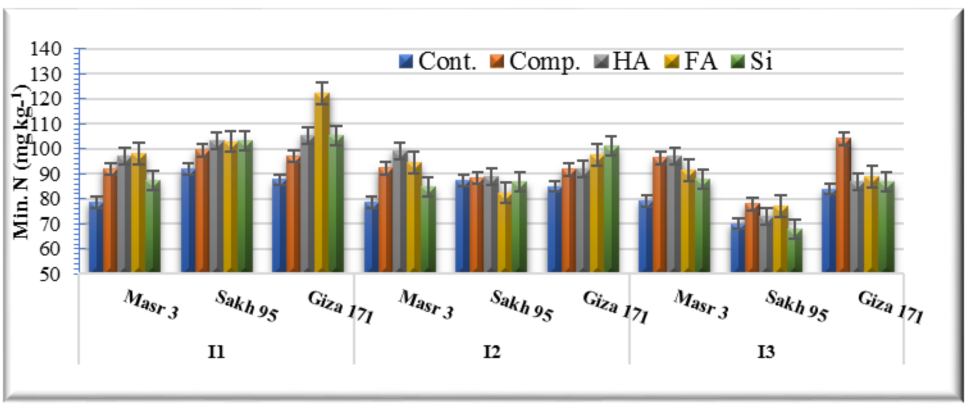


Fig. 13. The interaction among the irrigation regimes, wheat cultivars and types of fertilizer on soil mineral N, mg kg^{-1}

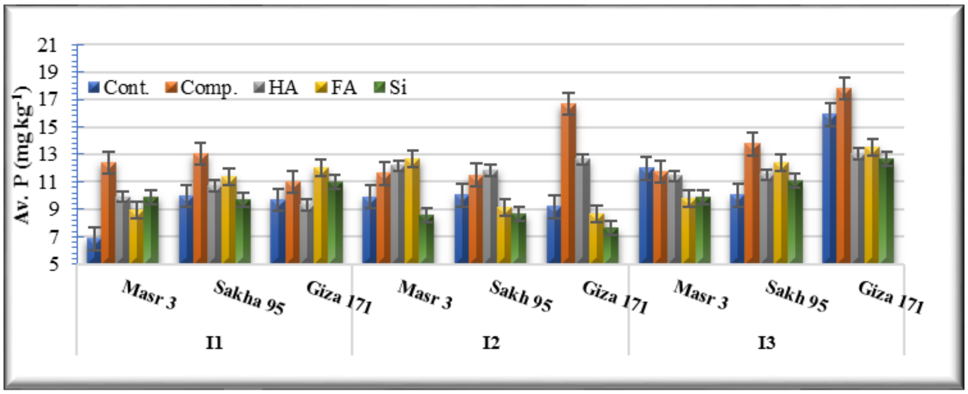


Fig. 14. The interaction among the irrigation regimes, wheat cultivars and types of fertilizer on Soil Av-P, mg kg^{-1}

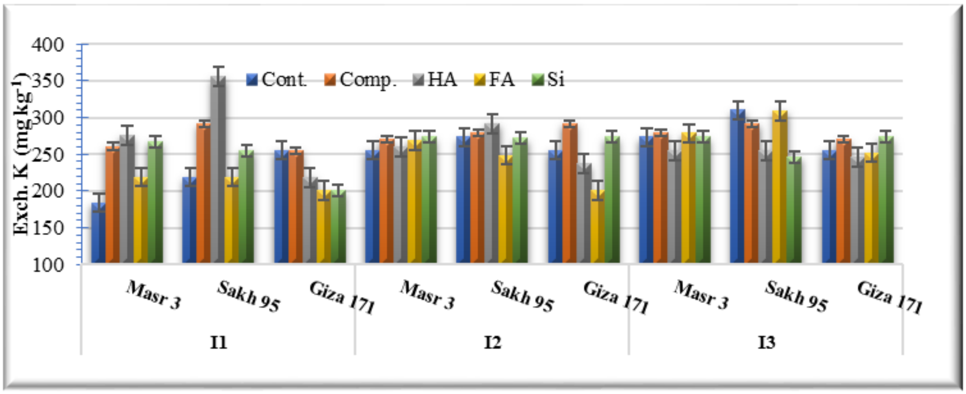


Fig. 15. The interaction among the irrigation regimes, wheat cultivars and types of fertilizer on soil Exch. K, mg kg^{-1}

Reduced irrigation decreases soil exchangeable K and mineral N, which may limit nutrient availability and uptake.

The impact of climate change on crop production can be significantly influenced by soil properties, such as soil water storage capacity, and long-term changes in soil fertility (Sirotenko *et al.*, 1997).

Research has shown that the long-term use of compost can enhance soil nutrition and sustainability. Compost is created when organic materials are decomposed by microorganisms in warm, humid, and aerobic conditions (Ayilara *et al.*, 2020). Therefore, maintaining and restoring healthy soils through sustainable management practices is essential. Healthy soils not only support food production but also promote biodiversity, carbon sequestration, and ecosystem services that are vital for agricultural sustainability and climate resilience (FAO, 2016).

To combat soil degradation and adapt to the impacts of climate change, evidence-based policies and coordinated global action are necessary to secure future food supplies (FAO, 2016). Composting increases soil organic matter (SOM) by introducing carbon-rich materials and promoting microbial activity (Diacono & Montemurro, 2011 and Abdelhameid *et al.*, 2025). Additionally, using farmyard manure in conjunction with mineral fertilizers is a more cost-effective approach than applying only nitrogen and phosphorus fertilizers, helping to maintain agricultural productivity (Bayu, 2020).

Research has shown that adding compost to soil can lower pH levels and reduce phosphorus fixation, while also increasing the organic matter content and the availability of phosphorus. These improvements are linked to higher wheat grain production (El-Ngar *et al.*, 2022). Additionally, the combined use of farmyard manure and nitrogen-phosphorus (NP) fertilizers promotes agricultural sustainability (Bayu, 2020).

In soil, potassium and phosphorus tend to be more stable compared to nitrogen. Drought conditions can reduce agricultural output; however, any fertilizer that is not utilized by crops may remain available for the next growing season. This means that after a drought, you might need to adjust your fertilizer management because soil levels of these nutrients may already be higher, requiring less added fertilizer.

To avoid overfertilizing, an action detrimental to both the environment and the economy it is essential to conduct a soil test to determine nutrient levels (Edward and Moore, 2015).

Adding organic acids to the soil leads to the formation of natural chelates, which help in the release of various elements from soil minerals and their chelation in the rhizosphere. The more organic acids that are added, the greater the release of minerals. Since organic acids are carbon compounds that contribute to the formation of plant tissues, they enhance the chemical, physical, and biological properties of the soil while also promoting plant growth. Studies have shown that soil availability of nitrogen, phosphorus, and potassium (NPK) significantly increases with the application of organic amendments compared to untreated control (El-Ghamry *et al.,* 2005 and Niel, 2021). In contrast, Ahmed and Ali (2005) found that organic fertilizers significantly increased the available phosphorus in the soil compared to the control group. Organic amendments play a crucial role in the soil ecosystem as they provide substrates for decomposing microbes, enhance soil structure, and improve water-holding capacity (Abiven *et al.,* 2009).

Silicon (Si) can influence microbial activity and nutrient cycling, which alters the breakdown of organic matter and consequently affects soil fertility and plant growth. Notably, the application of Si has been shown to increase nitrogen (N) concentration in non-leguminous plants growing in nitrogen-deficient grasslands (Hao *et al.,* 2020). Due to its considerable role in enhancing soil nutrient availability and promoting plant carbon accumulation, Si may significantly impact the biogeochemical cycles of carbon, nitrogen, and phosphorus (P) in terrestrial ecosystems (Hao *et al.,* 2020).

Furthermore, a connection between Si and P uptake, concluding that soil influences these interactions, a positive correlation between P and Si concentrations in wheat (Kostic *et al.,* 2017). This relationship might be linked to how Si absorption interacts with P metabolism in plants (Kostic *et al.,* 2017). Kostic *et al.* (2017) demonstrated that applying Si could enhance the expression of P transporter genes or increase rhizospheric organic acids, thus improving P bioavailability in soils with low phosphorus levels.

Additionally, compost enhances soil fertility by increasing organic carbon, nitrogen, and available phosphorus, while also boosting the availability of micronutrients like iron and zinc (Wang *et al.,* 2016).

CONCLUSION

Drought stress significantly reduces the growth and yield components of wheat. Drought-tolerant genotypes often demonstrate better osmotic adjustment through solute accumulation, increased cell wall rigidity, and efficient stomatal regulation. These adaptations help maintain leaf water status and protect cellular functions. Full irrigation (*IrrR*), when paired with high-performing cultivars (such as Sakha 53 and Giza 171) and the use of potassium silicate or compost fertilization, resulted in significantly increased wheat yields. This combination achieved grain yields of up to 4.70 Mg per fed, protein yields of 55.45 Mg per fed, and a harvest index of 22.77%. Among the cultivars, Sakha 53 excelled in both grain yield and protein content, while Masr 3 achieved the highest biological yield. The use of compost enhanced the weight of 1,000 seeds, and foliar application of potassium silicate optimized overall productivity. Also, full or intermediate irrigation combined with organic amendments (compost, fulvic acid) or silicate fertilizer, and optimal cultivar (Sakha 95 and Giza 171) improve nutrient uptake in wheat seed, strow nutrient content, biological N uptake, and maintain or enhance soil fertility parameters. Soil organic matter was not significantly affected by irrigation but was increased by compost application. Soil mineral nitrogen declined with reduced irrigation, whereas fulvic acid and compost amendments improved soil N and available phosphorus. Exchangeable potassium was highest under full irrigation and compost or potassium humate additions, particularly in Sakha 95 cultivar. These results highlight that optimal irrigation, careful cultivar selection, and targeted fertilization are crucial to sustain wheat productivity and soil fertility and for maximizing wheat yield and quality, especially under variable water conditions. These insights illustrate how targeted strategies can support Egypt in maintaining its progress in wheat production. Further research should investigate the long-term effects and economic feasibility of these practices.

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الملخص العربي

تأثير المُحسّنات العضوية وسليكات البوتاسيوم على محصول وإنتاجية أصناف القمح (*Triticum aestivum* L.) تحت إجهاد الجفاف وانعكاساتها على خصوبة الارض

انجه مصطفى عبد الهادي نايل، حمد علي زين العابدين ، شيماء محمد عبد العزيز ، عبد العزيز إبراهيم عبد الصادق يحيي

بسبب مناخ مصر الجاف وموارد المياه المحدودة بها فإن إدارة المياه أمر حيوي يؤثر بشكل كبير على نمو القمح ويقلل من إنتاج الحبوب. لدراسة تأثير استخدام المُحسّنات العضوية (أحماض الهيوميك والفولفيك والكمبوست) وسيليكات البوتاسيوم في الحد من إجهاد الجفاف وتعزيز نمو وإنتاجية القمح تم اجراء تجربة حقلية بنظام القطاعات العشوائية الكاملة بتصميم القطع المنشقة لمرتين خلال موسمي ٢٠٢١–٢٠٢٢ و ٢٠٢٢–٢٠٢٣. وأظهرت النتائج أن نظام الري الكامل حسّن بشكل ملحوظ معايير النمو، والمحصول ومكوناته، وخاصة وزن الألف حبة وإنتاجية الحبوب والمحصول البيولوجي. ومن بين الأصناف، أظهر صنف "سخا ٩٥" الأفضل في معظم مقاييس النمو ما عدا طول السنبلة وأعلى إنتاجية للحبوب. بينما أظهر صنف "جيزة ١٧١" كان أعلى تحمّلاً للإجهاد المائي، حيث تفوق في وزن الألف حبة وأظهر إنتاجية تنافسية للحبوب تحت أقصى عجز مائي. أثبت حمض الفولفيك أنه الأكثر فعالية كسماد حيث حقق أعلى عدد سنابل وأفضل نمو شامل. كما كان لسماد سيليكات البوتاسيوم تأثير إيجابي كبير على إنتاجية كل من الحبوب والبروتين. كما أدي الري الكامل مع أصناف القمح المختلفة والأسمدة إلى تحسين معايير الإنتاج بشكل ملحوظ. بالإضافة إلى ذلك كان لسماد سيليكات البوتاسيوم تأثير قوي على إنتاجية الحبوب. وتم تحديد الكومبوست كأفضل مُحسّن لخصوبة التربة حيث يعزز الكربون العضوي وكلها عوامل حيوية للزراعة المستدامة. ومما سبق ولمواجهة تغير المناخ وزيادة وحماية إنتاج القمح فأن أفضل الممارسات الزراعية تشمل تبني نظم الري الكامل بما يتناسب مع مدى توفر المياه واختيار أصناف القمح عالية الإنتاج ومقاومة للجفاف مثل "جيزة ١٧١" و"سخا ٩٥" مع استخدام استراتيجيات تسميد تشتمل على المحسنات العضوية والمنشطات البيولوجية " سيليكات البوتاسيوم وهيوميات وفلفات البوتاسيوم". وتعزز هذه الممارسات المتكاملة لإدارة خصوبة التربة والمياه نمو النبات والإنتاج وجودة الحبوب وصحة الأرض، مما يحسن من تحمل الإجهاد الناتج عن الجفاف ويحافظ على إنتاجية القمح في ظل تغير الظروف المناخية.

الكلمات المفتاحية: التغير المناخي، الإجهاد اللاحيوي، الإجهاد الناتج عن الجفاف، أصناف القمح، سيليكات البوتاسيوم، الأسمدة العضوية، الهيوميك، حمض الفولفيك.