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Magnetic Seeds, Potassium Sources and Irrigation Levels Effects on Wheat Grown in Sandy Soils

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AT ALI Mubarak Station, El-Bustan region, El-Behira Governorate, Egypt, a field experiment was conducted to evaluate the impact of four irrigation levels i.e. 60, 80, 100, and 120% ETo (reference crop evapotranspiration) and alleviating water stress treatments i.e. none magnetic wheat grains (NMG), NMG + potassium silicate (KS) foliar spray, 150 mg L^{-1}, NMG + potassium humate (KH) foliar spray, 1000 mg kg^{-1}, magnetic wheat grains (MG), MG + KS and MG + KH on wheat growth and grain yield grown in sandy soil. There were significant ($P<0.05$) effects of the experimental treatments on growth, grain yield and its attributes. Increasing water availability had a positive effect on improving growth of wheat plants and reflected on wheat grain yield and its attributes. Sowing with magnetic grains (MG) treatment produced higher values of wheat grain yield and its attributes compared with non-MG treatments. The foliar application of potassium humate or potassium silicate had a significant ($P<0.05$) positive effect on wheat grain yield as well as grain yield attributes compared to the control treatment. However, no significant differences on grain yield/ha between 120% ETo +MG + KH or KS treatments and 100% ETo + MG + KH or KS treatments in both research seasons were found. The wheat plants received 120% ETo + MG + KH or KS gave the greatest wheat grain yields (6.83 and 6.73 t/ha, respectively) and water productivity (1.4 and 1.25 kg grains/m^3, respectively). It could be concluded that irrigation level with 100% ETo + MG + KH or KS can save about 900 m^3/ha of applied irrigation water (about 20% of AIW) without having a major impact on wheat grain yield.

Keywords: Wheat, Growth, Yield, Water scarcity, Iirrigation, Magnetic field, Potassium, Silicate, Humate, Water productivity.

1. Introduction

Egypt is one of the leading importers of vegetable oils, grains, and animal proteins due to its limited fertile land and water resources. Egypt is the world's leading importer of wheat (*Triticum aestivum* L.), family Poaceae (FAO, 2021). In order to reduce land degradation, and save scarce resources, advances toward increasing agricultural productivity and self-sufficiency, must be implemented immediately. Wheat is the most significant cereal crops in Egypt (Emran, 2024). It is cultivated in about 1,436,734 hectares (77.61%) in the old lands, while in the new lands, the total area reaches about 321,741.18 hectares (22.39%) producing about 9, 842,272 tons of wheat grains. Wheat productivity could reach 6.85 ton/hectare (Economic Affairs Sector Ministry of Agriculture and Land Reclamation, 2021), reflecting a growth rate of 1.12% compared to previous years (FAO, 2022). Wheat is a main source of energy due to its high contents of carbohydrate and protein (Ebeed *et al.*, 2023).

On a global scale, the agricultural sector stands as the primary consumer of irrigation, utilizing over 70% of the world's freshwater resources (Ouda, 2016). Reducing the number of applied irrigations has been studied by several authors. Reducing the number of irrigations from seven to two per season resulted in a decline in wheat grain yield/ha from 5.88 to 3.73 tons (Abdelghany *et al*., 2016). Water stress reduced days to maturity in wheat, wheat stem height, spikes/m^2, kernels number /spike, 1000-kernel weight and biological yield values (El-Sayed *et al*., 2018). Furthermore, irrigation reduction causes significant decrease in morphological and physiological traits, grain yield, yield components, harvest index (Gab Alla *et al*., 2019). Application of water stress levels amount to 75% and 50% crop evapotranspiration resulted in reduction in grain yield of wheat by 11% and 26%, respectively (Ouda *et al*.,2021).

Generally, spikes m^{-2}, kernels spike^{-1}, weight of 1000 kernels, stem height and grain production were reduced with reducing number of irrigations. Water stress retards photosynthesis and translocation of photosynthates and

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shortens days to maturity (Abd El-Rady and Koubisy, 2023). Agricultural lands in arid and semi-arid regions are affected by drought stress that limits crop performance and development. For improving production in drought areas, selection wheat cultivars that use available water more efficiently and can withstand drought stress is desirable (Wang *et al*., 2023 and Abd El-Aty *et al*., 2024). Increasing irrigation rates resulted in a considerable increase in grain, straw and biological yields (Emran *et al.*, 2024).

The magnetic grains (MG) filed was investigated by many biologists and biophysics. Magnetic wheat grains using 50 Hz, 60 mT and an exposure time of 8s for 3 successive days increased root length, radicle length and protein % up to 10, 14 and 8%, respectively (Pietruszewski and Kania, 2010). Also, it was found that wheat roots grew quickly with MG field at 50 Hz, 30 mT (Hussein *et al*., 2012). Moreover, the magneto-primed plants yielded more quantity and number of seeds per plant compared to the untreated seeds (Gajendra and Anjali, 2016 and Rathod, *et al.*, 2016).

Potassium (K) is a crucial macronutrient that affects physiological and biochemical functions of plants by controlling photosynthate transport, turgor pressure, and hydration status (Hasanuzzaman *et al*., 2018). Potassium helps to keep ion homeostasis and osmotic equilibrium when there is an abiotic stress, moreover, K is essential for opening the stomata during drought stress, allowing plants to adjust water supplies (Francini *et al*., 2022).

Potassium humate increased nutrient uptake and plant biomass (Canellas *et al*., 2015). Improving wheat yield and its components under sodicity condition by application of potassium silicate may be attributed to increasing water contents in wheat and photosynthetic efficiency (Osman *et al*., 2017). The greatest increases in 1000 grain weight, harvest index, biological yield fed^{-1} (one feddan equal to 4200 m^2) were achieved by adding 6% potassium humate compared to 0% potassium humate (Othman *et al.,* 2000). Maize (*Zea mays*) production and nutrient contents significantly improved with potassium humate application (Abou Basha *et al., 2021*). Increasing rate of potassium silicate as a source of high soluble K and Si, resulted in increasing wheat stem height, number of grain spike^{-1}, seed index and grain yield where potassium has a vital role in cell division and maintenance of the water situation within plant tissues (Ghazi *et al*., 2021). Adding foliar K-silicate three times at 40, 60 and 80 days age achieved the highest values of grain yield and its components as well as water use efficiency (Gomaa *et al.,* 2021).

The most effective combinations for raising water use efficiency (WUE) is to include potassium silicate as a management practice (Saudy *et al*., 2023). Recently, silicon has generated a lot of interest in the agricultural industry because of its advantageous qualities which interacts with other essential and advantageous components, controls transcription, and improves the bioavailability of nutrients (Weisany and Razmi, 2023).

This field experiment was conducted to assess the effects of MG field and potassium foliar spray either silicate or humate form on alleviating the negative effect of water stress on growth, yield and its characteristics as well as water productivity of wheat grown in sandy soil.

2. Materials and Methods

2.1. Experimental site description

Experimental site was at Ali Mubarak Agric. Res. Sta. (30^o 39' N, 30^o 24' E, and elevation 20 m), El-Bustan region, El-Behira Governorate, Egypt. This experimental site represents the newly reclaimed sandy soil of West Nile Delta region. The location of this site is illustrated in Fig.1. The preceding crop was the peanut (*Aracchis hypogaea*) in both seasons. The reference ETo was determined using average monthly weather data throughout the experimental period from 2015 to 2019 and the results are shown in Table 1. The Basic Irrigation Scheduling model (BISm) (Snyder *et al*., 2004) was utilized to determine the monthly reference ETo values at the experimental site using the data in Table 1.

Four samples from soil surface at the depth of 15 cm were taken to estimate physical and chemical properties of the experimental soil as well as soil-moisture constants. Chemical and physical soil parameters were determined according to Tan (1996). The values of N, P, and K were 16.70, 5.50, and 65.10 mg kg^{-1}, respectively (Table 2). The soil was characterized by being low in fertility for wheat plant growth. Irrigation source was groundwater taken from a well. The chemical analysis of irrigation water is given in Table 2. Foliar applications of potassium either in silicate or humate form were done twice at 40 and 60 days from sowing date in both seasons. The chemical composition of potassium silicate and potassium humate is tabulated in Table 3.

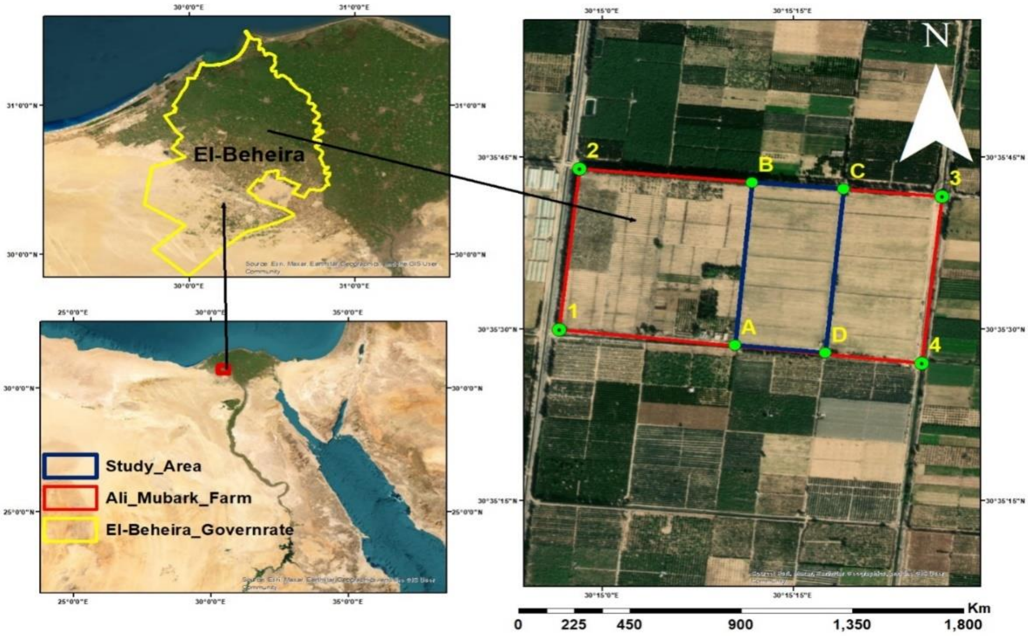

Fig. 1. Location of the study area.

Table 1. Monthly weather and evapotranspiration data at the experimental site during the wheat growing months.

Month	Solar radiation (MJ $(m^{-2}\ day^{-1})$	Maximum air temp. (^{o}C)	Minimum air temp. (^{o}C)	Wind speed $(m\ s^{-1})$	Dew point temp (^{o}C)	ETo $(mm\ day^{-1})$
November	10.20	18.50	4.50	2.10	2.40	1.98
December	10.80	18.60	3.80	2.50	3.20	2.20
January	11.50	17.70	4.20	2.00	4.450	1.80
February	12.70	18.25	4.40	2.50	4.30	2.60
March	15.40	20.00	7.60	2.90	6.90	3.20
April	19.50	24.40	11.00	2.80	6.80	4.70

ETo: reference evapotranspiration

Table 2. Soil and irrigation water analysis at the experimental site.

Soil analysis					**Irrigation water analysis**	
Soil properties	**Soil depth (cm)**					
	0-15	**15-30**	**30-45**	**45-60**	**Parameter**	**Value**
Particle size distribution					**pH**	7.91
Sand, %	91.25	90.50	90.25	90.15	**EC, dS/m**	0.46
Silt, %	3.75	3.80	3.85	3.90	**Soluble cations, mmol L^{-1}**	
Clay, %	5.00	5.70	5.90	5.95	**Ca^{2+}**	3.02
Textural class	Sandy	Sandy	Sandy	Sandy	**Mg^{2+}**	0.69
Bulk density, Mg m^{-3}	1.64	1.76	1.74	1.70	**Na^{+}**	0.67
Field capacity, % (w/w)	12.70	11.15	6.90	7.85	**K^{+}**	0.17
Permanent wilting point, % (w/w)	3.65	2.90	2.15	2.10	**Soluble anions, mmol L^{-1}**	
Available water, %	9.05	8.25	4.75	5.75	**CO_3^{2-}**	nd*
pH (1:2.5)	7.61	7.58	7.56	7.40	**HCO_3^{-}**	2.74
EC, soil past extract, dS m^{-1}	0.56	0.54	0.50	0.48	**Cl^{-}**	1.55
Soluble cations, mmol L^{-1}					**SO_4^{2-}**	0.26
Ca^{2+}	1.00	1.50	1.53	1.47		
Mg^{2+}	0.50	1.00	1.33	1.28		
Na^{+}	2.10	2.15	1.85	1.78		
K^{+}	0.18	0.12	0.11	0.10		
Soluble anions, mmol L^{-1}						
CO_3^{2-}	nd*	nd	nd	nd		
HCO_3^{-}	0.50	0.50	1.54	1.54		
Cl^{-}	2.25	2.50	2.90	2.79		
SO_4^{2-}	1.03	1.77	0.38	0.30		

***Not detected.**

Table 3. Chemical analysis of potassium silicate and potassium humate.

Parameter	Potassium silicate	Potassium humate
pH	8.02	9.00
SiO_2	23.33 %	-
K_2O	11.25 %	10.2 %

2.2. Experimental design and treatments

The field experiment was laid out in a split-plot design, with three replicates. The main plots were devoted to four irrigation levels. The tested irrigation levels were: 1. 120% ETo (5458 and 5330 m^3 ha^{-1}) in the 1st and 2nd seasons, respectively. 2. 100% ETo (4548 and 4440 m^3 ha^{-1}) in the 1st and 2nd seasons, respectively. 3. 80% ETo (3638 and 3525 m^3 ha^{-1}) in the 1st and 2nd seasons, respectively. 4. 60% ETo (2729 and 2666 m^3 $ha^{-1)}$ in the 1st and 2nd seasons, respectively. Alleviating water stress treatments were none magnetic wheat grains (NMG), NMG + foliar 150 mg L^{-1} potassium silicate (KS), NMG + foliar 1000 mg kg^{-1}potassium humate (KH), wheat magnetic grains (MG), MG + KS and MG + KH were randomly distributed in the sub-plots.

2.3. Cultural practices

Wheat Misr 3 cultivar was cultivated on the 13th and 24th of November in 2021 and 2022 winter seasons, respectively. At full maturity stage, wheat plants were harvested on the 19th and 30th of April in 2022 and 2023, respectively. Pre-sowing, half wheat grains were exposed to magnetic (MG) field (50 mT/ for 30 min). Wheat seeds (143 kg seeds/ha) were drilled in rows spaced 20 cm. The plants were irrigated using a solid-set sprinkler irrigation system with rotary sprinklers that had a discharge rate of 0.96 to 1.34 m^3/hr. at 2.85 bars of nozzle pressure. The PVC lateral lines (63 mm diameter), sub main PVC pipes (110 mm diameter), and main PVC pipeline (160 mm diameter) make up the sprinkler system. Irrigation water treatments started from the 10th irrigation after sowing date. In 80 % of irrigation time using the differential pressure tank, fertilizers were added through irrigation water. Ammonium nitrate (33.5% N), potassium sulphate (48%K) and phosphoric acid (60%) fertilizers were used at 284 kg N/ha,120 kg K_2O/ha and125 kg P_2O_5/ha rates, respectively. The fertigation started at 25 days after sowing. Micronutrients (Fe, Zn and Mn) were also added as foliar spray at 238, 238 and 238 g/ha rates, respectively. Graney star Herbicide at 19 g/ha rate was injected for 20 minutes with the irrigation water at 20 days after sowing through the differential pressure tank as stated by Taha (2022).

2.4. Parameters of wheat growth and grain yield

At maturity, stem height of 10 random main stems in random square meter of each experimental unite was measured. Grains of spike from random 10 spikes taken from each plot were counted and weighed. Plants of this m^2 were harvested, tagged and labelled properly to record, number of tillers and spikes/m^2, dry weight of stems/m^2, 1000 grains weight (seed index) and grain yield/m^2.

2.5. Irrigation-water measurements and crop-water relations

2.5.1. Distribution uniformity (DU)

In the field, DU of the sprinkler system was measured. The DU values were calculated according to Merrim and Keller,1978 as follows: $\mathrm{DU} = \frac{\mathrm{Diq}}{D} \times 100$

Where:

Diq: depth of water collected by cans from sprinklers at the low quarter of the field (cm).

D: average depth of water collected by cans from all sprinklers (cm).

2.5.2. Applied irrigation water (AIW)

The depth of applied irrigation water was calculated according to Vermeiren and Jopling (1984) as follows:

$$AIW = \frac{ETo \times I}{Ea\,(1-LR)}$$

Where:

AIW: depth of applied irrigation water (mm).

ETo: reference evapotranspiration (mm d^{-1}). ETo values were calculated using BISm.

I: irrigation intervals (days).

Ea: irrigation application efficiency of the sprinkler irrigation system (Ea = 77% in first seasons and 80% in second season).

LR: leaching requirements (was not considered in this experiment due to its indirect effect on the amount of water applied for water stress treatments).

2.5.3. Water productivity (WP)

According to Zhang (2003), WP is computed as follows: WP (kg m^{-3}) = Wheat grain yield, kg ha^{-1} / applied irrigation water, m^3 ha^{-1}

2.6. Statistical analyses

According to Steel and Torrie (1980), the collected data were statistically analysed. Differences between treatment means were detected by least significant difference test (LSD) at 0.05 level of significance.

3. Results

3.1. Uniformity of water distribution (DU)

For distribution homogeneity, the tests were carried out at the start of 1st and 2nd season. Uniformity of water distribution (DU) values were 82 and 84% in 1st and 2nd season, respectively. A little increase in DU values in the 2nd season vs. 1st season. This increase may be to increase sprinkler irrigation system application efficiency in the second growing season compared to the first one.

3.2. Amounts of applied irrigation water (AIW)

The AIW values were 5458, 4548, 3638 and 2729 m^3/ha during the 2021/2022 season and were 5330, 4440, 3525 and 2666 m^3/ha during the 2022/2023 season for the 120, 100, 80 and 60% ETo levels, respectively. The better application efficiency value (Ea = 80%) of the sprinkler system in the 2nd season is the reason why less water was applied compared to the 1st season.

3.3. Irrigation levels Effect

3.3.1. Wheat stem height

Increasing the amounts of applied water significantly increased stem height in both seasons. In 2021/22 season, stem height value was 117.3, 111.6, 95.7 or 87.2 cm for 120, 100, 80 and 60% ETo levels, respectively. Regarding the 2022/23 season, stem height was 118.5, 113.0, 96.5 or 88.1 cm under 120, 100, 80 and 60% ETo levels, respectively. Moreover, stem height at the 120% ETo level tended to be superior by 25.7% compared with 60% ETo level (Table 4).

3.3.2. Number of tillers/m^2

Number of tillers/m^2 was significantly affected by irrigation levels in both seasons. There were more tillers ($P<0.05$) per square meter in the 2nd season due to a comparatively greater water distribution uniformity value compared to the 1st season. In 2021/22 season, the highest number (٣٥٦,٦) was recorded when plants were irrigated with 120% ETo. The lowest number (285.7) was obtained when plants received 60% ETo only. Regarding to the results of 2022/23 growing season, significant differences between irrigation levels were found in number of tillers/m^2. Average number of tillers/m^2 values were 358.6, 325.2, 301.9 and 289.8 for the 120, 100, 80 and 60% ETo levels, respectively (Table 4).

3.3.3. Number of wheat spikes/m^2

Spikes number /m^2 was significantly affected by irrigation levels in both seasons. There were more spikes/m^2 in the 2nd season than its value in the 1st season due to increasing distribution uniformity and the availability of more water to wheat plants. The highest spikes number /m^2 (353.2) was obtained from 120% ETo irrigation, while the lowest one (282.6) was recorded from irrigation by 60% ETo during the 1st season. The results of the 2022/23 growing season, showed significant differences in number of spikes/m^2 in response to irrigation levels. Number of spikes/m^2 gradually decreased (355.4, 321.9, 298.1 and 286.3) with increasing water stress levels (120, 100, 80 and 60% ETo), respectively (Table 4).

3.3.4. Weight of wheat grains/spike

Irrigation levels significantly affected grains/spike weight during 2021/22 and 2022/23 seasons (Table 4).

Grains weight /spike gradually decreased with increasing water stress levels. In the first season, the heaviest grains /spike (2.31g) was obtained with 120% ETo irrigation level. The weight of grains /spike tended to decrease gradually to reach its lowest value (1.72g) under the 60% ETo irrigation level. The same trend was observed in the 2nd season. Grains weight of /spike with 120, 100, 80 and 60% ETo watering levels were 2.45, 2.20, 2.07 and 1.85g, respectively. These findings also indicated that grains weight /spike was greater in the 2nd season than its value in the 1st season due to increased distribution uniformity throughout the 2nd growing season (Table 4).

3.3.5. Number of wheat grains/spike

Irrigation levels significantly affected number of grains/spike in both growing seasons (Table 4). Grains number/spike gradually decreased with increasing water stress levels. In 2021/22 season, grains number /spike average was 51.44, 47.89, 46.56 and 44.11 under 120, 100, 80 and 60% ETo irrigation levels, respectively.

Regarding to 2022/23 season, average of grains number /spike was 53.00, 49.33, 47.94, and 46.22 for the same respective irrigation levels. This trend reflects by increasing applying amounts of water equivalent to 120% ETo during the growth season led to increasing the available amount of water in the root zone. Furthermore, number of grains/spike was higher in the second growing season than those of the first season.

3.3.6. Seed index (1000 wheat grains weight)

Results in Table 4 showed that seed index significantly affected by irrigation levels in both seasons. Seed index gradually decreased with increasing water stress levels. In 2021/22 season, seed index values decreased by about 13.34% with 60% ETo irrigation rate as compared to that of 120% ETo treatment. In 2022/23 season, there were significant differences in seed index between irrigation levels. The seed index values decreased by about 13.0% for plants irrigated with 60% ETo treatment as compared with the 120% ETo treatment.

3.3.7. Wheat grain yield/ha

Wheat grain yields were significantly affected by irrigation levels in both seasons (Table 4). Increasing the amounts of applied water significantly increased grain yield/ ha. In the 1st season, grain yields were 6.51, 5.96, 4.83 and 3.96 t/ha, respectively. In the 2nd season, the yields were 6.68, 6.1٠, 4.97 and 4.17 t/ha for the 120, 100, 80, and 60% ETo irrigation levels, respectively.

3.3.8. Water productivity (WP)

As shown in table 4, WP values (1.19, 1.31, 1.33, and 1.45 in the 1st season) and (1.25, 1.37, 1.41, and 1.57 kg grain/m^3 in the 2nd season) gradually increased with increasing water stress levels (120, 100, 80, and 60% ETo levels), respectively.

Table 4. Some agronomic traits of wheat affected by irrigation levels in the 2021/22 and 2022/23 seasons.

Irrigation Levels	**Stem height (cm)**	**Tillers/ m^2 (no)**	**Spikes/m^2 (no)**	**Stem height (cm)**	**Tillers/m^2 (no)**	**Spikes/m^2 (no)**
		2021/22			**2022/23**	
120% ETo	117.3 a	356.6 a	353.2 a	118.5 a	358.6 a	355.4 a
100% ETo	111.6 b	322.2 b	318.5 b	113.0 b	325.2 b	321.9 b
80% ETo	95.7 c	298.1 c	294.5 c	96.5 c	301.9 c	298.1 c
60% ETo	87.2 d	285.7 d	282.6 d	88.1 d	289.8 d	286.3 d
F Test	**	**	**	**	**	**
Irrigation Levels	**Grains/ spike (g)**	**Grains/ spike (no)**	**1000 Grains (g)**	**Grains/ spike (g)**	**Grains/ spike (no)**	**1000 grains (g)**
		2021/22			**2022/23**	
120% ETo	2.31 a	51.44 a	44.81 a	2.45 a	53.00 a	46.05 a
100% ETo	2.07 b	47.89 b	43.04 b	2.20 b	49.33 b	44.54 ab
80% ETo	1.95 b	46.56 bc	41.87 b	2.07 b	47.94 b	43.02 b
60% ETo	1.72 c	44.11 c	38.82 c	1.85 c	46.22 c	39.81 c
F Test	**	**	**	**	**	**
Irrigation Levels	**Grain yields (t ha^{-1})**	**WP (kg m^{-3})**	**Grain yields (t ha^{-1})**	**WP (kg m^{-3})**		
	2021/22		**2022/23**			
120% ETo	6.51 a	1.19c	6.68 a	1.25c		
100% ETo	5.96 b	1.31b	6.10 b	1.37b		
80% ETo	4.83 c	1.33b	4.97 c	1.41b		
60% ETo	3.96 d	1.45a	4.17 d	1.56a		
F Test	**	**	**	**		

ETo: Reference evapotranspiration (mm d^{-1}), AIW: Applied irrigation water, WP: Water productivity.
Means within a column followed by a different letter (s) are statistically different at 5%.

3.4. Alleviating water stress treatments on:

3.4.1. Wheat stem height

Stem height was significantly affected by the studied alleviating water stress treatments in the two growing seasons of study (Table 5). Stems of magnetic grains (MG) field treatment was significantly taller than those of nonmagnetic grains (NMG). Stem height for the MG treatment was 1.73% taller than that for the NMG treatment. The MG + potassium humate (KH) treatment recorded the tallest stem height (105.8 and 106.9 cm) in the 1^{st} and 2^{nd} seasons, respectively followed by those of MG + potassium silicate (KS) treatment. The shortest stem (100.3 and 101.7 cm) was recorded for the NMG treatment in both respective seasons, respectively).

3.4.2. Number of wheat tillers/m^2

Results showed that alleviating the negative impact of water stress treatments had a significant effect on the tillers number /m^2(Table 5). Tillers number /m^2 was significantly affected by the MG field treatment in both seasons. Number of tiller/m^2 of the MG treatment was1.8 and 0.3% higher than those of NMG treatment. Applying potassium humate (KH) significantly produced more number of tillers/m^2 than application of potassium silicate (KS). Results revealed also that the highest number of tillers/m^2 of 324.5 and 328.1 were recorded for the MG + KH in the 1^{st} and 2^{nd} seasons, respectively (Table 5).

3.4.3. Number of wheat spikes/m^2

Alleviating water stress treatments had a significant effect on the number of spikes/m^2. Spikes number /m^2 for the MG was 2.0 and 1.3% higher than those of NMG field treatment. The results also showed also that, applying potassium humate (KH) significantly affected the number of spikes/m^2 more than the application of potassium silicate (KS). In the 1^{st} and 2^{nd} seasons, the MG + KH recorded the height numbers of spikes/m^2 (321.2 and 324.5), respectively (Table 5).

3.4.4. Wheat grains weight/spike

Results showed that there were significant effects of alleviating water stress treatments on grain weight/spike (Table 5). There was a significant difference between grain weight/spike of MG field treatment and nonmagnetic grains. Grain weight/spike for the MG treatment were 1.٩4 and 2.02 g, while for the NMG treatment were 1.7٠ and 1.78 g in the 1^{st} and 2^{nd} growing seasons, respectively. Applying potassium humate (KH) was superior to all other treatments in producing heavier grain/spike followed by the foliar application of potassium silicate (KS). The heaviest spike grain weight (2.28 and 2.53 g) were recorded from spraying potassium humate (KH) in both seasons, respectively.

3.4.5. Number of wheat grains/spike

Significant differences between grains number /spike under all studied alleviating water stress treatments were found (Table 5). The number of grains/spike of MG treatment was significantly more than those of NMG treatment. Plants MG treatment gave 46.82 and 47.92 grains/spike while number of grains/spike for NMG treatment were 43.90 and 44.40 in first and second season, respectively. Spraying plants of magnetic or nonmagnetic grains with potassium humate (KH) was superior in producing more grains grain/spike followed by potassium silicate (KS). The highest number of grains /spikes of 50 and 54 were achieved from MG + KH treatment in the 1^{st} and 2^{nd} seasons, respectively (Table 5).

3.4.6. Seed index (1000 wheat grains weight)

Alleviating water stress treatments had a significant effect on the seed index. Sowing by magnetic grains (MG) produced grains (41.25 and 42.17g) heavier than those of nonmagnetic grains (38.55 and 39.97g) treatment in first and second season, respectively). The spraying potassium humate (KH) produced heavier seed index than potassium silicate (KS) treatments in both seasons. The greatest 1000 grain weight (45.27and 46.66g) were achieved from MG + KH treatment in the 1^{st} and 2^{nd} seasons, respectively (Table 5).

3.4.7. Wheat grains yield/ha

Grain yields/ha produced from using magnetic seeds (MG) in sowing were higher than those of using nonmagnetic seeds (NMG). Grain yields obtained from the MG treatment were 6.3 and 7.7% higher than those of NMG treatment. Applying the potassium humate (KH) was superior in producing more grain yield /ha followed by potassium silicate (KS). Sowing magnetic grains field with spray potassium humate produced the highest grain yields/ha (5.90 and 6.18 t) in the 1^{st} and 2^{nd} seasons, respectively (Table 5).

3.4.8. Water productivity (WP)

As shown in Table 5, the alleviating water stress treatments significantly affected water productivity. Using magnetic seeds (MG) in sowing produced higher values of water productivity compared with those of using nonmagnetic seeds (NMG). Water productivity values of MG treatment were 8.2 and 7.8% higher than those of NMG treatment in the 1^{st} and 2^{nd} seasons, respectively. Applying the potassium humate (KH) was superior in producing more water productivity followed by potassium silicate (KS). Sowing magnetic grains field with spray potassium humate produced the highest water productivity (1.48 and 1.61 kg grain/m^3) in the 1^{st} and 2^{nd} seasons, respectively (Table 5).

Table 5. Effect of alleviating water stress (AWS) treatments on some agronomic traits of in 2021/22 and 2022/23 seasons.

AWS treatments	Stem height (cm)	Tillers/ m^2 (no)	Spikes/ m^2 (no)	Stem height (cm)	Tillers/ m^2 (no)	Spikes/ m^2 (no)
	2021/22 season			2022/23 season		
NMG	100.3 e	307.7 f	304.0 f	101.7 e	310.7 e	308.0 e
NMG + KS	101.9 d	314.2 d	310.8 d	102.8 de	317.5 c	313.7 c
NMG + KH	103.6 bc	319.7 b	316.3 b	104.4 bc	322.3 b	318.0 b
MG	102.3 cd	310.2 e	306.0 e	103.3 cd	313.8 d	309.8 d
MG +KS	103.8 b	317.3 c	313.9 c	105.1 b	320.8 b	316.8 b
MG + KH	105.8 a	324.5 a	321.2 a	106.9 a	328.1 a	324.5 a
F Test	**	**	**	**	**	**
AWS treatments	**Grains/ spike (g)**	**Grains/ spike (no)**	**1000 grains (g)**	**Grains/ spike (g)**	**Grains/ spike (no)**	**1000 grains (g)**
	2021/22 season			2022/23 season		
NMG	1.70 d	43.90 d	38.55 d	1.78 d	44.40 d	39.97 d
NMG + KS	1.92 c	46.315 c	41.10 c	2.04 c	47.87 c	42.42 c
NMG + KH	2.10 b	48.475 b	42.97 b	2.20 b	49.82 b	44.22 b
MG	1.94 c	46.82 c	41.25 c	2.02 c	47.92 c	42.17 c
MG + KS	2.09 b	48.30 b	43.28 b	2.24 b	50.15 b	44.54 b
MG + KH	2.28 a	50.37 a	45.27 a	2.53 a	54.15 a	46.66 a
F Test	**	**	**	**	**	**
AWS treatments	**Grains yield ($t\ ha^{-1}$)**	**WP ($kg\ m^{-3}$)**		**Grains yield ($t\ ha^{-1}$)**	**WP ($kg\ m^{-3}$)**	
	2021/22 season			2022/23 season		
NMG	4.89 d	1.22 d		5.01 d	1.28 d	
NMG + KS	5.04 cd	1.25 cd		5.23 cd	1.33 cd	
NMG + KH	5.28 bc	1.32 bc		5.39 c	1.37 bc	
MG	5.20 c	1.30 c		5.40 bc	1.38 bc	
MG + KS	5.53 b	1.37 b		5.63 b	1.44 b	
MG + KH	5.90 a	1.48 a		6.18 a	1.61 a	
F Test	**	**		**	**	

AIW: Applied irrigation water, NMG: not magnetic grains, KS: Potassium Silicate 150 mgL^{-1} , KH: Potassium Humate 1000 mg kg^{-1}, MG: Magnetic Grains, WP: Water productivity.
Means within a column followed by a different letter (s) are statistically different at 5%.

3.5. Effect of the interaction between irrigation levels and alleviating water stress treatments on:

3.5.1. Stem height, number of tillers /m^2 and number of spikes/m^2

Wheat stems height under 120% ETo + MG + KH treatment was 120 and 122 cm, in the 1st and 2nd seasons, respectively. Whereas, those under 120% ETo + MG + KS treatment in the 1st season alone (118 cm) were significantly the tallest. Number of tillers/m^2 for the 120% ETo + MG + KH treatment (362.7 and 365.6) in the 1st and 2nd seasons, respectively and 120% ETo + NMG + KH treatment (360.0) in the 1st season were significantly higher than all other treatments. Number of spikes/m^2 (359 and 362) for the 120% ETo + MG + KH treatment in both seasons, respectively and those of 120% ETo + NMG + KH treatment (357) in the 1st season only were significantly higher than all other treatments (Table 6). In general, under either 120, 100, 80 or 60% ETo irrigation levels results recommended that sowing magnetic grains with spraying potassium humate 1000 mg kg^{-1} to obtain the highest values of stem height, number of tillers /m2 and number of spikes/m^2.

3.5.2. Grains weight/spike, 1000 grains weight and number of wheat grains/spike

The interaction effect between irrigation and Alleviating water stress treatments significantly affected grain weight/spike, number of grains/spike, and seed index (Table 7). Results indicated that plots sown by magnetic grains and received 120 ETo irrigation level as well as potassium humate (120% ETo + MG + KH treatment) produced the highest grain weight/spike (2.58 and 2.77g) and 1000 grains weight (48.13 and 49.16 g) in the 1st and 2nd seasons, respectively compared with the other treatments.

For number of grains/spike, treatments which sown by magnetic or nonmagnetic grains, sprayed by potassium humate or silicate and irrigated with 120% ETo gave the greeted number of grains/spike without significant difference in the two respective seasons. In general, under either 120, 100, 80 or 60% ETo irrigation levels results recommended that sowing magnetic grains with spraying potassium humate 1000 mg kg^{-1} to obtain the highest values of wheat grains/spike, 1000 wheat grains and number of wheat grains/spike.

3.5.3. Grains yield/ha

As shown in Table 8, the greatest wheat grain yield/ ha was obtained from treatments that cultivated by magnetic grains and received 120 ETo irrigation level with spraying potassium. Treatments 120% ETo + MG + KH (6.76 and 6.9٠ t/ha) and 120% ETo + MG + KS (6.66 and 6.8٠ t/ha) in the 1st and 2nd seasons, respectively yielded the highest grain yield /ha with no significant differences. Moreover, weight of grains /ha of 100% ETo + MG + KH treatment (6.53 and 6.63 t/ha) or 100% ETo + MG + KS treatment (6.36 and 6.43 t/ha) in the 1st and 2nd seasons, respectively was statically equal to that of 120% ETo. It could be recommended that, applying the 100% ETo + MG + KH or KS can save about 900 m^3/ha of applied irrigation water (about 20% of AIW) without any significant effect on wheat grain yield. In general, under either 120, 100, 80 or 60% ETo irrigation levels results recommended that sowing magnetic grains with spraying potassium humate 1000 mg kg^{-1} to obtain the highest grain yield /ha.

3.5.4. Water productivity (kg m^{-3})

The interaction between water stress levels and alleviating water stress treatments revealed that under all irrigation levels, the MG + KH and MG + KS treatments had the highest water productivity (WP) values. The obtained WP values for the MG + KH treatment varied from 1.24 to 1.56 kg grain/m^3 in the 1st season and from 1.55 to 1.82 kg grain/m^3 in the 2nd season for the 120% and 60% ETo irrigation levels, respectively. In general, under either 120, 100, 80 or 60% ETo irrigation levels results recommended that sowing magnetic grains with spraying potassium humate 1000 mg kg^{-1} to obtain the highest values of Water productivity.

Table 6. Interaction effects between irrigation levels and alleviating water stress (AWS) treatments on wheat stem height and number of tillers or spikes /m^2 in 2021/22 and 2022/23.

Irrigation levels	AWS Treatments	Stem height (cm)	Tillers/ m^2 (no)	Spikes/ m^2 (no)	Stem height (cm)	Tillers/ m^2 (no)	Spikes/ m^2 (no)
		2021/22			2022/23		
120% ETo	**NMG**	115.3 cd	349.7 d	346.0 c	116.3 cde	351.6 c	349.3 d
	NMG + KS	116.0 bcd	356.3 c	354.0 b	117.0 bcd	359.0 b	354.6 c
	NMG + KH	117.3 bc	360.0 ab	357.0 ab	118.0 bc	361.0 b	358.0 b
	MG	117.0 bc	352.0d	347.3 c	119.0 b	354.3 c	351.0 d
	MG + KS	118.0 ab	358.3 bc	355.0 b	119.0 b	360.0 b	356.0 bc
	MG + KH	120.0 a	362.7 a	359.3 a	121.7 a	365.6 a	362.0 a
100% ETo	**NMG**	108.0 g	312.3 h	309.0 gh	110.0 g	315.0 gh	311.6 hi
	NMG + KS	111.0 f	321.7 g	317.0 f	112.3 fg	325.0 f	322.0 g
	NMG + KH	113.7 de	327.7 f	324.0 de	114.7 def	331.0 e	327.0 ef
	MG	110.7 f	315.0 h	310.0 g	111.0 g	317.6 g	314.0 h
	MG + KS	112.0 ef	325.7 f	322.6 e	114.3 ef	328.0 ef	325.0 fg
	MG + KH	114.3 de	331.0 e	327.3 d	115.7 cde	334.6 d	330.0 e
80% ETo	**NMG**	93.7 jk	290.3 l	386.0 lm	94.7 ij	294.0 k	291.0 mn
	NMG + KS	95.3 hij	295.3 k	292.0 jk	96.0 hi	298.0 j	294.0 l
	NMG + KH	96.7 hi	301.3 j	298.0 i	97.3 h	305.0 i	298.0 jk
	MG	95.0 ij	293.7 k	289.6 kl	96.0 hi	297.3 j	293.0 lm
	MG + KS	96.0 hij	299.0 j	295.0 ij	97.0 hi	304.0 i	300.0 j
	MG + KH	97.7 h	308.7 i	305.0 h	98.0 h	313.0 h	310.0 i
60% ETo	**NMG**	84.3 n	278.3 n	274.6 p	85.7 m	282.0 n	280.0 q
	NMG + KS	85.3 n	283.7 m	280.0 no	86.0 m	288.0 lm	284.0 op
	NMG + KH	86.7 mn	289.7 l	286.0 lm	87.7 lm	292.0 k	289.0 n
	MG	86.3 mn	280.3 n	277.0 op	87.0 m	286.0 m	281.0 pq
	MG + KS	89.0 lm	286.3 m	283.0 mn	90.0 kl	291.0 kl	286.0 o
	MG + KH	91.3 kl	295.7 k	293.0 j	92.3 jk	299.3 j	296.0 kl
F Test		*	*	**	**	*	**

ETo: reference evapotranspiration (mm d^{-1}), NMG: not magnetic grains, KS: potassium silicate 150 mgL^{-1}, KH: potassium humate 1000 mg kg^{-1}, MG: magnetic grains.
Means within a column followed by a different letter (s) are statistically different at 5%.

Table 7. Interaction effects between irrigation levels and alleviating water stress (AWS) treatments on grains weight/spike, number of grains/spike and 1000 grain weight of wheat in 2021/22 and 2022/23 winter seasons.

Irrigation levels	AWS Treatments	Grains/ spike (g)	Grains/ spike (no)	1000 grains (g)	Grains/ spike (g)	Grains/ spike (no)	1000 grains (g)
			2021/22			**2022/23**	
120% ETo	**NMG**	2.02 f-i	48.30 bcd	41.70 ghi	1.993 hi	46.60 g-j	42.70 g-j
	NMG + KS	2.26 bcd	51.66 ab	43.60 ef	2.41 b-e	53.30 abc	45.20 c-g
	NMG + KH	2.39 bc	52.30 a	45.00 bcd	2.56 b	54.30 ab	47.20 abc
	MG	2.23 b-e	51.00 abc	43.80 ef	2.36 cde	53.00 bcd	44.60 d-h
	MG + KS	2.36 bc	51.60 ab	45.60 bcd	2.57 b	54.00 abc	47.30 abc
	MG + KH	2.58 a	53.60 a	48.13 a	2.77 a	56.00 a	49.16 a
100% ETo	**NMG**	1.79 jkl	45.00 efg	39.80 jk	1.92 ij	46.00 g-j	41.90 ijk
	NMG + KS	1.92 g-j	46.00 def	41.80 ghi	2.08 ghi	47.60 fgh	43.70 e-i
	NMG + KH	2.15 def	48.60 bcd	44.10 de	2.26 efg	50.00 def	45.40 c-f
	MG	2.01 f-i	47.30 de	42.30 fgh	2.05 hi	48.00 efg	42.50 hij
	MG + KS	2.12 def	48.00 cde	44.20 cde	2.33 de	51.00 cde	45.80 b-e
	MG + KH	2.41 b	52.30 a	46.00 b	2.54 bc	53.00 bcd	47.90 ab
80% ETo	**NMG**	1.65 kl	43.30 fg	38.10 l	1.75 jk	44.00 ijk	39.80 kl
	NMG + KS	1.88 hij	45.60 d-g	41.00 hij	1.97 hi	47.00 f-i	41.90 ijk
	NMG + KH	2.06 efg	48.00 cde	42.90 efg	2.09 ghi	48.00 efg	43.60 e-i
	MG	1.86 ij	46.00 def	40.40 ij	1.93 ij	46.00 g-j	42.00 ijk
	MG + KS	2.04 fgh	47.60 de	42.90 efg	2.14 fgh	48.60 efg	44.06 e-i
	MG + KH	2.22 cde	48.60 bcd	45.70 bcd	2.51 bcd	54.00 abc	46.60 bcd
60% ETo	**NMG**	1.37 m	39.00 h	34.60 m	1.47 l	41.00 k	35.50 m
	NMG + KS	1.62 l	42.00 gh	38.00 l	1.70 k	43.60 jk	38.90 l
	NMG + KH	1.82 jk	45.00 efg	39.90 jk	1.91 ij	47.00 f-i	40.70 jkl
	MG	1.68 kl	43.00 fg	38.50 kl	1.77 jk	44.70 hij	39.60 kl
	MG + KS	1.86 ij	46.00 def	40.43 jk	1.92 ij	47.00 f-i	41.00 jkl
	MG + KH	1.94 g-j	47.00 de	41.30 hij	2.30 ef	53.60 abc	43.00 f-j
	F Test	*	**	*	*	**	**

ETo: reference evapotranspiration (mm d^{-1}), NMG: not magnetic grains, KS: potassium silicate 150 mgL^{-1}, KH: potassium humate 1000 mg kg^{-1}, MG: magnetic grains.
Means within a column followed by a different letter (s) are statistically different at 5%.

4. Discussion

In arid and semi-arid regions of the world, the biggest factor limiting wheat productivity is water stress. In this study, the higher distribution uniformity value resulted in efficient utilization of applied water and fertilizer. El-Mehy *et al*. (2018), Taha *et al.* (2019) and Taha and Ghandour (2021) found that the irrigation water distribution uniformity values for the 2nd season were higher than those for the 1st one. The results indicated that wheat stem height, number of tillers or spikes /m2, weight and number of grains/spike, 1000 grains weight and grain yield/ha values of 120% ETo irrigation level followed by 100 % ETo irrigation level were higher than those of the other irrigation levels. The lowest values of wheat growth and grain yield traits were that of plants irrigated by 60 % ETo irrigation level in both season. These results are explained by the fact that more moisture is available, which promotes efficient nutrient absorption in the root zone. The obtained results concurred with those published by El-Nady and Borham (2013), Abdelghany *et al.* (2016), El-sayed *et al*. (2018), Gab Alla *et al.* (2019), Liwan *et al.* (2019), Sorour *et al*. (2019), Ghazi *et al*. (2021), Ouda *et al.* (2021), Abd El-Rady and Koubisy (2023), Hussein *et al*. (2023), Saudy *et al.* (2023), Emran *et al.* (2024) and Reddy *et al*. (2024) who indicated that the increase in the meristem activity by good absorption of nutrients and high levels of available moisture increased wheat growth, grain yield and its components.

With respect to magnetic grain (MG) treatments, wheat stem height, number of tillers or spikes/m^2, weight and number of grains/spike, seed index and grain yield/ha values were higher with sowing magnetic seeds (MG) compared with sowing nonmagnetic grains(NMG) in both respective seasons of study.

Table 8. Effect of interaction between irrigation levels and alleviating water stress (AWS) treatments on grain yield /ha and water productivity (WP) for wheat crop in 2021/22 and 2022/23 seasons.

Irrigation levels	AWS Treatments	Grain yield ($t\ ha^{-1}$)	WP ($kg\ m^{-3}$)	Grain yield ($t\ ha^{-1}$)	WP ($kg\ m^{-3}$)
		2021/22		2022/23	
120% ETo	**NMG**	6.20 abc	1.14 k	6.43 bc	1.21 ij
	NMG + KS	6.46 ab	1.18 ijk	6.63 abc	1.24 ij
	NMG + KH	6.66 a	1.22 ijk	6.80 ab	1.28 hij
	MG	6.30 ab	1.15 jk	6.50 abc	1.22 ij
	MG + KS	6.66 a	1.22 ijk	6.80 ab	1.28 hij
	MG + KH	6.76 a	1.24 h-k	6.90 a	1.30 f-j
100% ETo	**NMG**	5.50 de	1.21 ijk	5.60 e	1.27 hij
	NMG + KS	5.60 cde	1.24 j-k	5.80 e	1.31 f-j
	NMG + KH	5.70 cde	1.25 f-k	5.83 de	1.31 f-j
	MG	6.00 bcd	1.32 d-i	6.26 cd	1.41 d-g
	MG + KS	6.36 ab	1.40 c-g	6.43 bc	1.45 cde
	MG + KH	6.53 ab	1.44 b-e	6.63 abc	1.49 bcd
80% ETo	**NMG**	4.13 hi	1.13 k	4.23 ijk	1.20 j
	NMG + KS	4.3 ghi	1.18 ijk	4.56 ghi	1.29 g-j
	NMG + KH	4.66 fgh	1.28 e-k	4.70 fgh	1.33 e-i
	MG	4.70 fg	1.31 d-j	4.86 fg	1.38 d-h
	MG + KS	5.10 ef	1.41 b-f	5.13 f	1.46 cde
	MG + KH	6.06 bcd	1.67 a	6.36 bc	1.81 a
60% ETo	**NMG**	3.76 i	1.38 c-h	3.80 k	1.43 def
	NMG + KS	3.80 i	1.41 c-f	3.96 jk	1.49 bcd
	NMG + KH	4.10 hi	1.50 bc	4.26 hij	1.60 b
	MG	3.83 i	1.40 c-g	3.96 jk	1.49 bcd
	MG + KS	4.00 i	1.47 bcd	4.16 ijk	1.56 bc
	MG + KH	4.26 ghi	1.57 ab	4.86 fg	1.82 a
	F Test	*	*	**	*

ETo: reference evapotranspiration ($mm\ d^{-1}$), NMG: not magnetic grains, KS: potassium silicate 150 mgL^{-1}, KH: potassium humate 1000 $mg\ kg^{-1}$, MG: magnetic grains.
Means within a column followed by a different letter (s) are statistically different at 5%.

These results are in the same line with those of Rathod *et al.* (2016), Gajendra and Anjali (2016), Salem *et al.* (2017) and Rashad (2020). Magnetic grains pre sowing affect synthesis of proteins, enzyme activity changes, and increase in ascorbic acid content, and changing in the activity of the antioxidant system in plants (Balakhnina *et al.*, 2015). Sowing with magnetic grains caused a significant increase in grains chemical constituents, harvest index, wheat yields compared with sowing with nonmagnetic grains (Selim and Selim, 2019).

Sowing magnetic field wheat seed pre sowing improved germination, growth and development of seedlings, plant growth and development, agronomical traits and increase plant resistance to pathogenic diseases than no treated seeds (Podleśna *et al*., 2019). Plasma treated seeds which was at par with electro-MG radiation (EMR) for 200 mT led to the highest germination percentage and earlier emergence than untreated seeds (Sharma *et al.*, 2020).

Magnetic treatment of seeds improved seed germination, vigour index, shoot and root length, height, leaf area and dry weight three wheat cultivars plants under non saline and saline conditions. Magnetic field findings contributed to the information on plant development and biochemical contents after magnetic grain field application (El-Mugrbi *et al.*, 2022, Grinberg *et al.*,2024 and Kahraman, 2024).

The current study shows that, foliar addition of potassium humate (KH) or potassium silicate (KS) significantly improved grain yield and its attributes as compared with no applications. Applying potassium humate (KH) was superior to potassium silicate (KS) addition in its positive effect on stem height, number of tillers and spikes/m^2, weight and number of grains/spike, weight of 1000 grains and grain yield/ha. The obtained results indicate the importance of applying potassium humate or potassium silicate on increasing wheat growth parameters and its components as well as alleviating water stress effect on the growing plants. These results are in the same line with those of Karrou *et al.* (2012), Osman *et al.* (2017), Salem, *et al.* (2017), El-Sayed *et al.* (2018), Othman *et al.* (2000) and Ghazi *et al.* (2021), Thorne *et al.* (2021), El Shafei (2023) and Saudy *et al*. (2023) whom stated that potassium (K) is one of the vital elements required for plant growth and physiology, a constituent of the plant structure. Potassium has a regulatory function in protein synthesis, carbohydrate metabolism, and enzyme activation, as stomatal regulation and photosynthesis. Potassium(K) was found to provide abiotic stress tolerance. Under drought stress conditions, K regulates stomatal opening and helps plants adapt to water deficits (Alharbi *et al*., 2024). Concerning the interaction effects, the MG + potassium humate (KH) treatment gave the highest wheat straw and grain yields as well as its attributes and water productivity in both growing seasons followed by the MG + potassium silicate (KS) treatment. These results are in the same line with those of Salem *et al.* (2017) who said that silicon spraying improved growth and physiological indices hence could increase the ability of plants to resistance water stress.

For the three-way interaction, wheat stem height, number of tillers and spikes /m^2, weight and number of grains/spike, seed index for the 120% ETo + MG + KH treatment in the 1st and 2nd seasons were significantly higher than those of all other treatments. In both study seasons, there were no appreciable variations in grain yield/ha between the treatments of 100% ETo + MG + KH or KS and 120% ETo + KH or KS with MG or NMG. The obtained results indicate to the importance of applying potassium humate or potassium silicate in increasing wheat yields, its components and water productivity. The obtained results were in agreement with those of Merwad (2017), Saudy *et al*. (2023) and Iqbal *et al.* (2024).

5. Conclusion and recommendation

Irrigation levels and alleviating water stress treatments had a considerable impact on wheat straw and grain yields, their components and water productivity(WP). Over a two-year period, the irrigation water applied averaged 5394, 4494, 3582 and 2698 m^3/ha for 120, 100, 80, and 60% ETo irrigation levels, respectively. For 120 % ETo irrigation level grain yield /ha statistically maximized with all MG + foliar potassium treatments. For 100 % ETo irrigation level, the greatest grain yield was achieved with sowing magnetic seeds(MG) and foliar potassium either in form of silicate (150 mgL^{-1}) or humate (1000 mg kg^{-1}) treatments. Under 80 or 60 % ETo irrigation level, sowing magnetic seeds(MG) and foliar potassium 1000 mg kg^{-1} in form of humate (KH) treatment maximized grain yield /ha. The obtained results showed that grain yield / ha of 100% ETo + MG + KH or KS statistically at bar with 120 % ETo irrigation level treatments. According to the findings it could be recommended that, applying 100% ETo + MG + KH or KS can save around 900 m^3/ha of applied irrigation water (about 20% of AIW) without having any appreciable negative effects. WP values (1.19, 1.31, 1.33, and 1.45 in the 1st season) and (1.25, 1.37, 1.41, and 1.57 kg grain/m^3 in the 2nd season) gradually increased with increasing water stress levels (120, 100, 80, and 60% ETo levels), respectively.

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