Foliar Application of Different Potassium Silicate Fertilizer Types and Their Effect on Enhancing Drought Tolerance, Growth and Yield of Wheat Genotypes

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ABSTRACT

Water deficiency, is one of the most important environmental stresses, resulting in serious yield reductions in wheat production. Enhanced wheat resistance to drought stress has been attributed to silicon (Si). Therefore, two field experiments were conducted in order to study the effects of two potassium silicate treatments, mineral or nano form, under water stress on the growth and yield performance of three wheat cultivars. Experimental design, was a split split-plot design, with three replications. Drought stress significantly reduced grains per spike, 1000-grain weight, grain yield, and biomass of all wheat cultivars. In contrast, foliar-applied silicon, significantly increased these parameters and reduced electrolyte leakage. The results suggested that water stress during vegetative and reproductive development is equally injurious to wheat, and adequate water supply throughout crop development is essential to harvest maximum biological potential. In conclusion, the foliar application of silicon was very effective in indorsing tolerance of wheat plants to drought conditions by maintaining cellular membrane integrity and relative water content and increasing grain yield, and biomass of all wheat cultivars.

Key words: Abiotic stress, Water stress, Wheat Cultivars, Potassium Silicate.

INTRODUCTION

Wheat (*Triticum aestivum* L.), is considered one of the most vital crop plants in human nutrition because it aids energy and proteins (Poole *et al.*, 2021). Worldwide, the cultivated area of wheat is 214 million ha, with a total production of 762.06 million tons (FAO, 2020). Wheat production has many challenges including climate change (Paymard *et al.*, 2018 and Xiao *et al.*, 2018), limitation of irrigation water (Kirby *et al.*, 2017), uneven and random rainfall (Arshad *et al.*, 2018), imbalance fertilizer dose and timings of application, late sowing (Ghosh *et al.*, 2020) and seed quality (Feng *et al.*, 2019). Increasing population; therefore, increasing wheat production was needed to meet the increasing population in the future. The uncontrolled use of irrigation water either causes unavailability or leaches nutrients from the rhizosphere, affecting grain yield and quality (Ayub *et al.*, 2020). However, decreasing irrigation water is the greatest challenge to enhancing wheat production (Shiferaw *et al.*, 2013).

Water deficiency is a widespread problem seriously influencing wheat production and quality worldwide. In arid and semiarid regions of the world, drought is the primary limiting factor for wheat production; it negatively affects crop growth and yield. Advanced irrigation is an actual water management for deficiency of water and improving yield (Faramarzi *et al.*, 2010). Water stress prevents plant growth by affecting biochemical and physiological processes in plants. Water deficit affects the physiological consequences like prevention of photosynthesis, as a result of chlorophyll destruction, and disorder of a photochemical system (Tofig, 2015).

Wheat production in arid and semi-arid areas is being negatively impacted by the deficiency in irrigated water (Wang *et al.*, 2017). The annual loss of global wheat yields is 20% due to drought stress. In order to ensure food security, effective methods to increase wheat resistance to drought stress are urgently required. Especially during biotic or abiotic stresses, silicon (Si) has been regarded as a beneficial element for plant development (Elsokkary, 2018 and Seleiman *et al.*, 2021). Many studies have shown that Si can enhance drought tolerance in certain plants that have accumulated Si, such as rice (Wang *et al.*, 2019), wheat (Meunier *et al.*, 2017), maize (Ning *et al.*, 2020), and sorghum. Si's ability to regulate plant resistance to drought stress is mainly linked to crop root growth and water uptake (Hameed *et al.*, 2013). It has been reported that silica supplementation enhances the content of osmolytes (Xu *et al.*, 2022), improves the efficiency of antioxidant enzymes and alters photosynthetic activity and gas exchange (Kim *et al.*, 2017). Despite its abundance in soil, Si is not in available form for plant. Silicic acid is the sole form of Si that plants absorb. Exogenous foliar supplementation with Si is proven to be effective in alleviating drought damage in various plant species, such as wheat, as demonstrated by numerous studies (Maghsoudi *et al.*, 2016). Wheat growth is affected by drought stress at every growth stage, but crop respon.s.es to Si supplementation vary depending on the growth stage. Nano-Si as fertilizer

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consider is one of the promising technologies which can used for sustainable agriculture, and can be used to increase plant growth and yield production (Amin *et al.*, 2023). The regulated effect of Si on drought stress differs depending on the crop's growth stage. Wheat's water requirement is heavily dependent on the jointing, anthesis, and filling stages throughout its growth period. Therefore, the effects of two different types of potassium silicate as a foliar application were investigated in a field experiment, the physiological and biochemical responses of three wheat varieties, viz. Masr 3, Sakha 95, and Giza 171 under drought stress are being investigated.

MATERIALS AND METHODS

Study Site and Experimental Procedures:

Two field experiments were conducted at Etay El-Baroud Agricultural Research Station, El-Behera governorate (30º 89'E, 30º 65' N) through the winter seasons of 2020/2021 and 2021/2022, in order to investigate the effect of two different types of fertilization: nano potassium silicate, potassium silicate, and control (zero) under three irrigation regimes, i.e., 1: (I1) plant irrigated at sowing and after 21 days from sowing. 2: (I2) plants are irrigated three times at sowing and three-week intervals between each one. 3: Control (I3): All plants received the recommended irrigation four times, with 25 days between each of the following irrigations, on three wheat genotypes, i.e., Giza 171, Sakha 95, and Misr 3 (Table 1), growth, phenology, growing degree days, and yield components. Potassium silicate in mineral or nano form applied as foliar applications, at 65 and 80 days after sowing. Data in Table (2) shows some soil characteristics before planting.

Experimental design:

The experiment design used a split split-plot that relied on randomized complete block design with three replications. Irrigations were allotted in the main plots, which, were randomly distributed, wheat genotypes in subplots and fertilization applications illustrated in the sub-subplots.

Cultural practices:

Seeds sown on 15th Nov. by hand drill. The seedling rate was 60 kg acre^{-1} (acre = fed.). Phosphorus fertilizer in the form of superphosphate (15.5%) was applied at 31 kg P_2O_5 during soil preparation. Nitrogen fertilizers in the form of urea (46%) were applied in one dose after 21 days from sowing in the first irrigation treatment. In second and third irrigation treatments, N fertilizer was applied in two doses, half after 21 days from sowing and half before the next irrigation. All farming practices were done as recommend by “Ministry of Agriculture and Land Reclamation”.

Table 1. The Code number, name, pedigree and selection history of the studied bread wheat cultivars

Name	Pedigree and selection history
Giza 171	Sakha 93 /Gemmieza 9. GZ2003 –101-1GZ - 4GZ –1GZ - 2GZ - 0GZ.
Sakha 95	PASTOR//SITE/MO/3/CHEN/AEGILOPS SQUARROSA (TAUS) // BCN /4/ WBLL1 (CMSA01Y00158S-040P0Y-040M-030ZTM-040SY-26M-0Y-0SY-0S).
Misr 3	Rohf 07*2/Kiriti CGSS 05 B00123T-099T-0PY-099M-099NJ-6WGY-0B-0BGY-0GZ.

Table 2. Some physical and chemical properties of the used field experimental soil before planting

Soil Characteristics		2020/2021	2021/2022
Physical properties	Sand %	20.30	17.08
	Silt %	26.10	22.92
	Clay %	53.60	60.00
	Texture	Clay	Clay
Chemical properties	Soil (pH) 1:2.5	8.10	8.11
	*EC (ds m^{-1})	2.10	1.20
	Total $CaCO_3$ (%)	5.60	5.71
Nutrient properties	Total Carbon (%)	1.20	1.25
	Organic Matter (%)	2.07	2.16
	Available N (mg Kg^{-1})	59.85	60.04
	Available P (mg Kg^{-1})	11.90	10.09
	Available K (mg Kg^{-1})	160.50	151.04

*Soil paste

Table 3. Temperature (^{0}C) and rainfall during the wheat growing period in 2020/2021 and 2021/2022 seasons

Month	2020 / 2021				2021 / 2022			
	Max. T	Min. T	Mean	Total rainfall	Max. T	Min. T	Mean	Total rainfall
Nov.	20.24	12.96	16.60	86	23.57	13.87	18.72	19
Dec.	18.78	10.73	14.75	71	21.26	13.36	17.31	66
Jan.	17.23	8.43	12.83	35	18.77	10.74	14.76	72
Feb.	18.76	9.77	14.26	9	21.14	11.59	16.37	27
Mar.	21.08	13.64	17.36	5	24.39	13.81	19.10	5
Apr.	25.92	14.86	20.39	-	27.37	15.80	21.59	5
May	28.62	19.92	24.27	-	30.97	20.42	25.70	-

Where: T_{max} and T_{min} represent the maximum and minimum temperatures (Ahmed and Farooq, 2013). Weather data from planting to harvest were collected from the meteorological Station at Etay El-Baroud Agricultural Research Station (Table 3).

Sampling and Analysis:

Soil:

Soil samples (0-30 cm) were collected before planting and after plant harvesting, for the main physical, and chemical analysis. The particle size distribution (sand, silt, and clay) was measured by the hydrometer method (FAO, 1970). The electrical conductivity was measured in 1:2.5 soil–water suspension using a conductivity meter and the pH was measured in 1:2.5 soil-water suspension by a pH meter (Jackson, 1973). The amount of available-N in soil was determined by Kjeldahl method, the amount of available-phosphorus in soil was extracted by 0.5 N $NaHCO_3$ pH 8.5 as described by Olsen *et al.* (1954) and the concentration of P was measured calorimetrically using the ascorbic acid method (Olsen and Watanabe, 1965), and the amount of available-K was extracted with neutral normal NH_4-Acetate solution and measured by a flame photometer (Black *et al.,* 1965 and Cottenie *et al.,* 1982). The amount of 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 characteristics of the experimental soil, in the two growing seasons, are shown in Table (2).

Plant:

• Yield and yield components:

At harvest, plants were randomly taken from each sub-sub plot to estimate plant height, number of tillers m^{-2}, spike length, number of kernels $spike^{-1}$ and 1000 kernel weight and straw yield. Also, grain and biological yields were determined. Other characters were taken as heading date and maturity date.

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 (Jackson, 1973), and total potassium was measured by a flame photometer (Page *et al.,* 1982).

Statistical analysis:

Collected data were statistically analyzed and the least significant difference test (LSD) was used to test the difference between the means of treatments at 5% level. According to Snedecor and Cochran (1967), the combined analysis was conducted for the two growing seasons with an average data (L.S.D) of 5%.

RESULTS AND DISCUSSION

In the case of infrequent water supply and drought conditions, these practices in irrigated agriculture could lead to greater economic gains by maximizing yield per unit of water. Therefore, in areas with water shortages, it is important to see in which particular conditions to apply stress to crops. For example, this could be applied by selecting the tolerant growth stage of a particular crop, which leads to higher water productivity. This enables irrigators to understand specific crop growth stages and the level of stress to be imposed to enhance water productivity, as the yield response can vary depending on crop sensitivity at that development phase (FAO, 2002 and 2013).

Effect on Plant Growth:

Data illustrated in Table (4) showed the effect of water, wheat genotypes and silicate fertilizers treatment on some plant growth parameter.

Effect of water deficiency:

It was noticed that deficit irrigation caused a significant decrease and damage in all vegetative characters, days to heading, and days to maturity (Table 4). There was a significant decrease in spike length (cm), spikes number (m^{-2}), and plant height (cm). On the other hand, full irrigation resulted in a positive and significant increase in all growth and yield characteristics. The spike number (m^{-2}) at full irrigation treatment has the highest mean value (317.61), while the lowest mean value (239.02) was obtained by the first irrigation regime. The highest plant height of 118.62 cm was obtained at the third irrigation treatment, though the lowest mean value of 108.14 cm was at the first treatment. Vegetative growth parameters were significantly decreased by skipping irrigation at the tillering, heading, and/or milk-ripe stage. Furthermore, wheat plants were more sensitive to skipping irrigation in the tillering stage than in the heading stage and milk ripe stage, respectively (Ahmed and Ahmed, 2005). The significant reduction in vegetative characters of wheat plants under water deficit situations might be due to the decline in cell amplification and reduced turgor pressure (Shao *et al.*, 2008).

Effect of Wheat genotypes:

Also, data in Table (4) showed that, there were significant differences among the wheat varieties for all tested parameters, except, the number of days to maturity. However, Sakha 95 had the highest mean value 86.8 of days to heading, while, there were no significant differences between the other genotypes.

Effect of Silicon Sources:

Foliar application of potassium silicate sources was positively efficient with all vegetative and, yield compared with control for all tested parameters (Table 4). Potassium silicate fertilizer has the highest spike length (11.67 cm), while control has the lowest mean value (10.64 cm). Fertilization with potassium silicate is a promising knowledge as K_2SiO_3 is an elicitor that could induce plant resistance to abiotic stresses. This was clear that, when spraying potassium silicate efficiently improved the sharp reduction caused by deficit irrigation in all studied characters. Potassium silicate accumulation in transpiration organs, might affect the construction of a silica double layer that decreases stomata opening, leaf transpiration, and water losses without affecting plant growth due to drought pressure. Exogenous Si sources might preserve the integrity and stability of the plant cell membrane under biotic or abiotic stress. Hence, the effect of Si on plants could be related to morphometric changes and as a stimulus to biochemical defenses (Araújo *et al.*, 2019).

Table 4. Effect of water regime treatments, Wheat genotypes, type of potassium silicate on some vegetative characteristic

Treatments	Days to heading	Days to maturity	Spike length (cm)	Spike No. (m^{-2})	Plant height (cm)
One Irr. (I1)	82.06	132.09	10.61	239.02	108.14
Two Irr. (I2)	86.31	125.76	11.32	286.20	114.42
Full Irr. (I3)	87.94	124.13	11.74	317.61	118.62
	**	**	*	***	**
LSD 0.05	**1.636**	**2.4087**	**0.5632**	**13.8757**	**3.2452**
Masr 3	84.98	127.50	10.79	290.28	115.71
Shaka 95	86.80	127.02	10.57	287.91	115.45
Giza 171	84.54	127.46	12.30	264.65.	110.02
	***	n.s.	***	**	***
LSD 0.05	**0.877**	**0.880**	**0.2667**	**14.6685**	**1.2090**
Control	83.17	124.17	10.64	244.94	110.02
K_2SiO_3	86.31	129.20	11.67	298.28	114.80
Nano-Si	86.83	128.61	11.36	299.61	115.67
	***	***	***	***	***
LSD 0.05	**0.556**	**0.9281**	**0.2581**	**10.0571**	**1.3316**
Irr * var.	n.s.	n.s.	n.s.	n.s.	n.s.
Irr * Fer.	*	n.s.	n.s.	*	n.s.
Var. * Fer.	*	n.s.	***	n.s.	n.s.
Irr. * var. * Fer.	**	n.s.	**	n.s.	n.s.
LSD 0.05	1.6686	2.7843	0.7742	3.9947	30.1713

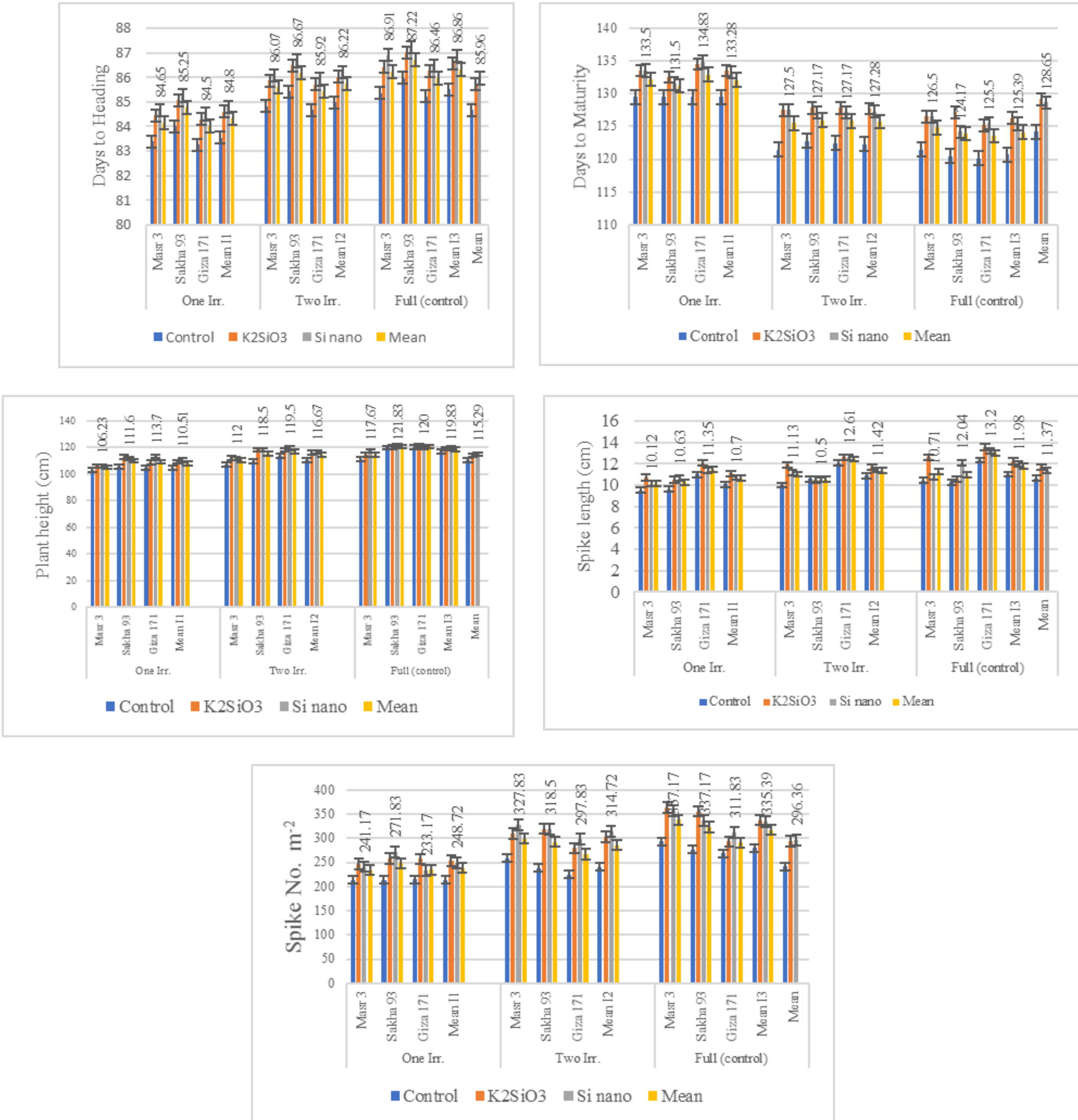

Fig 1. Effect of interaction among water regime treatments, Wheat genotypes, type of potassium silicate on some vegetative characteristic

Effect of the interaction among water stress, wheat verities, and Silicon Sources:

Table (4) showed insignificant differences in all tested parameters as a result of the interaction among different wheat genotypes and irrigation regimes. It is clear that, with all the characteristics of the study, the addition of potassium silicate to the irrigation regime added more and seriously raised the values than untreated plants. The interaction between wheat genotype and silicate source was significant in heading date and spike length, however, there were insignificant for date to maturity, spike no. and plant height.

The interaction among the tested treatments showed significant differences in the heading date parameter, with the highest mean value of 87.22 days obtained by the interaction between full irrigation treatment and foliar application of nano-silicon on the Sakha 95 wheat genotype. Also, the date to maturity parameter showed significant differences due to the interaction between different treatments and the lowest days 120.17 to maturity by control irrigation and fertilizer by Giza 171. Also, spike no. and plant length did not significantly differ due to the different treatments; the highest mean value (363.83 m^2, 121.83 cm) was obtained at full irrigation treatment for the two parameters and in Masr 3 and Sakha 95 genotypes and foliar potassium and nano-silicate, respectively. However, (Fig. 1) showed that there were significant differences in spike length (cm), with the highest mean value (13.55 cm) gained by full irrigation and foliar application of potassium silicate in the Giza 171 genotype.

When soil water availability is restrained plant growth is reduced, where development of shoot is more inhibited than root growth (Anithakumari *et al.,* 2012). The individual effects of water stress and variety on plant height of wheat were significant, but the interaction effect was non-significant (Ciadir *et al.,* 1999). Also, reported that Water stress treatments resulted in a significant decrease in the number of spikelets per spike. The number of spikelets per spike is significantly reduced by water stress during crown-root initiation or late tillering stages in wheat, as reported by Shalaby *et al.* (1988). Wheat varieties also significantly differ in plant height, the number of spikelets per spike, however, the effects of treatments that combined water stress and varieties on spikelets per wheat were not significant (Ciadir *et al.,* 1999). The different number of spikelets per spike in different varieties seems to be a result of their varying genetic makeup.

Yield and Yield Components:

Effect of water deficiency:

Data in Table (5) showed that reducing irrigation water significantly reduces biological weight (17.46 Mg $acre^{-1}$), while the weight of 1000 grains increased significantly (53.67 g) with increasing irrigation water; however, one and two irrigation regimes were insignificant with mean values of 50.18 and 50.02 g, respectively. Full irrigation gave the highest grain yield (3.66 Mg $acre^{-1}$), while one irrigation reduced the grain yield by (0.67 Mg $acre^{-1}$) compared with full irrigation treatment. This results in agreement with Hochman (1982) and Amir *et al.* (2005), who found that wheat's grain yield can be significantly reduced by water stress during any developmental stage. The adverse effect's magnitude is dependent on the wheat variety and stage of the crop subjected to water stress. Also, Anjum *et al.* (2016) stated that the degree of drought stress and the stage of imposition have an impact on wheat yield. Water deficiency during propagative development reduced grain yield ha^{-1}, which was significantly compared with control but was statistically equal to water stress during vegetative development (Ciadir *et al.,* 1999). Gomaa *et al.* (2021) revealed that irrigation after exhaustion of 55% available soil water verified the highest mean values of yield and yield components i.e. (100-pods weight, no. of pods $plant^{-1}$, pods yield fed^{-1}, biological yield fed^{-1} and straw yield fed^{-1}). The negative effects of drought on the seed yield of different wheat genotypes were reported by Agarwal and Sinha (1984). Also, moisture stress causes yield loss depending on genotype, plant developmental stage, intensification, and period of water shortage (Korte *et al.,* 1993 and Kedir, 2020). Full irrigation enhances the availability of moisture content surrounding the roots, which causes more proliferation of root biomass and, consequently, higher water and nutrient uptake, which leads to an increase in the metabolism process in plants and therefore higher vegetative biomass (El-Saadony *et al.,* 2017).

Effect of Wheat genotypes:

Wheat genotypes reflect significant differences in yield and yield components (Table 5). Masr 3 has the highest mean value followed by Giza 171 for biological yield while, Sakha 95 gave the highest weight of grain yield (3.43 Mg $acre^{-1}$). Masr 3 genotype reflect lowest 1000- grain weight (48.84 g) as mean value for the two growing seasons.

Effect of potassium silicate sources:

Potassium silicate fertilizer exceed nano-Si and gave the highest mean value for grain and biological yield and 1000-grain weight, 19.89, 3.55 Mg $acre^{-1}$ and 52.17 g, respectively, compared with control treatment.

Regarding potassium silicate fertilizers, it has been suggested by Trenholm *et al.* (2004) that silicate crystals deposited in epidermal cells form a barrier that prevents water loss through the cuticles. Wheat yields markedly responded to potassium silicate application. The impact of potassium silicate on wheat yields was more pronounced with a lower water supply. The use of Si can enhance dry weight in wheat, and it can also boost crop growth in drought conditions by maintaining high leaf areas to ensure high assimilation efficiency. Cuticle thickness is significant in reducing water loss through evapotranspiration.

Table 5. Effect of water regime treatments, Wheat genotypes, type of potassium silicate on yield and yield component

Treatments	Biological weight	Weight of 1000 grains	Grain weight
	Mg acre^{-1}	**g**	**Mg acre^{-1}**
One Irr.	17.46	50.18	2.99
Two Irr.	19.59	50.02	3.40
Full Irr.	19.73	53.67	3.66
Mean	**	***	***
LSD 0.05	**1.1507**	**0.6170**	**0.1908**
Masr 3	19.36	48.84	3.35
Shaka 95	18.37	50.16	3.43
Giza 171	19.00	54.87	3.27
Mean	**0.8031**	**0.3955**	**0.2037**
LSD 0.05	*****	*******	*****
Control	17.40	50.42	3.13
K_2SiO_3	19.89	52.17	3.55
Nano-Si	19.44	51.29	3.37
Mean	***	***	***
LSD 0.05	**0.6435**	**0.5339**	**0.1835**
Irr * Var.	n.s.	**	n.s.
Irr * Fer.	n.s.	**	n.s.
Var. * Fer.	***	***	*
Irr. * Var. * Fer.	n.s.	***	n.s.
LSD 0.05	**1.9304**	**1.6017**	**0.5505**

Effect of the interaction among water stress, wheat verities, and Silicon Sources:

There was significant different between water regimes and diverse wheat genotype for weight of 1000-grains, however, the interaction was insignificant differ for biological and grain yield. The interaction between types of water regimes and sources of potassium silicate was insignificantly differ for biological and grains weight. Also, the same treatment gave the highest mean value (54.24 g) of 1000 grain weight, however, there were significant different among the different interaction.

The interface between wheat genotypes and silicate sources has significant different for biological, grains and 1000- grains weight. Giza 171 genotype has highest mean value (21.27 Mg acre^{-1}, 55.02 g) by interact with potassium silicate application and control, for biological and 1000 grain weight, respectively. While, Sakha 95 with potassium silicate application has the highest mean value (3.98 Mg acre^{-1}) grain yield.

The obtained data cleared that, there were not significant different among the interaction of tested treatment for biological and grain yield, although, the weight of 1000 grain was significant different. The highest grain and biological yield (4.16, 22.78 Mg acre^{-1}) respectively, obtained by the interaction among the second irrigation regime with potassium silicate fertilizer for Giza 171 wheat genotype. While, the highest mean value for 1000- grain weight (57.42 g) obtained by the interaction between full irrigation treatment without silicate fertilizer for Giza 171 genotype (Fig. 2).

Affectation to the interaction between water stress and wheat verities Vorasoot *et al.* (2003) observed that under drought conditions, the peanut agronomic characteristics and grain yield of all cultivars decreased significantly. The 1000-grain weight was statistically on par with the control crop due to water stress during vegetative development (Ciadir *et al.*, 1999).

Fig. 2. Effect of interaction among Water regime treatments, Wheat genotypes, type of Potassium Silicate on Yield and Yield component

Macro-Micro nutrients concentration in grains of wheat plants

Effect of water deficiency:

Table (6) cleared that N content in grains wheat was significantly increased by irrigation regimes treatments, the highest mean value of the two growing seasons was 2.08 % for full irrigation treatment. However, the N content in the flag leaf showed insignificant differences between the full and half irrigation treatment compared with the first irrigation regime which has the lowest mean value of 2.95 %. Regarding the effect of irrigation levels, data in Table (6) showed that increasing irrigation levels led to increased protein content in grains. As mean values of the two growing seasons, the heist protein content obtained in full irrigation treatment was 11.99 %. However, the second irrigation regime was 17.78% as the mean value in flag leaf, while the first treatment had the lowest value 16.98%. Phosphorus contents in grains were insignificant increased with increasing applied irrigation water, thus as mean values of the two growing seasons (Table 6). Also, data in Table (6) cleared that there were no significant differences in potassium contents among tested water regimes. Data in Table (6) also cleared that insignificant effect due to the different water regimes in micronutrient contents.

Effect of Wheat genotypes:

Nitrogen content in grains was significantly differed among different wheat genotypes, where the highest N content was in Shaka 95 genotype 2.09 % while the lowest N value obtained in the Mase 3 genotype. Concerning the protein content as affected by differences in wheat genotype, Sakha 95 has the highest mean values of 12.01 and 17.58 % in grains and flag leaf, respectively. While, the Masr 3 genotype has the lowest mean values 10.5 and 17.17 % in grains and flag leaf, respectively. The different wheat genotype has no significant effect on grain P content (Table 6). However, Giza 171 genotype has the highest mean value for the two grown seasons (0.20 %). Also, the different wheat genotype was insignificant between Giza 171, Masr 3 and Masr 3, Sakha 95 for Potassium content % (Table 6). As to the effect on micronutrient contents, Fe has significate different the highest mean value obtained by Masr 3 (3.31 %), Giza 171 has lowest mean value (2.24 %). Also, Masr 3 has highest mean value for Mn content (1.72 %), while there was not significant different between Sakha 95 and Giza 171 genotype. Whereas, the was insignificant effect in Zn content among different wheat genotypes.

Effect of potassium silicate sources:

Regards to silicate fertilizers source control treatment gave the highest mean value of N content at 2.07 % followed by nano silicate at 2.01%, whereas potassium silicate gave the lowest mean value of 1.82 %. Also, P and K contents were highly significant and potassium silicate gave highest mean value (0.20 and 0.32 %) respectively. Same results obtained for Fe and Mn content, however, there was not significant different for Zn content as a result for Silicate fertilizer compared with control treatment.

Effect of the interaction among water stress, wheat verities, and Silicon Sources:

Table (6) also declared that the interaction effect between irrigation regime treatments and different wheat genotypes on N content was insignificant, however, the highest value was 2.08% from the interaction between Sakha 95 and the second irrigation regime. While the interaction between irrigation regimes and sources of silicate fertilizers was highly significant for protein percentage, Fe and Mn content. However, wheat grain content of NPK and Zn content were insignificant differ as result for the interaction between different water regimes and silicate treatments. Wheat Giza 171 genotype without silicate application gave the highest mean value for N content (2.08 %), though the lowest mean value (1.85 %) by Sakha 95 treated with potassium silicate.

Table 6. Effect of water regime treatments, wheat genotypes, type of potassium silicate on macro-micro nutrients concentration (%) in grains of wheat plants

Treatments	N LF	Protein LF	N grain	Protein	P	K	Fe	Mn	Zn
One Irr.	2.95	16.98	1.95	11.22	0.18	0.31	2.82	1.27	0.42
Two Irr.	3.09	17.78	1.88	10.79	0.19	0.33	2.45	1.20	0.42
Full Irr.	3.06	17.59	2.08	11.99	0.20	0.33	2.82	1.23	0.43
	*	***	**	***	n.s.	n.s.	***	n.s.	n.s.
LSD 0.05	**0.0874**	**0.0450**	**0.0949**	**0.1196**	**0.0255**	**0.0220**	**0.0515**	**0.1466**	**0.0197**
Masr 3	2.99	17.17	1.83	10.50	0.19	0.32	3.31	1.72	0.42
Shaka 95	3.06	17.58	2.09	12.02	0.18	0.31	2.55	0.99	0.44
Giza 171	3.06	17.60	1.99	11.47	0.20	0.33	2.24	0.10	0.40
	***	***	***	***	n.s.	*	***	***	n.s.
LSD 0.05	**0.0325**	**0.0780**	**0.0534**	**0.0820**	**0.0201**	**0.0130**	**0.0631**	**0.0985**	**0.0355**
Control	3.10	17.82	2.07	11.91	0.18	0.32	2.51	1.14	0.42
K_2SiO_4	3.06	17.58	1.82	10.50	0.20	0.32	2.51	1.50	0.43
Nano-Si	2.95	16.95	2.01	11.57	0.19	0.32	3.08	1.07	0.42
	***	***	***	***	***	**	***	***	n.s.
LSD 0.05	0.0644	0.0682	0.0457	0.1559	**0.0075**	**0.0106**	**0.0496**	**0.0724**	**0.0476**
Irr * Var.	***	***	n.s.	***	n.s.	n.s.	***	**	n.s.
Irr * Fer.	***	***	***	***	n.s.	n.s.	***	***	n.s.
Var. * Fer.	***	***	***	***	*	***	***	***	n.s.
Irr. * Var. * Fer.	***	***	***	***	***	***	***	***	n.s.
LSD 0.05	**0.1931**	**0.2048**	**0.1372**	**0.46786**	**0.0226**	**0.0319**	**0.1487**	**0.2171**	**0.1428**

The interaction among the different treatments significantly differed with the highest mean value of 2.41% obtained by the interaction between full irrigation treatment, Giza 171 genotype, and without silicate fertilizer. But the lowest mean value was 1.40% obtained by Giza 171 at the first level of irrigation and without silicate for N content of grain as shown in Fig. (3). Also, diagram 3 showed significant effect for maro-micronutrient except of Zn content. The highest mean value for P content in grain (0.23 %) obtained by Giza 171 genotype and second irrigation treatment with foliar application of potassium silicate, or with full irrigation fertilized with nano silicate. The interaction between Sakha 95 genotype, Potassium silicate and full irrigation treatment has highest mean value of K content (0.37 %) for the two growing seasons. Also, for micronutrients content Fig. 3 illustrated that Masr 3 has highest mean value for Fe and Mn content (4.37, 2.87 %) with foliar application of nano silicate irrigated with full and second irrigation treatments receptively. But Zn content showed no significant effect by different interaction treatment.

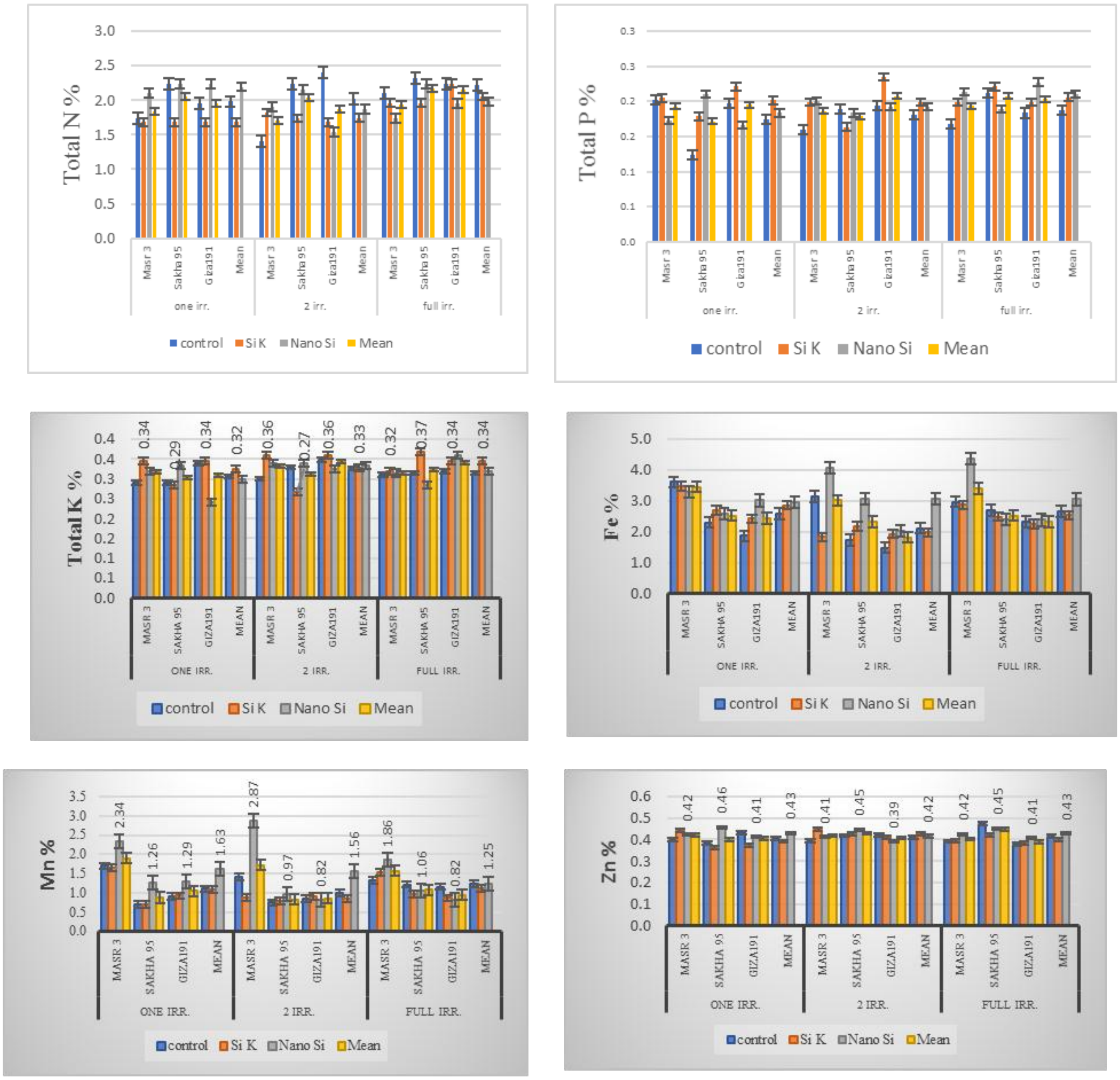

Fig. 3. Maro- and micronutrient content in wheat grains affected by the interaction among water, wheat verities and silicate fertilizers

The application of Si improved the morphological features of both wheat genotypes and lessened the significant impact of drought. Si treatment has been known to decrease oxidative damage in plants by promoting essential plant antioxidant enzyme activities like SOD, CAT, POD, and APX efficiently improve the plant ROS-scavenging ability to keep the balance of ROS metabolism and decrease the reactions of oxidative stress, thus promoting the growth of plants (Malik *et al.,* 2021).

The deficiency of water also is the principal reason for the reduction in the nutritional quality of seeds (Amir *et al.,* 2005). However, water deficiency considered one of the most important abiotic stresses unfavorably affects crop production in numerous districts of the world (Gupta *et al,* 2001 and Secenji *et al.,* 2005). Moisture distresses nitrogen nourishment through its impact on nitrogen uptake, mineralization of organic nitrogen, and nitrogen losses such as denitrification or volatilization (Kedir, 2020). As a result of drought, plant growth, yield, pigment alignment, and photosynthetic efficiency is enormously pretentious by water stress (Praba *et al.,* 2009).

This result is in agreement with Kedir (2020) who stated that wheat protein content plays a role in heredity, climate, water availability, and available N. Nitrogen and water stress is the most limiting factor for wheat production that affects the rapid plant growth and improves grain yield.

Macronutrient content in the Straw:

Effect of water deficiency:

Nitrogen and protein content in the straw showed significant effect as affected by water regimes, the highest mean values were (0.35, 2.00 %), respectively obtained by the lowest irrigation treatment. P content showed insignificant effect as results of different water regimes. The highest mean value for the two grown seasons for K content (1.61 %) obtained by the full irrigation treatment. Regards to Nitrogen and protein content, Giza 171 genotype has highest mean values (0.36, 2.06 %) respectively. However, data in Table (7) showed insignificant effect for P, K content.

Table 7. Effect of water regime treatments, wheat genotypes, type of potassium silicate on Macronutrients concentration in straw of wheat plants

Treatments	N	Protein	P	K
	%	%	mg kg^{-1}	%
One Irr.	0.35	2.00	163.02	1.41
Two Irr.	0.33	1.91	129.87	1.37
Full Irr.	0.31	1.77	169.30	1.61
	**	**	n.s.	*
LSD 0.05	**0.0130**	**0.0653**	**62.2153**	**0.1530**
Masr 3	0.31	1.77	154.19	1.56
Shaka 95	0.32	1.86	145.29	1.45
Giza 171	0.36	2.06	145.29	1.38
Mean	***	***	n.s.	n.s.
LSD 0.05	**0.0169**	**0.0362**	**33.4628**	**0.1711**
Control	0.33	1.90	146.67	1.34
K_2SiO_3	0.30	1.72	137.74	1.50
Nano-Si	0.36	2.08	167.79	1.56
Mean	***	***	*	n.s.
LSD 0.05	**0.0102**	**0.0379**	**25.4767**	**0.1996**
Irr * Var.	***	***	n.s.	n.s.
Irr * Fer.	***	***	n.s.	n.s.
Var. * Fer.	**	***	n.s.	n.s.
Irr. * Var. * Fer.	***	***	n.s.	n.s.
LSD 0.05	0.0305	0.1137	76.3401	0.5987

Effect of Wheat Varieties:

Also, date given in Table (7) showed significant effect in nitrogen and protein content, the highest mean value of the two growing seasons for both parameters was (0.36, 2.06 %) respectively obtained by Giza 171 genotype. Meanwhile, the lowest value gained by Masr 3 genotype. However, data in Table (7) showed insignificant effect on straw P, K contents.

Effect of Silicon Sources:

Likewise, Table (7) cleared that nano-silicate foliar application gave the highest mean values for tested parameters followed by control. While potassium silicate has lowest mean value for different parameters.

Effect of the interaction among water stress, wheat verities and Silicon Sources:

Likewise, N and protein content was significant differ as result of interaction between water regimes and foliar application of silicate. Even though, P, K content show insignificant different. Also, significant effect appeared as a result for interaction between water regimes and silicate fertilizer on N and protein content, while it was insignificant on P, K content. The highest N content (0.38%) obtained by Giza 171 genotype with foliar application of nano silicate. Regarding to K content the highest mean value (1.69 %) obtained by Masr 3 genotype with potassium silicate fertilizer. Concerning P content Giza 171 without silicate fertilizer give highest mean value (179.92 mg kg^{-1}). The highest N content (0.53 %) of straw occur as result of interaction between first irrigation regime and Giza 171 genotype with foliar fertilizer with nano Si. While, the interaction among one irrigation treatment without Si fertilizer gave the highest P content (246.21 mg kg^{-1}). Total K in wheat straw highest mean value (2.04 %) transpire in Masr 3 genotype at the first irrigation treatment with nano Si fertilizer (Fig. 4).

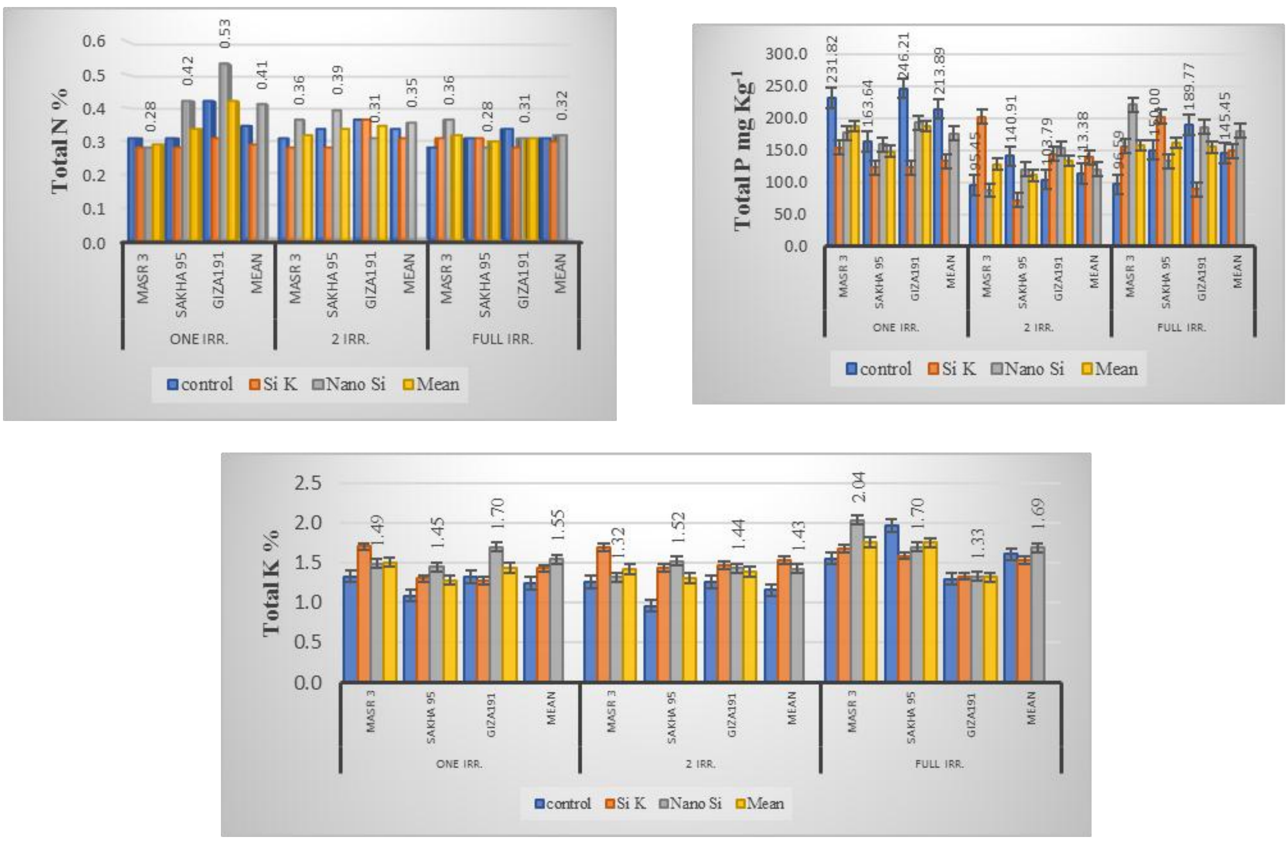

Fig 4. Macronutrients content in wheat straw affected by the interaction among water, wheat verities and silicate fertilizers

On the contrary, Khattab *et al.* (2011), found that increasing irrigation water levels resulted in an increase in the percentage of nitrogen in the pomegranate leaf. It is motivating to say that during periods of drought stress, soil available N (NO_3^- and NH_4^+), N uptake, N_2 fixation, and nitrogen use efficiency decrease will result in low N accumulation, leading to low dry matter production and low crop yield as many investigators have documented these results (Hoseinlou *et al.,* 2013). Similar conclusions were observed by Abdel-Razik (2011) on mango rootstocks and Junjittakarn *et al*. (2013) on peanut genotypes, they found that, decreased irrigation level resulted in a significant reduction in the phosphorus content in mango leaves and peanut shoots genotypes.

Soil fertility parameters:

Effect of water deficiency:

Table (8) showed significant effects of irrigation regimes on soil organic matter (SOM) content, the highest mean values of the two growing seasons was 2.17 % for full irrigation treatment. This increase may be due to increasing applied irrigation water, which enhances the growth of microbes and root activity resulting in increasing SOM contents in soils. Availability of N significantly affected by irrigation regimes, and full irrigation treatment has lowest available N (42.00 mg kg^{-1}). Also, soil available P, K significantly affect by irrigation treatment. While, two irrigation treatment gave the lowest mean value of available P (6.66 mg kg^{-1}), while the full irrigation treatment presents the highest mean value of available K (276.63 mg kg^{-1}).

Effect of Wheat Varieties:

Table (8) also, indicated that there was a significant increase in the amount of SOM in soil resulting from wheat variety. Masr 3 has the highest mean value (2.03%), while there was no significant difference between Shaka 93 and Giza 171. Available N significantly affect due to different wheat genotype, Masr 3 results in high mean value (76.83 mg kg^{-1}) compared with other genotypes. While, the different genotypes have no significant effect on available P, K.

Effect of Silicon Sources:

Soil organic matter as mean values of the two growing seasons decreased due to foliar application of silicate from 1.99 to 1.89 and 1.82 for control, nano-potassium silicate, respectively. Significant effect occurs on available N, K while, available P was insignificant differ due to foliar application of silicate fertilizer. Potassium silicate fertilizer has highest mean value for available P, K (9.16, 269.31 mg kg^{-1}), respectively.

Table 8. Effects of different Water regimes, Silicate fertilizer and different Wheat genotypes on soil nutritional status after harvest of wheat plants

Treatments	Organic Matter (%)	Available N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})
One Irr.	1.85	78.00	10.11	240.90
Two Irr.	1.77	62.97	6.66	247.76
Full Irr. (control)	2.17	42.00	9.00	276.63
	***	*	*	*
LSD 0.05	**0.0575**	**11.1395**	**2.0119**	**10.7025**
Masr 3	2.03	76.83	8.67	250.23
Shaka 95	1.87	50.92	8.41	255.80
Giza 171	1.89	55.22	8.68	259.27
	***	*	n.s.	n.s.
LSD 0.05	**0.0295**	**7.3160**	**1.2805**	**11.3759**
Control	1.99 a	64.06	7.99	247.60
K_2SiO_3	1.82 b	63.42	9.16	269. 31
Nano-Si	1.89 b	55.47	8.62	248.34
	***	*	n.s.	*
LSD 0.05	**0.06501**	**5.0237**	**1.5052**	**5.8810**
Irr * Var.	***	*	***	*
Irr * Fer.	***	*	n.s.	*
Var. * Fer.	***	*	n.s.	*
Irr. * Var. * Fer.	***	n.s.	n.s.	*
LSD 0.05	0.1952	15.0711	4.5155	35.6431

Effect of the interaction among water stress, wheat verities, and Silicon Sources:

Highly significant effect occurs due to water regimes and different wheat genotypes on SOM, the highest mean value of the two grown season was 2.48 % by control irrigation treatment and Masr 3 genotype. Regarding to macronutrient availability, N, P, K have significant different, highest available N mean value (93.83 mg kg^{-1}) obtained by the interaction between second irrigation treatment and Masr 3 genotype. While full irrigation treatment with interaction with Giza 171 has highest P, K values (13.34, 285.60 mg kg^{-1}) respectively. Also, full irrigation treatment without silicate fertilizer has highest mean value of SOM (2.64 %), while the interaction between one irrigation treatment without silicate fertilizer gave the lowest mean value 1.61 % in the two grown seasons. Also, significant effect occurs on available N, K. Whereas, available P was insignificantly affected.

There was highly significant effect on soil organic matter and available N, K parameters, while the effect on available P was insignificant. Low irrigation treatment in absents of silicate fertilizer provided highest mean value 2.29 % of soil organic matter. Foliar application of potassium silicate on Masr 3 genotype results in high mean value of available N, P (80.17 and 11.32 mg kg^{-1}) respectively. The highest mean value of available K (270.70 mg kg^{-1}) obtained by Giza 171 genotype and foliar application of K_2SiO_3.

Also, soil organic matter showed highly significant affect due to the interaction among the tested treatment as shown in Fig. (5). Full irrigation treatment with Masr 3 genotype without using silicate fertilizer has highest mean value (3.14 %). The tri-interaction showed significant effect on available K, while the effect was insignificant on available N, P. The highest N available mean value (95.50 mg kg^{-1}) obtained by the interaction between second irrigation regimes on Masr 3 genotype without silicate fertilizer. Maximum mean value of available P (15.71 mg kg^{-1}) gained by lowest irrigation regimes with K_2SiO_3 fertilizer on Masr 3 wheat verity. While, Giza 171 under full irrigation treatment and foliar application of potassium silicate gave the highest available K mean value (306.37 mg kg^{-1}).

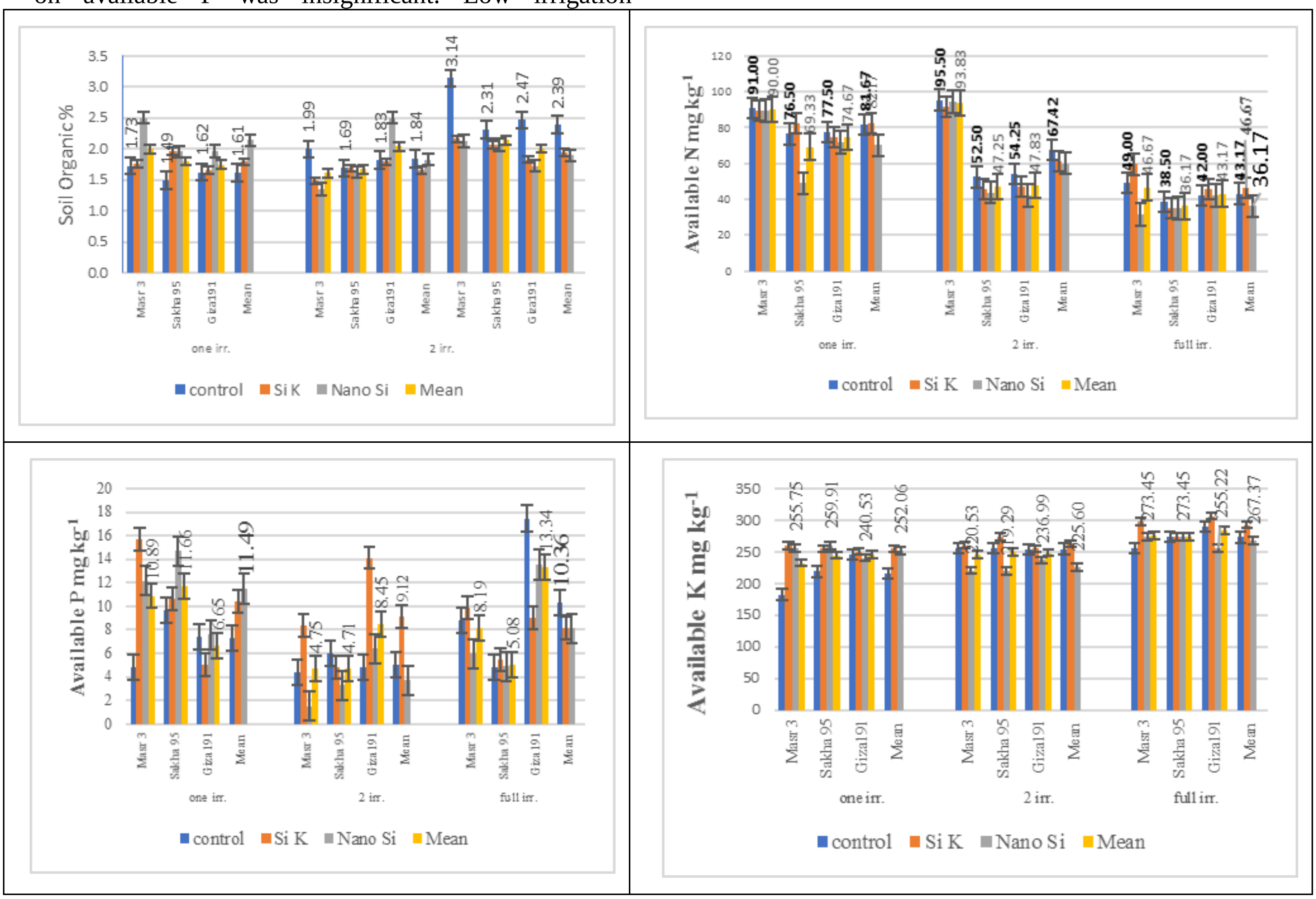

Fig 5. Some soil fertility parameters affected by the interaction among water, wheat verities and silicate fertilizers

CONCLUSION

Drought on.s.et, frequency, and severity have been predicted to increase shortly due to the ongoing global climate change and intensifying greenhouse gas emissions, which could affect plant growth, development, and metabolism. Drought is caused by factors such as low rainfall, salinity, high temperature, and high light intensity. To cope with drought, the plant has taken measures to shorten its life cycle and yield penalty. Also, the plants respond to drought by maintaining metabolic activities at low tissue water potential. Plants show physiological adaptation to dehydration tolerance by osmotic adjustments such as increased accumulation of proline, glycinebetaine, and sugars, inducing antioxidant activities (enzymatic and non-enzymatic systems) by scavenging ROS, maintaining cell membrane stability, expression of aquaporins, and altered growth regulators are vital mechanisms of drought tolerance. To curtail the effects of water stress, plants exhibit various signaling pathways and respond by upregulating antioxidant activity, accumulating of osmolytes, and changing the growth pattern by producing chaperones and stress proteins. The production of drought-tolerant transgenic plants by combining traditional breeding methods and gene manipulation helps curtail the adverse effects of drought on plants. Also, several other strategies in agricultural fields for drought management. It has been suggested that the combination of high yield stability and high relative yield under drought can serve as a useful selection criterion for determining genotypic performance in different levels of water stress (Pinter *et al.*, 1990). The results recommend spraying the Giza 6 variety of peanut crop with potassium silicate at 1500 mg l^{-1} silicate four times as applied after (35, 45, 55, and 65 days from planting) to alleviate deleterious impacts of drought stress and irrigation after depletion of 55% available soil water to save water under water deficit conditions at South Tahrir El-Beheira Governorate as this combination has a significant effect and obtained high yield and its components under this study conditions and the similar conditions areas.

Nanotechnology has been utilized in nano-fertilizers to synchronize the release and absorption of phosphorous and nitrogen in and prevent the interaction between nutrients, microorganisms, water, and air. The low efficiency of conventional chemical fertilizers could lead to a significant loss of money that could be prevented with the use of nano fertilizers. In addition, nanoparticles can increase the yield through light reduction of nitrogen gas. Generally, some benefits of nano fertilizers application include (1) an increase of efficiency and food quality due to accelerated absorption, (2) prevention of fertilizers loss by leaching and complete absorption by the plant due to availability and controlled release in the growth period, and (3) reduction in soil and water pollution and consequently food products through reduction of fertilizer leaching. Silica nanoparticles absorbed by roots produce a layer in the cell wall which helps to tolerate stresses and improve yield in plants (Derosa *et al.*, 2010).

It can be concluded that reducing irrigation water reflect in decreasing biological yield by (13 %) and grain yield by (22.4 %). However, yield and yield components were affected by the different genotypes. Also, foliar fertilizer of potassium silicate as mineral surpassed nano silicate by for yield and yield component parameters. Mineral potassium silicate fertilizer alleviates drought stress sequel by (12.46 %) for grain yield. Soil fertility parameters were affected by drought.

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الملخص العربي

تأثير الرش بسماد سيليكات البوتاسيوم على مقاومة الجفاف والنمو والمحصول لأصناف القمح المختلفة

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يعتبر الجفاف من أهم الاجهادات البيئية، مما يؤدي إلى انخفاض كبير في إنتاجية القمح. يعتبر السيليكون (Si) مفيدًا في مقاومة القمح لإجهاد الجفاف. ولهذا إجريت تجربتين حقليتين لدراسة تأثيرات إضافة سماد سيليكات البوتاسيوم معدنية أو نانوية تحت الإجهاد المائي على نمو وإنتاجية ثلاثة أصناف من القمح، وكان تصميم التجربة القطع المنشقة لمرتين في تصميم عشوائي كامل في ثلاث مكررات. أدى إجهاد الجفاف إلى انخفاض معنوي في محصول الحبوب الكلي ووزن ١٠٠٠ حبة والوزن الكلي للمحصول لجميع أصناف القمح. التسميد بسماد السيليكات أدي إلي زيادة معنوية في الإنتاجية ووزن ١٠٠٠ حبه والمحصول الكلي. وأوضحت النتائج أن الإجهاد المائي أثناء النمو النباتي وطرد السنابل خفض إنتاجية القمح. بينما الري بكميات كافية أثناء نمو المحاصيل ضروري للحصول علي أعلي انتاجية. وختاماً، فإن الرش بالسيليكات فعال في مقاومة نباتات القمح لظروف الجفاف عن طريق الحفاظ على سلامة الغشاء الخلوي والمحتوى المائي النسبي وزيادة محصولي الحبوب والتبن لجميع أصناف القمح.