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IMPACT OF FOLIAR APPLICATION WITH DIFFERENT MAGNESIUM SILICATE CONCENTRATIONS ON YIELD AND ITS COMPONENT OF SOME RICE (*ORYZA SATIVA* L.) VARIETIES AND INCREASING WATER USE EFFICIENCY UNDER NORMAL AND WATER DEFICIT CONDITIONS

Mahmoud I. Abo Yousef; Mohamed A. Gomaa; Abdelsalam B. Elsehely and Ibrahim A. Talha

Rice Research Department, Field Crops Research Institute, Agriculture Research Center, Egypt.

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ABSTRACT: Two field experiments were conducted during 2022 and 2023 seasons to assess the impact of magnesium silicate on growth, yield and its components of three rice varieties under both environmental normal condition (6 days) and water deficit (12 days) during two seasons at the farm of Rice Research and Training Center, Sakha Agricultural Research station, Kafr El-Sheikh Egypt, Strip - split plot in randomized complete block design with three replications was used. The horizontal plots were irrigation treatments and the vertical plots were located for levels of silicon (Si 0, Si 2000, Si 4000 and Si 6000) ppm, while rice varieties namely; Sakha108, Sakha 109 and Giza 179 were assigned in sub–subplots. Eight different traits were measured including morphological and yield components. Among irrigation treatments, the irrigation every four days (normal condition) recorded significantly higher grain yield and its component when compared to water deficit treatment during two seasons. Effect of the concentrates of silicate application on growth, grain yield and its components, the maximum grain yield was achieved from the application of Si 6000 ppm. Regarding to rice varieties, Sakha 108 and Giza 179 recorded the desirable values for agronomic characteristics. The optimum combination which recorded the highest rice grain yield when Sakha 108 and Giza 179 rice varieties foliated with magnesium silicate at 6000 ppm when irrigated every 6 days in normal irrigation condition during growing seasons, Hence the results showed that the higher concentrate of magnesium silicate enhanced the productivity of rice varieties under irrigation every 6 days, silicon use efficiency was higher at lower concentrations. Also, results could be concluded that, irrigation every 12 days for either Giza 179 or Sakha 108 rice varieties which gave the great grain yield and reached to 8.240 and 8.100 ton/ha respectively with an average of 8.170 ton/ha and grain yield reduction 22.43%, the total water used were 10520 and 11775 m^3/ha average of11147.5 m^3/ha with average of water saved 1221 m^3/ha.

Keywords: Irrigation treatment, magnesium silicate, Rice varieties, Agronomic silicate use efficiency, Water use efficiency.

INTRODUCTION

Rice (*Oryza sativa*) is a staple food crop that accounts for more than 22% of world's population calorie intake, with Asia and Africa as the largest consuming regions which cultivated in 114 countries around the world Gutaker *et al.* (2020).

It is one of the crops that consume large quantities of mineral fertilizers in different growth stages Naher *et al.* (2019).

It is the major source of calorie input and the staple food for further than three billion people in the world Datta *et al.* (2017); Ullah *et al.* (2017). The demand for rice is steadily adding due to an increase in global population. Still, certain constraints similar as water scarcity, pest infestation, inadequate fertilizer use and growing of low-yielding traditional varieties restrict yield increase Datta *et al.* (2017).

*Corresponding author: abo_yousef709@yahoo.com

Climate changes such as extreme weather, unexpected temperature and rainfall fluctuations have affected crop productivity Georgescu *et al.* (2011) and Lobell *et al.* (2011). Abdullah (2015) reported that a 1^{oC} increase in daily average temperature in the peninsular nation of Malaysia might reduce rice yield by 10%. In addition, according to Tao *et al.* (2008), rice yield reduction would range from 6% to 19%, 14% to 32% and 24% to 40% for global mean temperature increase of 1, 2 and $3^{O}C$, respectively. Other negative effects were also noted for atmospheric carbon dioxide (CO_2) concentration of 400–800 ppm and precipitation fluctuations of 14% Masud *et al.* (2014).

Water deficit stress increase stomata resistance, leaf hydrogen peroxide and proline concentrations, as well as, leaf lipid peroxidation in rice. However, Silicon fertilization improves these factors and alleviated membrane damage due to increasing the content of relative water in leaves. Silicon as an anti-stress agent can reduce cuticle transpiration and increase water use efficiency (Mauad *et al.,* 2016).

Generally, drought stress is one similar abiotic stress which causes major setbacks to agricultural productivity. Thus, cereal crops (e.g., rice) have differing adaptive responses to cope with drought (Javaid *et al.*, 2022).

Silicon (Si) is the alternate most abundant element in the earth's crust and soil. It has been considered to be quasi essential element for plant growth Epstein and Bloom, (2005). Also, plays a major part in improving plant growth and increasing its grains yield, and its insufficiency can lead to a serious problem in crop production, especially rice yield Meharg and Meharg (2015).

Also, silicon (Si), as a macro element, has a vital role in plants cycles. This element is the eighth most common element in nature and the alternate most common element found in soil after oxygen. One of the main functions of Si is improving plant growth and yield especially in stress condition. To achieve plant tolerance. Si promotes plant photosynthesis by favorably exposing leaves to light. Plant growth depends on several elements existing in the soil. These elements can be categorized into beneficial, essential, and toxic groups Bienert *et al.* (2008). In addition, silica plays a vital role in improving the physiological activities and enhancing cellular metabolic rates in plants to response drought stress, thus enhancing water use efficiency, growth, and biomass (Li *et al.*, 2018).

In general, drought is one of the most ruinous climate events that threaten agricultural production worldwide. Water privation inhibits cell division, resulting in short stems, reduced internodal length, truncated tilling capability, and a compromised root system (Hannan *et al.*, 2020). Related to rice, Si application has proven that Si deposition beneath cuticle could reduce water loss through transpiration and increase stem strength Ma and Yamaji (2008). Moreover Bray *et al.* (2000) stated that crops yield could decrease due to abiotic stress up to 51% to 82%.

Foliar application of silicon increases soil fertility by improving its physical properties in the root zone as well as preserving available the nutrients to plants Meena *et al.* (2015). Plants uptake silicon from the soil solution in the form of Mono-silicic acid [Si (OH)4] and its concentration increases in plant cell, the solution becomes supersaturated and changes to form a highly polymerized gel, the acid precipitates in the form of amorphous silica (SiO2-nH2O), then turns into polymers (Phytoliths) that enter into the cell wall synthesis, which in turn bind with many other biological compounds, they interact with pectin and polyphenol therefore enhance the durability and strength of the cell wall without having a direct role in the plants metabolism process Cooke and Leishman (2011).

Objectives

The current study aims to determine the effect of foliar spraying with magnesium silicate concentrations on morphological and yield to determine the best treatment in achieving the highest growth indicators and yield under normal and water-deficit conditions.

MATERIALS AND METHODS

Experimental site

This experiment was carried out at Experimental Farm for Rice Research and Training center Farm, Sakha, Kafr El-Sheikh, Egypt ((31°05′17″N 30°56′44″E, with an altitude of 7 meter) during the two successive seasons of 2022 and 2023 to study response of some rice varieties yield and its components of some rice varieties to concentrations of magnesium silicate as foliar application under normal and water deficit conditions.

Meteorological data recorded during the rice growing seasons are presented in Table 1. The Mechanical and chemical properties of the soil at the experimental site are showed in Table 2.

Table 1: Monthly maximum and minimum temperature (C^o), relative humidity% and wind speed (Km/h) at Rice Research and Training Center Sakha, Kafr EL Sheikh Governorate during 2022 and 2023 seasons.

Month	2022 season					2023 season				
	Temperature (C^0)		Relative Humidity (%)		Wind Velocity (Km/h)	Temperature (C^0)		Relative Humidity (%)		Wind Velocity (Km/h)
	Max	Min	7.30	13.00		Max	Min	7.30	13.00	
May	32.48	24.75	73.68	42.74	99.23	30.00	21.82	78.38	44.13	100.58
June	32.14	25.52	80.40	50.23	110.76	33.04	25.74	82.57	50.50	89.30
July	34.89	27.84	85.13	50.45	96.03	33.33	25.57	64.55	77.26	107.67
August	35.68	28.27	85.37	48.28	83.53	34.59	26.02	77.67	68.12	102.97
Sept.	32.55	25.03	84.13	49.57	96.70	32.99	25.97	88.87	55.97	96.67
Oct.	28.5	22.3	76.50	61.20	80.23	28.75	20.79	91.26	56.77	84.97

Table 2: Mechanical and chemical analysis of soil for the experimental site.

Soil analysis	2022 season	2023 season
Mechanical analysis		
Clay %	59.85	60.70
Silt %	30.30	30.10
Sand %	10.65	10.55
Texture class	Clay	Clay
Chemical analysis		
Organic matter%	1.68	1.65
E.C. Ds/m	2.03	2.00
pH	8.10	8.04
Total N ppm	485	455
Available P ppm	15.5	14.1
Available K ppm	327	330
Available Zn ppm	0.89	0.90

Plant material

The genetic materials used in this investigation included three rice varieties, namely Sakha 108, Sakha 109 and Giza 179 which received from the Germplasm Unit of the Rice Research Center as presented in Table 3.

Table 3: The studied three rice genotypes with their pedigree and origin.

No.	Rice genotypes	Pedigree	Origin
1	Sakha 108	Sakha 101 x HR5824-B-3-2-3//Sakha 101	Egypt
2	Sakha 109	Sakha 105 x Sakha 101	Egypt
3	Giza 179	GZ1368-5-5-4/GZ6296	Egypt

Treatments and experimental design

The experiments were carried out in strip split-plot design and the factors were distributed according in Randomized Complete Blocks Design (RCBD) arrangement, where the irrigation treatment normal irrigation (irrigation every 6 days) and water deficit (irrigation every 12 days) were the horizontal plot and the concentrations of silicates; Control (without), 2000, 4000 and 6000 ppm) were the vertical plot, while, rice varieties (Sakha 108, Sakha 109 and Giza 179) were allocated in the sub sub-plot.

Date of sowing was in May 1stduring 2022 and 2023 seasons. The rice varieties were transplanted in seven rows with five meters long as a single plant, at a distance of 20 x 20 cm among plants. Rice varieties were grown in a Randomized Complete Block Design (RCBD) with three replications.

The nursery land was fertilized with calcium superphosphate (15.5% P_2O_5) at a rate of 37 kg P_2O_5 ha^{-1} before plowing. Nitrogen was added in the form of urea (46.0% N) at a rate of 165 kg N fed^{-1} after leveling and immediately before planting.

Weeds were controlled chemically with Saturn 50% [S-(4-chlorophenolmethyl) diethylcarbamothiate] at a rate of 4.8 L ha^{-1}. The permanent field was fertilized with 50 kg P_2O_5 ha^{-1} before plowing. After 30 days of planting, seedlings were carefully pulled from the nursery and manually transplanted into plots (10 m^2) with a spacing of 20 × 20 cm at a rate of one seedling mound. Seven days after transplanting, Saturn 50% herbicide was added at a rate of 4.76 liters per ha^{-1}.

The plots remained flooded until two weeks before harvest. Potassium fertilizer was added in the form of potassium sulphate (48% K_2O) at a rate of 25 kg/fed^{-1} to the soil in two equal doses 30 and 45 days after transplanting. All the recommended cultural practices as recommended by RRTC (2021) for rice were applied during the growing seasons.

Data were recorded on 25 randomly selected plants from each replicate and the mean values were used for statistical analysis. In this study fifteen morphological and yield and yield component include, days to heading (day), plant height (cm), chlorophyll content (SPAD), flag leaf area (cm^2), number of panicles m^{-2}, number of filled grains per panicle, 1000-grain weight (g), and grain yield (t ha^{-1}) as recommended by Standard Evaluation System (SES) of IRRI (2016).

Agronomic Silicon Use Efficiency (ASiUE)

The agronomic SiUE refers to an increase in rice yield (kg ha^{-1}) per unit of Si applied Dobermann, and Fairhurst, (2000).

Agronomic SiUE = Yield$_t$–Yield$_c$ / Si

Where,

Yield t = rice yield from Si application (kg/ha),

Yield 0 = rice yield from without Si application (Kg/ha),

Si = amount of Si applied (ppm/L).

The measured physiological and yield characters after deficit irrigation conditions and its component characters as well as drought susceptibility index (DSI) were determined. The DSI for each genotype was calculated according to the formula given by Negarestani *et al.* (2019).

$$DSI= \frac{Y_n - Y_s}{Y_s}$$

Where Yn is yield under normal irrigation condition and YS is yield under drought condition.

Water use efficiency (W U E) was calculated as the weight of grain yield (kg) per unit of water used one m^3 (kg grains/ m^3 water). Water Use

Efficiency (WUE) was determined according to Israelsen and Hansen (1962) as follows :

$$WUE = \frac{\text{Rice grain yield (kg/ha)}}{\text{Total water used (m}^3\text{/ha)}}$$

The relative yield reduction (YR) of the crop challenged by water deficit under field conditions was estimated using equation according calculated as Venkatesan *et al.* (2005) and Servestani *et al.* (2008)

C. Reduction% for yield and its components =

$$1- \frac{\text{Trait under Stress}}{\text{Trait under normal}} \times 100$$

Statistical Analysis

Data obtained were subjected to analysis of variance according to Gomez and Gomez (1984). The means treatments were compared when the differences between them were significant using Duncan's multiple range test (Duncan, 1955) at the probability level of 0.05 (Al-Rawi and Khalaf Allah, 1980). All statistical analysis were performed using the analysis of variance technique via the computer software package "COSTAT".

RESULTS AND DISCUSSION

1- Morphological and physiological characteristics

Results obtained a highly significant difference was obtained among various irrigation treatments, concentrations of magnesium silicate and rice varieties, as well as, their interactions on morphological and physiological characteristics as shown in Table 4.

Results showed differences between irrigation treatment which the highest values for growth characteristics achieved under normal irrigation condition (irrigation every 6 days) comparing with water deficit irrigation condition, as drought stress is one of the important environmental stress factors that affects plant growth and development Singh *et al.* (2017).

There were high significant differences between magnesium silicate concentrations for physiological and growth characters during two seasons. The increase in magnesium silicate concentration led to improve plant height, chlorophyll content and flag leaf area characters in addition to record the desirable values for days to heading for the rice plants to become more erect and reduced self-shading of lower canopy leaves. This makes plants more efficient in photosynthesis and more able to exploit the available space to intercept solar radiation, thus increasing the leaf area index, dry matter, and plant height. A similar result was found by De Oliveira *et al.* (2016) and Pati *et al.* (2016).

Concerning the rice varieties, there were high significant between rice varieties for the morphysiological characteristics. Giza 179 rice variety gave the desirable values for days to heading, plant height and leaf area while, Sakha 108 and Sakha 109rice varieties were superior for chlorophyll content in both seasons (Table 4). This may be due to the different genetic backgrounds of rice genotypes. Similar results were also reported by Patil *et al.* (2017), and Gaballah *et al.* (2021).

The interaction between irrigation treatments and magnesium silicate concentrations and rice varieties significantly produced for growth during two seasons (Table 4).

Results illustrated that water deficit reduced plant height, leaf area and chlorophyll content. This may be due to decreased cell swelling, which prevents cell division and expansion. Flag leaf area is a critical factor affecting crop growth and production and is mainly responsible for the plant growth activity. The decline in flag leaf area in the current study might have resulted from the compact size and senescence of leaves, as well as the short growing season Pascual, and Wang (2017).

Table 4: Days to heading (day), plant height (cm), chlorophyll content (SPAD) and flag leaf area (cm^2) as affected by different irrigation treatment and of magnesium silicate concentrates and rice varieties and their interactions during 2022 and 2023 seasons.

Main effect	Days to heading (day)		Plant height (cm)		Chlorophyll content (SPAD)		Flag leaf area (cm^2)	
	2022	2023	2022	2023	2022	2023	2022	2023
Irrigation treatments (IT)								
Normal (6 days)	97.78 a	97.05 a	99.89 a	101.17 a	42.87 a	42.95 a	34.66 a	36.29 a
Water Deficit (12 days)	95.81 b	95.00 b	85.19 b	84.64 b	36.69 b	37.54 b	30.34 b	31.94 b
F - test	*	**	**	**	**	**	**	**
Si concentration (SC)								
Control	99.17 a	98.55 a	90.88 c	91.13 c	35.30 d	35.77 d	28.48 d	29.44 d
2000 ppm	97.33 b	96.66 b	92.35 b	92.76 b	39.14 c	40.29 c	31.64 c	33.75 c
4000 ppm	96.50 c	95.77 c	93.31 a	93.91 a	41.15 b	41.64 b	33.85 b	36.08 b
6000 ppm	94.17 d	93.11 d	93.62 a	93.82 a	43.51 a	43.29 a	36.03 a	37.22 a
F - test	**	**	**	**	**	**	**	**
Rice varieties (RV)								
Sakha 108	101.13 a	100.29 a	95.41 a	95.70 a	41.41 a	42.03 a	31.26 b	32.65 b
Sakha 109	96.42 b	95.87 b	91.26 b	95.70 b	40.93 a	40.68 b	30.69 b	32.61 b
Giza 179	92.83 c	91.91 c	90.95 b	91.23 c	36.99 b	38.02 c	35.55 a	37.09 a
F - test	**	**	**	**	**	**	**	**
Interaction								
IT* SC	**	**	NS	*	**	*	*	**
IT * RV	**	**	**	**	**	NS	**	*
SC * RV	**	**	**	**	**	**	**	**
IT * SC*RV	**	**	*	**	**	**	**	**

*, ** and NS indicate $p<0.05$, $p<0.01$ and not significant, respectively. In each factor means followed by a common letter are not significantly different at the 5% level by DMRT.

The interaction between irrigation treatments, magnesium silicate concentration and rice varieties, as well as, between irrigation treatments and concentration with rice genotypes were significant for days to heading, plant height, chlorophyll content and flag leaf area.

The interaction between irrigation treatments and magnesium silicate concentration was significantly the desirable values for days to heading recorded by application magnesium silicate at rate of 6000 ppm under water deficit condition. The short stature values for plant height were recorded under water deficit condition without applying magnesium silicate as shown in Table 5. These results support the findings of Patil *et al.* (2017). The interaction between irrigation treatments and rice varieties was significant for number of days to heading and plant height during the two seasons Table 6. The desired values for these characteristics were achieved under water deficit condition by foliar spraying with magnesium silicate at rate of 6000 ppm during two consecutive seasons.

The interaction between magnesium silicate concentration and rice varieties was significant with respect to the number of days to heading and plant height during two seasons (Table 7). It was clear from the obtained results that the shortest flowering and plants were recorded by the rice genotype Giza 179 with 6000 ppm and without magnesium silicate treatment for the number of days to heading and plant height, respectively. However, un desirable values for days to heading and plant height were obtained with the Sakha 108 rice variety without magnesium silicate concentrate for the number of days to heading and foliar application at rate of 6000 ppm for plant height trait during the 2022 and 2023 seasons.

The interaction between irrigation treatment, magnesium silicate concentrations and rice genotype were significant for the number of days to heading and plant height in both seasons as shown in Table 8. Results reported that the Giza 179 rice variety gave the minimum number of days to heading by spraying at rate of 6000 ppm magnesium silicate treatment under water deficit treatment. While, Sakha 108 rice variety recorded the highest number of days to heading by without magnesium silicate application under normal irrigation condition during 2022 and 2023 seasons.

Plant height was also significantly affected by irrigation treatment, magnesium silicate concentrate and rice varieties during the two seasons, the shortest plants were recorded (80.97 cm and 80.33 cm) for Sakha 109 rice variety without applying magnesium silicate under water deficit condition during two seasons, while, the tallest plants recorded (104.33 and 105.40 cm) with foliar application at rate of 6000 ppm magnesium silicate of Sakha 108 rice variety under normal condition during two seasons as shown in Table 8. Accumulation of silicon in the plant reduces the parts' residence and enhances their resistance to biotic and abiotic stress.

Table 5: Effect of the interaction between different irrigation treatments and magnesium silicate concentration on the number of days to heading (day) and plant height (cm) during 2022 and 2023 seasons.

Treatment	Days to heading (day)				Plant height (cm)			
	2022		2023		2022		2023	
Si concentration	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit
Control	100.55 a	97.77 b	100.44 a	96.66 c	98.06 d	83.70 g	99.37 d	82.88 h
2000 ppm	98.44 b	96.22 c	98.11 b	95.22 d	99.50 c	85.21 f	100.96 c	84.55 g
4000 ppm	97.66 b	95.33 d	96.55 c	95.00 d	100.55 b	86.06 e	101.87 b	85.94 e
6000 ppm	94.44 e	93.88 e	93.11 e	93.11 e	101.44 a	85.79 e	102.47 a	85.17 f

Table 6: The effect of the interaction between different irrigation treatments and rice varieties on the number of days to heading (day) and plant height (cm) during 2022 and 2023 seasons.

Treatment	Days to heading (day)				Plant height (cm)			
	2022		2023		2022		2023	
Rice varieties	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit
Sakha 108	102.41 a	99.83 b	101.83 a	98.75 b	102.70 a	88.11 d	103.73 a	87.66 d
Sakha 109	97.91 c	94.91 d	97.16 c	94.58 d	100.10 b	82.42 f	101.61 b	81.95 f
Giza 179	93.00 e	92.66 e	92.16 e	91.66 e	96.85 c	85.04 e	98.17 c	84.30 e

Table 7: Effect of the interaction between different magnesium silicate concentration and rice varieties on the number of days to heading (day) and plant height (cm) during 2022 and 2023 seasons.

Treatment	Days to heading (day)						Plant height (cm)					
	2022			2023			2022			2023		
Si concentration	Sakha 108	Sakha 109	Giza 179	Sakha 108	Sakha 109	Giza 179	Sakha 108	Sakha 109	Giza 179	Sakha 108	Sakha 109	Giza 179
Control	103.33 a	98.16 d	96.00 e	102.66 a	97.50 d	95.50 e	93.46 c	89.86 fg	89.32 g	93.65 c	90.30 hi	89.43 i
2000 ppm	101.83b	96.66 e	93.5 g	101 b	96.33 e	92.66 f	95.48 b	90.97 e	90.61 ef	95.78 b	91.75 efg	90.75 gh
4000 ppm	100.83 c	96.5 e	92.16 h	100.00 c	96.33 e	91.00 g	95.81 b	92.01 d	92.10 d	95.66 b	92.89 cde	93.16 cd
6000 ppm	98.5 d	94.33 f	89.66 i	97.50 d	93.33 f	88.50 i	96.88 a	92.21 d	91.76 d	97.70 a	92.18 def	91.6 fg

Table 8: Effect of the interaction between different magnesium silicate concentration and rice varieties on the number of days to heading (day) and plant height (cm) and plant height (cm) under normal and water deficit condition during 2022 and 2023 seasons.

Treatment		Days to heading (day)				Plant height (cm)			
		2022		2023		2022		2023	
Si concentration	Rice varieties	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit
Control	Sakha 108	104.33 a	102.33 b	104.33 a	101.00 bc	100.50 cd	86.43 k	101.98 c	85.33 j
	Sakha 109	100.00 c	96.33 fg	99.66 cd	95.33 fgh	98.75 e	80.97 o	100.28 e	80.33 n
	Giza 179	97.33 ef	94.66 h	97.33 efg	93.66 hi	94.93 g	83.71 m	95.86 g	83.00 kl
2000 ppm	Sakha 108	104.33 a	99.33 cd	103.66 a	98.33 de	102.66 b	88.29 j	103.90 b	87.66 i
	Sakha 109	97.33 ef	96.00 fg	97.33 efg	95.33 fgh	99.66 de	82.27 n	101.16 d	82.33 lm
	Giza 179	93.66 i	93.33 i	93.33 hij	92.00 ijk	96.16 g	85.06 l	97.83 f	83.66 k
4000 ppm	Sakha 108	102.33 b	99.33 cd	101.66 b	98.33 de	103.33 b	88.29 j	103.66 b	87.66 i
	Sakha 109	98.00 de	95.00 gh	96.66 efg	96 efg	100.66 cd	83.36 m	102.62 c	83.16 kl
	Giza 179	92.66 ij	91.66 jk	91.33 k	90.66 k	97.66 f	86.53 k	99.33 e	87.00 i
6000 ppm	Sakha 108	98.66 cde	98.33 de	97.66 ef	97.33 efg	104.33 a	89.44 i	105.40 a	90.00 h
	Sakha 109	96.33 fg	92.33 ij	95.00 gh	91.66 jk	101.33 c	83.09 mn	102.36 c	82.00 m
	Giza 179	88.33 l	91.00 k	86.66 l	90.33 k	98.66 e	84.85 l	99.66 e	83.53 k

Silica plays a vital role in promoting cell elongation as a result of enhanced cell extensibility in rice Hossain *et al.* (2002) and promotion of K uptake Liang *et al.* (1999). Gong *et al.* (2003) observed that Si increases plant height. These results are coincided with those reported by Shashidhar *et al.* (2008), Awais *et al.* (2012) and Ahmad *et al.* (2013). Moreover, Si plays an important role in reducing the susceptibility of plants to biotic and abiotic environmental stresses Ma and Yamaji (2006).

The interaction between irrigation treatments and magnesium silicate concentration showed the highest means for chlorophyll content and flag leaf area (cm^2) in two seasons (Table 9). The best combination of normal irrigation (4 days) with spraying magnesium silicate concentrates 4000 and 6000 ppm recorded the highest values for flag leaf area and chlorophyll content (46.96 46.10 SPAD, 37.20, 38.44 cm^2) respectively. However, the lowest means were (32.48 and 33.71 SPAD) for chlorophyll content and (25.93 and 26.71 cm^2) for flag leaf area gave in water deficit condition with the treatment (without magnesium silicate) in 2022 and 2023 seasons Table 9. These results support the findings of Patil *et al.* (2017) obtained leaf area is a critical factor affecting crop growth and production and is mainly responsible for the photosynthetic activity of the plant. The decrease in flag leaf area in the study may be due to small size and leaf senescence, as well as short growing season.

The interaction between irrigation treatments and rice varieties was significant for chlorophyll content and flag leaf area during two seasons under the study (Table 10). The highest means values for chlorophyll and flag leaf area recorded with Giza 179, Sakha 108 and Sakha 109 rice varieties, respectively, in normal condition (44.73, 44.83 SPAD, 36.64, 38.78 cm^2). However, the lowest value (34.63 and 35.56 SPAD, 27.05, 30.05 cm^2) were obtained with Sakha 109 and Giza 179 rice varieties under water deficit during two seasons, respectively.

Table 9: Effect of the interaction between different irrigation treatments and magnesium silicate concentration on flag leaf area (cm^2) and chlorophyll content (SPAD) during 2022 and 2023 seasons.

Treatment	Chlorophyll content (SPAD)				Flag leaf area (cm^2)			
	2022		2023		2022		2023	
Si concentration	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit
Control	38.13 e	32.48 h	37.82 e	33.71 f	31.03 c	25.93 e	32.16 d	26.71 e
2000 ppm	41.96 c	36.33 g	43.01 c	37.56 e	34.42 b	28.87 d	36.28 b	31.22 d
4000 ppm	44.43 b	37.88 f	44.87 b	38.41 e	36.00 a	31.70 c	38.44 a	33.71 c
6000 ppm	46.96 a	40.06 d	46.10 a	40.48 d	37.20 a	34.85 b	38.29 a	36.14 b

Table 10: Effect of the interaction between different irrigation treatments and rice varieties on flag leaf area (cm^2) and chlorophyll content (SPAD) during 2022 and 2023 seasons.

Treatment	Chlorophyll content (SPAD)				Flag leaf area (cm^2)			
	2022		2023		2022		2023	
Rice varieties	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit
Sakha 108	44.52 b	38.29 d	44.83 a	39.24 d	33.03 c	29.50 d	34.92 b	30.38 c
akha 109	44.73 a	37.14 e	43.53 b	37.83 e	34.33 b	27.05 e	35.18 b	30.05 c
Giza 179	39.36 c	34.63 f	40.49 c	35.56 f	36.64 a	34.46 b	38.78 a	35.40 b

The interaction between magnesium silicate concentration and rice varieties was significant for chlorophyll content and flag leaf area during two seasons (Table 11). It was clear from the results obtained that the desirable values were (44.26, 44.53 and 44.63 SPAD) showed by the Sakha 108 rice variety with magnesium silicate foliar application at rate of 4000 and 6000 ppm for chlorophyll content, while, the best combination growing the Giza 179 rice variety with foliar magnesium silicate concentrate 6000 ppm achieved the highest means for flag leaf area (39.81 and 42.96 cm^2) in 2022 and 2023 seasons. However, the un-desirable means for flag leaf area and chlorophyll content were (32.48 and 33.71 SPAD, 27.73, 29.07 cm^2) showed by growing the Sakha 108 and Giza 179 rice varieties without magnesium silicate treatment, respectively.

Chlorophyll content (SPAD values) was affected by the interaction between irrigation treatment, silicate concentrates and rice varieties during 2022 and 2023 seasons are presented in Table 12. Data clarified that, Sakha 108 rice variety produced the highest mean of chlorophyll content in the leaves reached 47.60, 47.72 SPAD with application foliar magnesium silicate at rate of 6000 ppm under normal irrigation condition compared with Giza 179 rice variety recorded the mean 30.24 and 32.61 SPAD by untreated plants with silica in the two seasons under water deficit condition. The results of the current study regarding the stimulating effect of silica fertilization are consistent with the findings of Patel *et al.*, (2018) the significant role of calcium silicate fertilization at levels (150, 300 and 450 kg Si ha^{-1}) is increasing chlorophyll content, plant height, grain yield, biological yield and harvest index with increasing levels of fertilizer addition in a positive manner, respectively.

Flag leaf area as affected by the interaction between irrigation treatment, silicate concentrate and rice varieties were found in Table 12, the results showed the highest values (40.13 and 45.15 cm^2) for flag leaf area was recorded for Giza 179 rice variety treated with magnesium silicate spraying at rate of 6000 ppm under normal irrigation condition, while the lowest flag leaf area values were (24.21 and 24.90 cm^2) recorded for Sakha 109 and Sakha 108 rice varieties when untreated any silicate or foliar at concentrate of 2000 ppm in the two seasons under water deficit condition. These findings are in harmony with those observed by Pati *et al.* (2016).

This demonstrates the important role of magnesium silicate on a broader scale when applying magnesium. The stimulating effect of silicates on these growth traits may be the result of enhancing cell division and enlargement, which reflects positively on flag leaf area.

Yield and yield components characteristics

The results obtained, there were differences between both environmental which the highest values for yield characteristics recorded under normal irrigation (irrigation 6 days) condition comparing with water deficit irrigation condition (irrigation every 12 days).

Results in Table 13 showed the effect of irrigation treatments and magnesium silicate concentration, rice varieties and their interactions on number of panicles per m^{-2}, number of filled grains per panicle, weight of 1000-grain and grain yield t/ ha during 2022 and 2023 seasons.

Results revealed that the number of panicles per m^{-2}, number of filled grains per panicle, 1000-grain weight and grain yield t/ ha were highly affected by irrigation treatments through two seasons. The maximum values for number of panicles per m^{-2}, number of filled grains per panicle, weight of 1000-grain and weight of grain yield t/ ha traits were recorded in normal irrigation, but, the lowest means value for the same characteristics were recorded under water deficit condition. This enhancement of yield components through magnesium silicate application may be due to the effectiveness of silicon in enhancing carbohydrate assimilation in rice panicles, leading to improved grain filling rate Jawahar *et al.* (2015). Similar results were also obtained by Arab *et al.* (2011), Gholami and Fallah (2013) and Dallagnole *et al.* (2014). In this regard, other researchers found that application of Si in different sources on rice plants caused an increase in the number of flower panicles m^{-2} (Ahmed *et al.*, 2013) as well as leaf area index and dry matter production/hill, Mohamed *et al.* (2015).

Table 11: Effect of the interaction between different magnesium silicate concentration and rice varieties on flag leaf area (cm^2) and chlorophyll content (SPAD) during 2022 and 2023 seasons.

Treatment	Chlorophyll content (SPAD)						Flag leaf area (cm^2)					
	2022			2023			2022			2023		
Si concentration	Sakha 108	Sakha 109	Giza 179	Sakha 108	Sakha 109	Giza 179	Sakha 108	Sakha 109	Giza 179	Sakha 108	Sakha 109	Giza 179
Control	36.65 e	36.96 e	32.31 g	36.41 d	36.60 d	34.30 e	27.73 g	27.57 g	30.15 ef	29.07 g	29.63 g	29.61 g
2000 ppm	41.13 c	42.40 b	33.90 f	42.58 b	41.87 b	36.41 d	30.97 de	28.99 fg	34.97 c	32.80 ef	32.04 f	36.40 c
4000 ppm	43.58ab	41.10 c	38.79 d	44.63 a	41.52 b	38.78 c	32.41 d	31.87 d	37.27b	34.80 d	34.03 de	39.40 b
6000 ppm	44.26 a	43.28 ab	42.98 ab	44.53 a	42.74 b	42.60 b	33.94 c	34.33 c	39.81 a	33.95 de	34.75 d	42.96 a

Table 12: Effect of the interaction between different magnesium silicate concentration and rice varieties on chlorophyll content (SPAD and flag leaf area (cm^2) under normal and water deficit condition during 2022 and 2023 seasons.

Treatment		Chlorophyll content (SPAD)				Flag leaf area (cm^2)			
		2022		2023		2022		2023	
Si concentration	Rice varieties	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit
Control	Sakha 108	39.41 k	33.89 s	38.15 f	34.67 h	31.03 d-g	24.43 j	33.25 f-i	24.90 l
	Sakha 109	40.61 i	33.30 t	39.33 ef	33.86 hi	30.14 fgh	24.99 j	32.3 hij	26.97 k
	Giza 179	34.37 r	30.24 v	36.00 g	32.61 I	31.92 c-f	28.38 hi	30.95 ij	28.27 k
2000 ppm	Sakha 108	44.23 f	38.04 n	45.03 bc	40.13 de	32.72 c-f	29.23 ghi	35.21 def	30.38 j
	Sakha 109	45.60 d	39.21 l	44.00 c	39.73 def	33.77 cd	24.21 j	35.76 c-f	28.33 k
	Giza 179	36.06 q	31.73 u	40 de	32.83 i	36.78 b	33.16 cde	37.86 c	34.94 efg
4000 ppm	Sakha 108	46.86 b	40.30 j	48.43 a	40.83 de	33.92 c	30.9 efg	37.01 cde	32.6 g-j
	Sakha 109	45.16 e	37.03 o	44.87 bc	38.16 f	36.38 b	27.36 i	37.15 cde	30.91 ij
	Giza 179	41.26 g	36.31 p	41.33 d	36.24 g	37.72 b	36.83 b	41.17 b	37.63 cd
6000 ppm	Sakha 108	47.60 a	40.93 h	47.72 a	41.33 d	34.45 c	33.43 cde	34.23 fgh	33.66 fgh
	Sakha 109	47.56 a	39.00 m	45.92 b	39.56 def	37.01 b	31.65 c-g	35.50 c-f	34 fgh
	Giza 179	45.73 c	40.24 j	44.65 bc	40.55 de	40.13 a	39.48 a	45.15 a	40.76 b

Table 13: Number of panicles m^{-2}, number of filled grains panicle^{-1}, 1000- grain weight and grain yield t ha^{-1} as affected by different irrigation treatments and of magnesium silicate concentration sand rice varieties and their interaction during 2022 and 2023 seasons.

Main effect	Number of panicles m^{-2}		Number of filled grains panicle^{-1}		1000- grain weight (g)		Grain yield t ha^{-1}	
	2022	2023	2022	2023	2022	2023	2022	2023
Irrigation treatments (IT)								
Normal (6 days)	454.47 a	453.91 a	138.16 a	139.92 a	27.91 a	28.02 a	10.34 a	10.38 a
Water Deficit (12 days)	388.32 b	385.55 b	110.95 b	111.70 b	23.87 b	23.92 b	7.86 b	7.83
F - test	**	**	**	**	**	**	**	**
Si concentration (SC)								
Control	383.42 d	378.83 d	116.87 d	117.62 d	25.41d	25.47 d	8.13 d	8.24 d
2000 ppm	399.66 c	397.83 c	122.42 c	123.16 c	25.66 c	25.66 c	8.83 c	8.84 c
4000 ppm	438.23 b	438.5 b	125.92 b	127.91 b	26.15 b	26.20 b	9.50 b	9.46 b
6000 ppm	464.28 a	463.77 a	133.01 a	134.55 a	26.37 a	26.55 a	9.95 a	9.89 a
F - test	**	**	**	**	**	**	**	**
Rice varieties (RV)								
Sakha 108	435.16 b	433.91 b	130.92 a	132.48 a	26.24 a	26.31a	9.35 a	9.29 b
Sakha 109	386.14 c	383.25 c	120.93 b	123.32 b	25.32 c	25.52 c	8.62 b	8.60 c
Giza 179	442.89 a	442.04 a	121.81 b	121.62 c	26.12 b	26.08 b	9.33 a	9.43 a
F - test	**	**	**	**	**	**	**	**
Interaction								
IT* SL	**	**	**	**	**	**	**	**
IT * RV	**	**	**	**	**	**	**	**
SL * RV	**	**	**	*	**	**	**	**
IT * SL*RV	**	**	**	**	**	**	**	**

*, ** and NS indicate p<0.05, p<0.01 and not significant, respectively. In each factor means followed by a common letter are not significantly different at the 5% level by DMRT.

Results in Table 13 showed that there are significant differences between concentration of magnesium silicate in some characters namely number of panicles per m^{-2}, number of filled grains per panicle, 1000-grain weight and grain yield t/ ha. Increasing concentration of magnesium silicate up to 6000 ppm recorded the best means value for some yield characters comparing with untreated in two experiments. Cuong *et al.* (2017) reported that the number of grains per panicle increasing by increasing silicon application.

For rice varieties, there were high significant between rice varieties for yield component characteristics. The Sakha 108 rice variety gave the highest means of number of filled grains/ panicle and weight of 1000-grain and weight of grain yield t/ ha while that, the Giza 179 rice variety recorded the best means for number of panicles m^{-2} and grain yield t/ ha. But, the Sakha 109 rice variety gave the lowest means of the same traits as shown in Table 13. This may be due to the different genetic backgrounds of rice genotypes. Similar results were also reported by Patil *et al.* (2017), and Gaballah *et al.* (2021).

The interaction between irrigation treatment, magnesium silicate concentration and rice genotypes were significant for number of panicles m^{-2}, number of filled grains panicle^{-1}, 1000-grain weight and grain yield t/ ha.

The interaction between irrigation treatments and magnesium silicate concentrates significantly produced the highest means number of panicles $m^{-2}$and number of filled grains panicle^{-1} in 2022 and 2023 seasons (Table 14). The best combination of normal irrigation (6 days) with spraying magnesium silicate concentrate (6000 ppm) recorded the highest values number of panicles m^{-2} and number of filled grains panicle^{-1} (500.77, 501.88 panicles, 147.43 and 149.22 grain), respectively. However, the lowest means were (353.17 and 350.33 panicles) for number of panicles m^{-2} and (102.58 and 102.99 grains) for number of filled grains panicle^{-1} gave in water deficit condition with control (without magnesium silicate) treatment in the two 2022 and 2023 seasons (Table 14). Cuong *et al.* (2017) reported that with addition of silicon, rice grain yield was improved due to increased growth, yield components, and better absorption of nutrients. Silicon application, especially at reproductive stages increases chlorophyll content, number of panicles per hill, percentage of spikelet's filled, and finally improves rice grain yield, that may be referred to the role magnesium silicate for increasing suppressed the tillering ability and gave the highest of panicles of number Tamai and Ma, (2008).

The interaction between irrigation treatments and rice varieties was significant on number of panicles m^{-2} and number of filled grains panicle^{-1}in both two seasons (Table 15). The highest values for number of panicles m^{-2} and number of filled grains panicle^{-1} achieved with Giza 179 and Sakha 108rice varieties in normal irrigation condition (471.16, 472.25 panicle, 144.36 and 145.52 grains). But, the lowest means values (347.95 and 345.83 panicle, 105.12 and 106.73 grains) were obtained with Sakha 109 rice variety under water deficit during two seasons, respectively. In similar results, the researchers were studying different sources of silicon and methods of applications as soil and NPs foliar reported that the maximum fertile tiller number per hill was obtained by nano-SiO2 foliar application for two crop Yazdpour *et al.* (2014). In addition, potassium silicate as, also, source of potassium which has an important role in increasing photosynthesis rate and increase stored carbohydrates and grain filling Szczerba *et al.* (2009). These positive effects of silicon application in improving rice grain yield were, also, obtained by Hakim *et al.* (2012) and Manal Emam *et al.* (2014).

The interaction between magnesium silicate concentration and rice varieties was significant with respect to the number of panicles m^{-2} and the number of filled grains panicle^{-1} during two seasons (Table 16). It was revealed from the results obtained that the highest values were (482.53 and 482.00 panicle) showed by Giza 179 rice variety with foliar application magnesium silicate at 6000 ppm, while the best combination growing Sakha 108 the rice variety with foliar magnesium silicate concentrate 6000 ppm gave the highest mean values number of filled grains panicle^{-1} (141.18 and 140.94 grains) during both seasons in normal irrigation condition. However, the lowest means values for the same traits were (330.73, 331.66 panicle, 94.93 and 95.91 grains) showed by growing Sakha 109the rice variety without magnesium silicate treatment under water deficit condition. Application of silica at reproductive stages of rice had a very positive effect on improving number of filled grains per panicle Lavinsky *et al.* (2016), which confirms the results of this experiment.

For the number of panicles m^{-2}, the (Table 17) revealed that, Sakha 108 and Giza 179 the rice varieties gave the highest values for number of panicles m^{-2} with foliar application magnesium silicate at concentrate 6000 ppm (516.33 and 518.33 panicle). For The combination of using potassium silicate at rate of 6000 ppm for Sakha 108 the rice variety recorded the highest number of filled grains/ panicles (166.00 and 164.66 grains), that may be referred to the role potassium and magnesium silicate for increasing tillering ability and gave the highest of number of panicles. Cuong *et al.* (2017) reported that with the addition of silicon, rice grain yield was improved due to increased growth, yield components and better absorption of nutrients. Application of Silicon, especially at reproductive stages increases chlorophyll content, the number of panicles per hill, percentage of filled spikelet's and finally improves rice grain yield Tamai and Ma, (2008). In similar results, the researchers by studying different sources of silicon in the methods of soil and NPs foliar application reported that the maximum panicles number per hill was obtained by nano-SiO2 foliar application for two crop years Yazdpour *et al.* (2014).

The interaction between irrigation treatments and magnesium silicate concentrates significantly achieved the highest means value weight of 1000-grain weight and grain yield t ha^{-1} in both two seasons (Table 18). The best combination of normal irrigation (6 days) with spraying magnesium silicate concentration 6000 ppm recorded the highest values of 1000-grain weight (g) and grain yield t ha^{-1} (28.29, 28.51 g, 11.01 and 11.02 t/ha), respectively. But the lowest mean values were (24.08, 23.33 g) for 1000-grain weight and (6.76 and 6.82 t/ ha) for weight of grain yield t ha^{-1}recordedwith water deficit condition without magnesium silicate treatment during two seasons (Table 18). The erectness exposed the plant to sunlight and enhances the photosynthetic activity and assimilation of constituents. Applying silicon to rice plant enhances plant's sturdiness and helps grow erect without lodging. This assimilation enhances the growth and development of the crop and reduces and occurrence of pests and disease. The crop's vigorous growth might be the reason for increasing the grain yield. The response of rice to Si application was increased in harvest index over the control, these results corroborate those obtained by Detmann *et al.* (2012), Aarekar *et al.* (2014) and Patil *et al.* (2017).

Table 14: Effect of the interaction between different irrigation treatments and magnesium silicate concentration on number of panicles m^{-2} and number of filled grains $panicle^{-1}$ during 2022 and 2023 seasons.

Treatment	Number of panicles m^{-2}				Number of filled grains $panicle^{-1}$			
	2022		2023		2022		2023	
Si concentration	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit
Control	413.66 e	353.17 h	407.3 e	350.3 h	131.16 d	102.5 g	132.2 d	102.9 h
2000 ppm	431.00 c	368.33 g	430.44 c	365.22 g	134.77 c	110.06 f	136.33 c	109.99 g
4000 ppm	472.44 b	404.02 f	476.00 b	401.00 f	139.26 b	112.57 e	141.88 b	113.94 g
6000 ppm	500.77 a	427.78 d	501.88 a	425.66 d	147.43 a	118.59 d	149.22 a	119.87 f

Table 15: Effect of the interaction between different irrigation treatments and rice varieties on number of panicles m^{-2} and number of filled grains $panicle^{-1}$ during 2022 and 2023 seasons.

Treatment	Number of panicles m^{-2}				Number of filled grains $panicle^{-1}$			
	2022		2023		2022		2023	
Rice varieties	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit
Sakha 108	467.91 b	402.40 e	468.83 b	399.00 f	144.36 a	117.49 d	145.52 a	119.45 d
Sakha 109	424.33 c	347.95 f	420.66 c	345.83 e	136.74 c	105.12 e	139.91 b	106.73 f
Giza 179	471.16 a	414.62 d	472.25 a	411.83 d	133.37 b	110.25 f	134.33 c	108.91e

Table 16: Effect of the interaction between different magnesium silicate concentration and rice varieties on number of panicles m^{-2} and number of filled grains $panicle^{-1}$ during 2022 and 2023 seasons.

Treatment	Number of panicles m^{-2}						Number of filled grains $panicle^{-1}$					
	2022			2023			2022			2023		
Si concentration	Sakha 108	Sakha 109	Giza 179	Sakha 108	Sakha 109	Giza 179	Sakha 108	Sakha 109	Giza 179	Sakha 108	Sakha 109	Giza 179
Control	388.74 fg	367.03 h	394.48 f	387.83gh	357.33 j	391.33 g	123.88 e	112.55 g	114.20 g	125.56 e	114.79 h	112.50 i
2000 ppm	408.89 e	364.60 h	425.50 d	408.83 e	362.83 i	421.83 f	126.36 d	120.27 f	120.63 f	128.79 d	121.20 f	119.49 g
4000 ppm	462.83 c	382.80 g	469.06 b	458.83 c	383.66 h	473.00 b	132.28 b	123.15 ef	122.32 ef	134.64 b	125.27 e	123.83 e
6000 ppm	480.19 a	430.12 d	482.53 a	480.16 a	429.16 d	482.00 a	141.18 a	127.75 cd	130.11 bc	140.94 a	132.04 c	130.66 c

Table 17: Effect of the interaction between different magnesium silicate concentration and rice varieties on number of panicles m^{-2} and number of filled grains $panicle^{-1}$ under normal and water deficit condition during 2022 and 2023 seasons.

Treatment		Number of panicles m^{-2}				Number of filled grains $panicle^{-1}$			
		2022		2023		2022		2023	
Si concentration	Rice varieties	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit
Control	Sakha 108	418.00 m	359.48 t	420.33 g	355.33 l	136.00 f	111.76 lm	136.75 e	114.38 k
	Sakha 109	403.33 n	330.73 v	383.00 i	331.66 n	130.16 h	94.93 p	133.66 f	95.91 p
	Giza 179	419.66 l	369.30 s	418.66 g	364.00 k	127.33 i	101.06 o	126.33 h	98.68 o
2000 ppm	Sakha 108	439.66 i	378.11 r	441.66 ef	376.00 j	138.50 e	114.22 l	140.66 d	116.93 j
	Sakha 109	400.66 o	328.54 w	402.66 h	323.00 o	134.66 f	105.87 n	136.66 e	105.73 n
	Giza 179	452.66 f	398.34 p	447.00 e	396.66 h	131.16 gh	110.1 m	131.66 g	107.32 mn
4000 ppm	Sakha 108	497.66 d	427.99 j	495.00 c	422.66 g	145.00 b	119.56 k	148 b	121.28 i
	Sakha 109	420.66 k	344.94 u	424.66 g	342.66 m	139.46 de	106.85 n	141.66 d	108.88 m
	Giza 179	499.00 c	439.12 i	508.33 b	437.66 f	133.33 fg	111.31 lm	136 e	111.66 l
6000 ppm	Sakha 108	516.33 a	444.04 h	518.33 a	442.00 ef	157.96 a	124.40 j	156.66 a	125.21 h
	Sakha 109	472.66 e	387.58 q	472.33 d	386.00 i	142.66 c	112.83 lm	147.66 b	116.42 j
	Giza 179	513.33 b	451.73 g	515.00 a	449.00 e	141.66 cd	118.55 k	143.33 c	118.00 j

Table 18: Effect of the interaction between the different irrigation treatments and magnesium silicate concentrations on 1000-grain weight (g) and weight grain yield t ha^{-1} during 2022 and 2023 seasons.

Treatment	1000-grain weight (g)				Grain yield t ha^{-1}			
	2022		2023		2022		2023	
Si concentration	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit
Control	27.42 d	23.40 h	27.61 c	23.33 g	9.51 d	6.76 h	9.66 d	6.82 h
2000 ppm	27.70 c	23.63 g	27.67 c	23.65 f	10.13 c	7.53 g	10.13 c	7.55 g
4000 ppm	28.21 b	24.08 f	28.30 b	24.11 e	10.72 b	8.27 f	10.73 b	8.18 f
6000 ppm	28.29 a	24.44 e	28.51 a	24.58 c	11.01 a	8.88 e	11.02 a	8.76 e

The interaction between irrigation treatments and rice varieties was significant concerning 1000-grain weight (g) and weight of grain yield t ha-1during two seasons (Table 19). The highest mean values for 1000-grain weight and grain yield t ha-1gave with Sakha 108 and Giza 179 the rice varieties in normal irrigation condition (28.10, 28.26 g, 10.55 and 10.65 t /ha). But, the lowest means values (22.82, 24.01 g, 7.16 and 7.23 t/ha) were obtained with rice variety Sakha 109 under water deficit during two seasons, respectively.

The increase in thousand grains weight with silicate application may be associated with enhanced photosynthetic activity and efficient translocation of photosynthetic. This resulted in better assimilation of carbohydrates and increasing of number of filled grains leads to increase in thousand grains weight. This may be due to high nutrient status and ability to retain moisture-holding, which is the basic requirement of paddy. The favorable impact of potassium silicate as the foliar application might be attributed to increasing leaf water potential. These results support those obtained by Jawahar and Vaiyapuri, (2010).

The interaction between magnesium silicate concentration and rice varieties was significant for thousand grain weight (g) during two seasons (Table 20). It was revealed from the results obtained that the highest values were (26.76 and 26.82 g) showed by Giza 179 and Sakha 108the rice varieties with foliar application magnesium silicate at 6000 ppm, while that, the best combination growing Sakha 108 the rice variety with foliar magnesium silicate concentrate 6000 ppm gave the highest means value weight grain yield (10.34 and 10.28 t ha^{-1}) during two seasons in normal irrigation condition. However, the lowest means values for 1000-grain weight and weight of grain yield t ha^{-1} traits were (24.89, 25.02 g, 7.71 and 7.87 t ha^{-1}) showed by growing Sakha 109 the rice variety without magnesium silicate treatment under water deficit condition. The application of silica in the reproductive stages in rice fields had a very positive effect in improving the number of filled grains per panicle Lavinsky *et al.* (2016), which confirms the results of this study.

Table 19: Effect of the interaction between different irrigation treatments and rice varieties on 1000-grain weight (g) and grain yield tha^{-1} during 2022 and 2023 seasons.

Treatment	1000-grain weight (g)				Grain yield t ha^{-1}			
	2022		2023		2022		2023	
Rice varieties	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit	Normal condition	Water deficit
Sakha 108	28.10 a	24.39 d	28.26 a	24.36 d	10.55 a	8.15 e	10.53 b	8.04 e
Sakha 109	27.83 b	22.82 e	28.02 b	24.01 e	10.09 c	7.16 f	9.97 c	7.23 f
Giza 179	27.79 c	24.45 f	27.78 c	24.39 d	10.39 b	8.26 d	10.65 a	8.22 d

The increase in thousand grains weight with silicate application may be associated with enhanced photosynthetic activity and effective translocation of photosynthetic. This resulted in better absorption of carbohydrates and an increase in number of filled grains leads to an increase in weight of thousand grains. This may be due to high nutrient status and moisture-holding capacity, which is the basic requirement of paddy. The favorable impact of potassium silicate upon foliar application might be attributed to increase leaf water potential. These results corroborate those obtained by Jawahar and Vaiyapuri (2010).

The interaction between irrigation treatments, magnesium silicate concentrates and rice varieties was significant for 1000-grain weight in the 2022 and 2023 seasons (Table 21). Giza 179 and 108 Sakha rice varieties gave the highest value of 1000-grain weight (28.47 and 28.60 g) using magnesium silicate at rate 6000 ppm, moreover, the highest grain yield means were obtained by using magnesium silicate at rate 6000 ppm for Sakha 108 and Giza 179 the rice varieties (11.35 and 11.18 t ha^{-1}) respectively in normal irrigation condition. The results may be related to genetic factors attributed to genetic makeup relationships of the rice varieties studied. The results are consistent with the findings of El-Habet, (2021). Also, results were confirmed with Patil *et al.* (2016) who revealed that significantly highest grain yield of rice was recorded that the highest observed rice grain yield was recorded by applying the recommended dose of fertilizer with silicon at 200 kg/ha.

On the other side, the lowest mean values for 1000-grain weight (22.43 and 22.38 g) were recorded without magnesium silicate application for Sakha 109 the rice variety in both seasons under water deficit condition, also, the lowest means were produced without any silicate treatment for Sakha 109 the rice variety (6.31 and 6.40 t ha^{-1} in both seasons in normal irrigation condition as shown in Table 21.

Agronomic Silica Use Efficiency (ASiUE)

Rice varieties significantly affected by the Silica use efficiency and obvious recovery of rice magnesium silicate (Figure 1). The highest value on Si Use Efficiency was observed with Sakha 108 and Giza 179 rice varieties. This might be due to the increasing absorption and efficient utilization of applied silicon. Among silicon concentration, the highest silica utilization efficiency was observed agronomic efficiency and obvious silicon recovery below 2000 and 4000 ppm under normal irrigation and water deficit condition. On the contrary, the Sakha 108 and Giza 179 rice varieties achieved the highest agronomic silica use efficiency when applied silica at the rate of 2000 and 4000ppm under normal irrigation and water deficit as shown in Table 22.

Therefore, results of the current study revealed that applying silicon at higher levels enhances nutrient uptake of normal growing rice by increasing soil available nutrients and the lower levels is favorable for increasing silicon utilization efficiency.

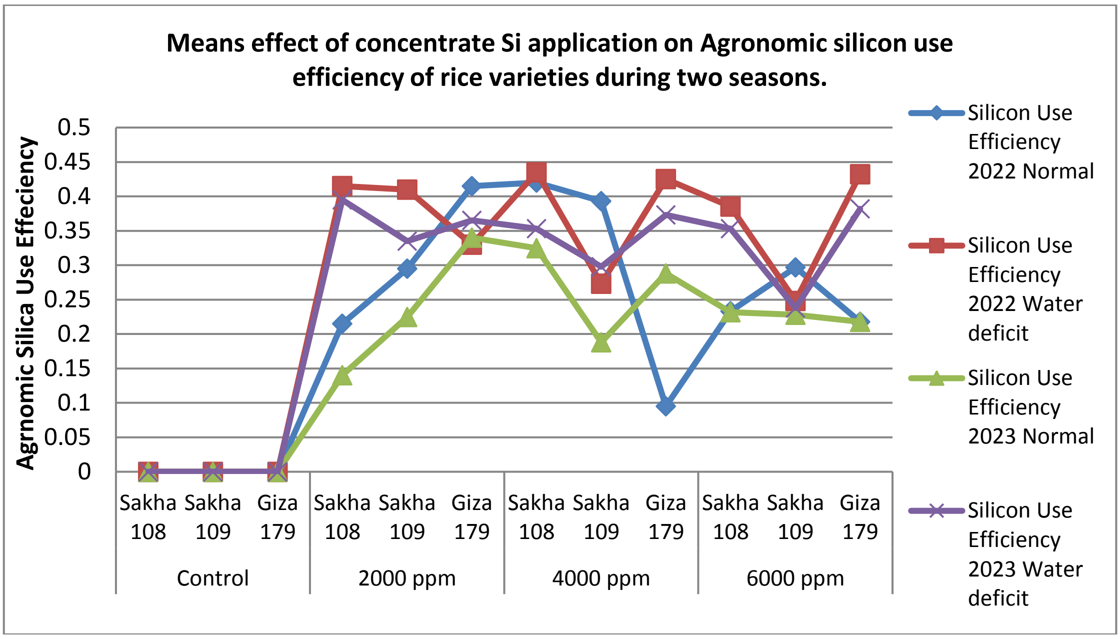

Fig. 1: Influence of silicate concentrate and rice varieties on agronomic silica use efficiency (ASUE) under normal and deficit condition during two seasons.

Table 22: Means effect of concentrate Si application on Agronomic silicon use efficiency of rice varieties during 2022 and 2023 seasons.

Treatment		**Silicon use efficiency**			
		2022		**2023**	
Si concentration	**Rice Varieties**	**Normal**	**Water deficit**	**Normal**	**Water deficit**
Control	**Sakha 108**	0.000	0.000	0.000	0.000
	Sakha 109	0.000	0.000	0.000	0.000
	Giza 179	0.000	0.000	0.000	0.000
2000 ppm	**Sakha 108**	0.215	0.415	0.140	0.395
	Sakha 109	0.295	0.410	0.225	0.335
	Giza 179	0.415	0.330	0.340	0.365
4000 ppm	**Sakha 108**	0.420	0.435	0.325	0.353
	Sakha 109	0.393	0.273	0.188	0.298
	Giza 179	0.095	0.425	0.288	0.373
6000 ppm	**Sakha 108**	0.233	0.385	0.232	0.353
	Sakha 109	0.297	0.248	0.228	0.238
	Giza 179	0.218	0.432	0.218	0.382

Water relations

Results showed that increasing irrigation intervals from irrigation every 6 days up to 12 days tended to reduce the amount of water used. The different rice varieties were varied in its water used under irrigation treatments. Sakha 108 rice variety had the highest value of water used followed by the Sakha 109, while Giza 179 rice varieties had the lowest one. It could be attributed to the total duration and number of leaves and leaf area of Sakha 108 variety followed by Sakha 109rice variety. So, rice varieties need more water to build their highest canopy beside the high loses of water through the transpiration especially, during 2022 season whereas, the minimum temperature was 22.30^{O} C comparing to 2023 season temperature was 20.79^{O} C as shown in Table 1, while, Giza 179 rice variety had less canopy than the other tested varieties, so it need less amount of irrigation water. In other study by Nada (2012), found that, total water used by rice according to different irrigation treatment were (13417.3 and 13605.2), (12673.7 and 12589.6), (11062.3 and 11031.6 m^3/ha). For continuous flooding, every 6 and 12 days intervals through seasons of the study.

Water use efficiency (WUE)

Regarding water productivity, data in Table 23. Indicated that irrigation every 12 days for Giza 179 rice variety had the best water use efficiency comparing with irrigated every 6 days which gave almost the same value in these aspects followed by Sakha 108 rice variety under the same irrigation, while the lowest value of WUE was observed when rice variety Sakha 109 irrigated every 12 days. The best water use efficiency of Giza 179 rice variety when irrigated every 12 days could be attributed to the greatest grain yield against low water input under previously mentioned condition. Hassan *et al.* (2015) mentioned that, 7 days interval irrigation improved productivity of water (grain produced per unit of water).

Grain yield, total irrigation water saved % and yield reduction % as influenced by irrigation intervals are presented in Table 2. The results indicated that grain yield of the three tested rice varieties were decreased as irrigation periods increase up to 12 days. It could be easily observed that Giza 179 rice variety used water amount of 10520 m^3/ha from seed to seed and saved water by about 10.52 % which equal about 1237 m^3/ha from total water used in the same time, grain yield reduction were 21.70 % of the current study when irrigated every 12 days.

Sakha 109 rice variety came in the second rank after Giza 179 rice variety which saved water by about 9.78% that equal about 1220 m^3/ha and grain yield reduction were 28.30 % when irrigated every 12 days intervals. In Similar study by Bouman and Toung (2001) reported that, water productivity in continuous flooding rice was typically of 0.2 - 0.4 g grain/kg water in India and 0.3 - 1.1 g grain per kg water in the Philippines. Irrigation water saving increases water productivity up to maximum of about 1.9 g grain per kg water but decreased the total grain yield.

Table 23: Grain yield (ton/ha), total water used (TWU), water saved percentage and grain yield reduction percentage as affected by irrigation treatments during 2022 and 2023 seasons.

Rice varieties / Irrigation treatments	2023/2024	2023/2024	2023/2024	2023/2024	2023/2024	2023/2024
	Grain yield (t/ha)	TWU (m^3/ha)	WUE	Water saved %	DSI	Yield reduction %
Sakha 108						
6 days	10.540	12980	0.812	-	-	--
12 days	8.100	11775	0.688	9.28	0.231	23.15
Sakha 109						
6 days	10.030	12480	0.804	-	-	--
12 days	7.194	11260	0.639	9.78	0.283	28.30
Giza 179						
6 days	10.524	11757	0.895	-	-	--
12 days	8.240	10520	0.769	10.52	0.217	21.70

From these results, could be concluded that, irrigation every 12 days for either Giza 179 or Sakha 108 rice varieties which gave the great grain yield and reached up to 8.240 and 8.100 ton/ha respectively with an average of 8.170 ton/ha and yield reduction 22.43%, the total water used were 10520 and 11775 m^3/ha by an average about 11147.5 m^3/ha with an average of water saved 1221 m^3/ha. It means that, if the target rice area in Egypt one million Feddan, so the averages of total amount of paddy rice will be 4.4 million ton which used irrigation water by about 5.196 million m^3under irrigation 6 days while, irrigation every 12 days average of total amount of paddy rice will be 3.4 million ton with irrigation water by about 4.683 million m^3 water and saved about 0.513 million m^3 water in case the two rice varieties and the water use efficiency will be 0.729. The amount of water saved can be used to irrigate another crop or for reclamation new land area when irrigation every 12 days for the previous varieties under the same condition.

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تأثير الرش الورقي بالسيلكا علي المحصول ومكوناته وزيادة كفاءة استخدام مياه الري لبعض أصناف الأرز تحت ظروف الري الطبيعي والعجز المائي

محمود إبراهيم أبو يوسف؛ محمد عباس جمعة؛ عبد السلام بسيوني السحلي؛ ابراهيم عبد النبي طلحة

قسم بحوث الأرز، معهد بحوث المحاصيل الحقلية، مركز البحوث الزراعية، مصر

الملخص العربي

أجريت تجربتان حقليتان لتقييم تأثير إضافة سليكات الماغنسيوم علي النمو والمحصول ومكوناته لثلاثة أصناف من الأرز في بيئتين (الري العادي "٦ أيام" والنقص المائي "١٢ أيام") خلال موسمي الزراعة ٢٠٢٢ و ٢٠٢٣ م في المزرعة البحثية لمركز البحوث والتدريب في الأرز - محطة البحوث الزراعية بسخا - كفر الشيخ - مصر، حيث تم تصميم التجربة بنظام الشرائح المتعامدة فى ثلاثة مكررات، القطع الأفقية كانت لمعاملات الري والقطع الرأسية لمستويات السيلكا وهي صفر ، ٢٠٠٠ ، ٤٠٠٠ ، ٦٠٠٠جزء في المليون، بينما وضعت أصناف الأرز سخا ١٠٨، سخا ١٠٩ وجيزة ١٧٩ في القطع الفرعية، وتم أخذ بيانات ثمانية صفات مختلفة من الصفات المورفولوجية و المحصول ومكوناته.

من بين معاملات الري سجلت معاملة الري كل ستة أيام (الرى العادى) ارتفاعاً معنوياً في محصول الحبوب ومكوناته مقارنة بمعاملة النقص المائي خلال الموسمين. أما بالنسبة لتأثير إضافة تركيزات السيليكات على النمو ومحصول الحبوب ومكوناته، فقد تم تحقيق أقصى إنتاجية لمحصول الحبوب بإضافة السيلكا بتركيز ٦٠٠٠جزء في المليون. أما بالنسبة لأصناف الأرز فقد سجلت الاصناف سخا ١٠٨ وجيزة ١٧٩ أفضل القيم المرغوبة للصفات المحصولية.

سَجلت التوليفة الأمثل التي أعطت أعلى إنتاجية لمحصول الأرز لصنفي أرز سخا ١٠٨ وجيزة ١٧٩ برش سليكات الماغنسيوم بتركيز ٦٠٠٠ جزء في المليون في ظروف الري العادية خلال موسمي الزراعة، ومن هنا أظهرت نتائج الدراسة أنه على الرغم من أن التركيز العالي من سيليكات الماغنسيوم عززت الإنتاجية بالنسبة لأصناف الأرز في الظروف الطبيعية بينما أدت إضافة السيلكا تحت ظروف الاجهاد المائي إلى التأثير لي العلاقات المائية وتحسين كفاءة التمثيل الضوئي والحالة المائية داخل الورقة ، كما سجلت أعلى كفاءة استخدام للسيليكون عند التركيزات المنخفضة.

هذا وقد أوضحت النتائج أن الري كل ١٢ يوم للأصناف جيزة ١٧٩ وسخا ١٠٨ أعطت أعلي إنتاجية من محصول الحبوب عن الصنف سخا١٠٩وبلغت ٨,٢٤٠ و ٨,١٠٠ طن/هكتار على التوالي بمتوسط ٨,١٧٠ طن/هكتار وخفض المحصول بنسبة ٢٢,٤٣%. وبلغ إجمالي المياه المستخدمة ١٠٥٢٠ و ١١٧٧٥ م٣/هكتار بمتوسط حوالي ١١١٤٧,٥ م٣/هكتار بمتوسط توفير مياه ١٢٢١ م٣/هكتار.

الكلمات الدالة : معاملات الري، سيلكات الماغنسيوم، أصناف الأرز ، كفاءة استخدام السيلكا المحصولية، كفاءة استخدام المياه.