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Effect of Gypsum Application on the Behavior of Some Rice Varieties under Salt Affected Soil Conditions

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ABSTRACT

Rice cultivation in the salt-affected soil in northern Delta regions is an important issue to confront soil deterioration. Therefore, adopting rice varieties of lower water demand and maintaining optimum productivity is becoming one of the national issues coincident with the current circumstances and expected water shortage. For this purpose, the behavior of some rice genotypes during the two summer seasons of 2018 and 2019 under gypsum amended salt-affected soil conditions and their relations is of interest. However, gypsum application positively enhanced rice varieties' growth parameters, photosynthetic pigments, relative water content, leaves potassium content, yield, yield attributes and crop water productivity (WP), meanwhile leaves sodium content, proline content, and Na^+/K^+ ratio influenced negatively. In addition, relative reduction in the soil layer's salt content and sodium adsorption ratio (SAR), whose recorded values seemed to be affected predominantly by the crop duration period. On the other hand, Egyptian hybrid one (EHR1) rated the highest grain yield, followed by Giza 178 with the corresponding values of 4.66 and 4.26 t fed.$^{-1}$, respectively. Despite that, Sakha 107 followed by Giza 177 rated the highest water productivity varieties with the corresponding values of 0.86 and 0.80 kg m^{-3}, respectively.

Keywords: Rice, gypsum, water productivity, soil salinity

1. Introduction

Salt-affected soil is a widespread phenomenon threatening agricultural lands and increases progressively as time goes on, particularly in those countries with arid and semi-arid climate conditions, which reached about 1 billion hectares of soil (Yang, 2006; Ivushkin *et al.*, 2019). In Egypt, salt-affected soil covers about 60% of the northern parts of Delta Egypt (Ouda and Zohry, 2015), and it has increased gradually (AbdelRahman *et al.*, 2022). Furthermore, the issue is getting more worrying due to climatic turbulence and heat waves in light of water scarcity (El-Marsafawy *et al.*, 2019). Not only that, but the representative studied area of the Sahel El-Husainia plain is at risk of being exposed to two directions of seawater intrusion from El-Manzala lake on the north side and the Suez Canal on the east side. Moreover, the blended water of the El-Salam Canal is the only irrigation water source. For these reasons, soil leaching requirements and rice cultivation are the prevalent tools for salinity control, upward flux, and conserve plant root zone (El-Mowelhi, 1993; Ouda and Zohry, 2015).

Soil salinity has a greater detrimental efficiency on the wheat plant development that resulted in a reduction in all growth parameters, i.e., seed emergency (Maas and Poss, 1989) and mineral constitute and ion accumulation (Hu *et al.*, 2006). In the similar pattern to wheat, rice exhibited drastic perturbation in the physiological response and generating high levels of reactive oxygen species, ROS, that resulted in impaired the photosynthetic functions and increase oxidative damage that led to plant toxicity (Jahan *et al.*, 2021; Liu *et al.*, 2022). On the other hand, the ion concentration and chemical composition of downstream flow characterized by high salinity that may causes additional osmotic stress on crops that lead to a significant interruption on the physiological processes (Ashraf 2004; Slama

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et al. 2015) which obstruct plant growth and reduce soil productivity (Munns 2005). Furthermore, the gradual uses of wastewater contributing in soil salinity and sodicity development (Chaganti *et al*., 2021).

Rice (*Oryza sativa* L.) is a worldwide growing crop, not just for salinity control, but as a consuming cereal food, similar to wheat and maize, for more than half of the world population (Lou *et al*., 2012; Anis *et al*., 2016; Moonmoon *et al*., 2017). From this point of view, the rapid population increase represents an overburden pressure on agricultural production of rice and cereal grains, in general, and due to the scarcity of water resources in arid and semi-arid areas aggravated by salinity development (Xiao *et al*., 2022), water rationalization has become an urgent necessity (Ali and Wani, 2021). Therefore, developing rice strains characterized by a short growth period and adapted to salt stress becomes an important issue. The Rice plant, in general, is one of the salt-sensitive crops and has varying responses during the different growth stages (Zeng *et al*., 2002). It is a relative most salt-tolerant at the germination, active tillering, and maturity growth stages. Despite this, it is most sensitive at the early seedling and reproductive stages (Munns and Tester, 2008).

The salt-affected soils showed a significant response to various restoration processes worldwide. The results revealed that soil responses varied according to the reclamation mechanisms method (Ryu *et al*., 2021) and techniques used and depended mainly on the type and efficiency of the amendments materials (Qadir *et al*., 2021; Xiao *et al*., 2022), water quality (Sharma and Minhas, 2005), and the application method. Generally, gypsum is one of the most important and cheapest ameliorant materials (Mokoi and Verplancke, 2010; Shi *et al*., 2022). Although it is slow to dissolve, it has pleiotropic positive effects on soil and plants (Singh *et al*., 2016; Rosolem *et al*., 2017; Holland *et al*., 2018). And through the release of calcium ions, the adsorbed sodium is substituted on the colloidal soil surfaces (Schultz *et al*., 2017), reducing clay dispersion and coagulating soil particles supporting aggregate stability (Luo *et al*., 2015) for these reasons, facilitating soil permeability and salts washing, especially the sodium ion. In addition, increasing calcium ions in the soil solution increases the plant's ability to withstand salt stress (Liu *et al*., 2022). As a result improving plant physiological functions resulted in improved crop productivity (Islam *et al*., 2019; Abdul Qadir *et al*., 2022).

Therefore, this study aims to study the effect of gypsum application on the performance of some newly cultivated rice strains in the studied area, which have a different growth cycle and their impacts on salt washing out of the soil. In addition, crop productivity and water unit efficiency are of concern.

2. Materials and Methods

2.1. Experimental site and layout:

A field trial was executed for two successive rice cropping seasons within the side in the salt-affected soil nearby El-Manzala lake (31˚00′15″ N 32˚ 08′15″ E) of South El Husainia Plain, El Sharqia governorate, Egypt, during the years 2018 and 2019, to assess the impact of gypsum treatment on seven rice genotypes and some soil properties. The productivity and physiological reaction of the involved rice varieties, i.e., growth parameters, photosynthetic pigments, relative water content, yield, and yield attributes of the interest. In addition, proline, Na^+, and K^+ contents in rice plant leaves were measured. In addition, the soil layer`s salt content for 0.6 m depth and their sodium adsorption ratio (SAR) besides water productivity are of top concern. The experimental design was implemented in the split-plot scheme with three replications during the study period and following flood irrigation technique as the prevalent site activities. Again, principle plots received rice varieties, and at the same time, the subplots have acquired a gypsum treatment assigned as $G^\bullet$ on the opposite side of the G^o plot without gypsum. The experimental plot size was 5mX15m (75 m^2) and the post winter crop (wheat) followed precisely the experimental lay out with the common farmer practices.

2.2. Soil sampling, analysis, and gypsum dose:

Soil samples from the experimental area were collected in 20cm increments to a depth of 0.6 m in the first year before land preparation, and their physical and chemical parameters are shown in Table 1. At rice harvesting time, representative soil layer samples were obtained for each plot in a similar manner to initial samples for chemical analysis to examine the effects of gypsum and crop duration (in light of its measurements to the applied water) on soil parameters. According to Richards (1954), the electrical conductivity of the saturated soil paste extract (ECe) was used to assess the soil layers' salt content.

Meanwhile the cations analysis of the soil paste extract was used to calculate the sodium adsorption ratio (SAR) as an indicator for ESP (exchangeable sodium percent) terms as stated by Suarez (2001), Chaganti *et al*. (2021) and Yahya *et al*. (2022). In addition, before starting the second summer season, the soil bulk density of each replicate was determined using the undisturbed core method (Richards, 1954). ESP was assessed according to the following equations:

$$\text{ESP} = ((1.475*\text{SAR}) - 1.26) / ((0.01475*\text{SAR}) + 0.9874) \qquad \text{Eq. (1)}$$

The 5.33 ton / fed soil gypsum requirement was calculated based on gypsum purity (90%) and Na:Ca exchange efficiency factor (1.25) and be evenly divided between the two summers. Soil gypsum requirements (GR) values were calculated based on reducing the estimated ESP of the surface soil layer from 19.68% to 10%. Based on Richards (1954) 1 mill-equivalent (meq) of Ca^{2+} is required to replaced 1meq Na^{+} of 100g soil, or in other terms 0.86 (g) of pure gypsum is accounted for substituting 1meq Na+ per each kg of soil. Consequently, GR per feddan was calculated based on the following equations:

$$\text{GR (kg) per kg of soil} = \frac{(\text{ESP initial} - \text{ESP final}) * \text{CEC} * 0.86}{100*1000} \qquad \text{Eq.(2)}$$

$$\text{Feddan weight (kg)} = \text{Area } (m^{2}) * \text{bulk density } (kg\ m^{-3}) * \text{soil depth } (m). \qquad \text{Eq. (3)}$$

$$\text{GR (ton fed}^{-1}) = \frac{\text{Eq. (2)} * \text{Eq. (3)}}{1000} * \frac{100}{\text{Gypsum purity}} * 1.25 \qquad \text{Eq.(4)}$$

2.3. Experimental plot preparation:

Before commencing the experiment, the soil was chiseled twice to a depth of 20 cm, followed by straight shank sub-soiling at 2.5 m and 45-50 cm depths (at the start of the experiment), gypsum dose manually broadcasted, properly blended by rotavator, and lastly, land leveling was created. The main plots were divided by a light drain ditch (40cm depth), whereas the experimental area had a subsurface drainage net (15m spacing and 60-70cm depth) linked to a shallow open drain of 0.9 m. The ditching drain and plot sides were smooth-toned to avoid lateral water movement and precisely exact water readings.

Table 1: Initial analysis of some physical and chemical properties of the experimental soil layers.

Depth cm	**Clay %**	**Silt %**	**Sand %**	**Texture**	**pb g cm^{-3}**	**$CaCO_3$%**	**O.M %**	**pH (1:2.5)**	**ESP**
0 - 20	53.38 ±2.1	28.17 ±1.5	18.45 ± 1.2	clay	1.41 ±0.01	80.18 ±3.3	1.15 ±0.04	8.41 ±0.16	19.68 ±3.7
20 - 40	58.78 ±2.4	25.2 ±1.31	16.02 ±0.9	clay	1.43 ±0.01	64.47 ±2.7	0.79 ±0.02	8.37 ±0.21	21.73 ±4.0
40 - 60	62.42 ±3.0	23.99 ±1.8	13.59 ±1.6	clay	1.45 ±0.01	57.76 ±2.4	0.4 ±0.01	8.28 ±0.19	26.84 ±3.4

Soluble cations and anions (mmol$_c$ L^{-1})

Depth cm	**EC$_e$ dSm^{-1}**	**Na^{+}**	**Ca^{2+}**	**Mg^{2+}**	**K^{+}**	**CO_3^{2-}**	**HCO_3^{-}**	**Cl^{-}**	**SO_4^{2-}**
0 - 20	6.6 ±0.89	49.86 ±3.6	5.45 ±0.95	10.85 ±1.17	0.96 ±0.9	nd	3.10 ±0.7	50.68 ±4.1	13.34 ±2.6
20 - 40	9.87 ±0.94	75.63 ±3.9	8.37 ±1.03	21.17 ±1.6	1.05 ±0.6	nd	2.50 ±0.4	80.44 ±4.3	23.28 ±3.5
40 - 60	22.4 ±1.6	145.93 ±4.8	18.99 ±.1.4	45.35 ±1.8	1.55 ±0.4	nd	2.44 ±0.6	167.76 ±6.2	41.62 ±4.1

Note ± indicate stander deviation, ρb: bulk density, $CaCO_3$: calcium carbonate, OM: organic matter, SAR and EC$_e$: Sodium adsorption ratio and electrical conductivity of saturated soil past extract, nd: not detected. * CEC: Cation exchange capacity of soil layer 0-20 cm = 38.9 (cmol$_c$ kg^{-1}), and estimated soil gypsum requirements = 5.33 ton/fed^{-1} for 20cm soil depth.

2.4. Irrigation water supply:-

For irrigation water measurements, a water pump with a valve and a calibrated water meter (m_3) was employed, and water was conveyed via a polyethylene sheet in front of the pump. The quantity of water given to plots is accurately under control, and the measures include the amount of water needed for soil preparation (7-day ponding with following increments until a constant steady infiltration). In addition, the amount of irrigation water provided for each treatment was recorded to determine the overall amount of water applied during the crop growth phase, which ends 15 days before harvest. During irrigation days (5-6 days intervals), the average water depth of all treatments was roughly 5 cm. According to Israelsen and Hansen (1962), the water productivity WP, or water usage efficiency, was calculated as follows:

$$\text{WUE} = \text{Rice grain yield (kg fed.-1) /Total water used } (\text{m}^3 \text{ fed.}^{-1}).$$

It's worth noting that throughout the study period, irrigation water quality was tested twice a month; in addition, water samples were monitored for EC values and subjected to chemical tests when the recorded EC value changed; and the average data is presented in Table 2.

Table 2: Chemical analysis of the irrigation water used. Average of (1st and 2nd seasons).

EC_{iw} (dS m^{-1})		pH	SAR
2.15 ± 0.63		7.18 ± 0.04	4.38 ± 1.24
Cations		**Anions**	**(g m^{-3})**
Na^+	244 ±83.0	HCO_3^-	179.1 ±26.8
K^+	21.61 ±6.8	Cl-	254.7 ±86.8
Ca^{2+}	84.96 ±16.6	SO_4^{2-}	1003 ±290.8
Mg^{2+}	61.65 ±17.4	NO_3^-	17.5 ±2.2
NH_4^+	15.56 ± 3.3	mean ± stander deviation	

EC_{iw} and SAR: Electrical conductivity and Sodium adsorption ratio of irrigation water, respectively.

2.5. Rice varieties:-

Two types of rice are the common varieties cultivated in the studied area, namely Giza 178 and Sakha 101, each of them revealed the adequate performance and relative yield (Mehana *et al*., 2021) , the latter characterized by a long growth period and more applied water. Very few studies focused on estimating the applied irrigation water of these species under the site conditions. Furthermore, adopting varieties with different growth cycles in the region requires also a deep study dealing with the growth performance of the concerned tested rice cultivars, i.e., the applied water amount of them and the extent of their response to the addition of amending soil gypsum, besides the impact of these factors on the salt content of soil layers. It may be worth mentioning that the tested genotype is supported by the Department of Field Crops Research Institute according to their appropriate performance in vast conditions (Moursi and Abdelkhalek, 2015; Abd El- Megeed *et al*., 2016; EL-Habet *et al*., 2018). On the other hand, the rice variety Sakha 101was excluded due to its extensive water requirements during the first growing season (2018), following the agriculture Ministry prohibitions. However, Table 3 summarizes the pedigree of the tested varieties.

Table 3: The studied seven Egyptian rice genotypes and their pedigree and type

No	Genotypes	Pedigree	Type
1	Egyptian hybrid one (EHR1)	IR69625A / Giza178	Indica
2	Giza 178	Giza 175 / Milyang 49	Indica- japonica
3	Giza 177	Giza 171 / YomjiNo.1 // Pi No.4	Japonica
4	Sakha107	Giza177 / BL1	Japonica
5	Sakha 106	Giza 177 / Hexi 30	Japonica
6	Sakha 104	GZ 4096-8-1 / GZ 4100-9-1	Japonica
7	Sakha 101	Giza 176 / Milyang 79	Japonica

Rice varieties seeds soaked overnight, left to dry, then broadcasted. All seed types received the prevalent practices according to the recommendations of the Egyptian Field Crops Research Institute at the site.

2.6. Growth characters:-

A random five plants per replicate were used to determine leaf area index (LAI), net assimilation rate (NAR), and crop growth rate (CGR) in terms of g $m^{-2}day^{-1}$ at 65, 80 and 95 days after seeding (DAS) following Hunt (1990) formulas as follow:

- Leaf area index (LAI) = leaf area of plant (cm^2) /land area occupied by plant (cm^2).

- Net assimilation rate, in g $m^{-2}day^{-1}$ (NAR) = $(W_2\text{-}W_1)\ (\log_e A_2\text{-}\log_e A_1) / (A_2\text{-}A_1)\ (t_2\text{-}t_1)$.
- Crop growth rate, in in g $m^{-2}day^{-1}$ (CGR) = $(W_2\text{-}W_1) / (t_2\text{-}t_1)$.

Where:-

A_2-A_1; differences in leaf area between the two samples, W_2-W_1; differences in dry matter accumulation of whole plants between two periods in (g), t_2-t_1; Number of days between two successive periods (day), and Log_e: Natural logarithm. In addition, other plant samples were oven dried (70 °C) until a constant weight.

Meanwhile, At 80 (DAS), based on the fresh weight, photosynthetic pigments (chlorophyll a, chl a, chlorophyll b, chl b, and carotenoids) in terms of mg/g, leaf proline concentration in terms of µg/g, and relative water content percentage (RWC %) were determined following Metzener *et al.* (1965), Bates *et al.* (1973), and Cao *et al.* (2015), respectively. The equation used for the calculated RWC percentage, could be represented by-

RWC (%) = (Fresh weight-Dry weight) x 100 / (Turgid weight-Dry weight).

On the other hand, at the same period potassium and sodium content (mmol/kg) in wheat plant dry weight was determined following Allen *et al.* (1974) method. In addition, at harvest time yield and yield attributes, i.e., plant height (cm), panicle length (cm) and panicle weight (g) were determined and after harvest 1000-grain weight (g), grain and straw yields ton/ feddan (t $fed.^{-1}$) were determined.

Data of the two seasons were subjected to statistical analysis of variance according to Steel and Torrie (1980). The treatments average was compared using LSD test at 0.05 level of significant.

3. Results and Discussion

3.1. Growth and growth analysis:-

Data in table 4 indicated that LAI, CGR, and NAR values of different rice cultivars were increased significantly as the time progressed, i.e., 65- 80 and 80-95 DAS, respectively, with the superiority of the Egyptian hybrid one (EHR1) variety followed by Giza 178 over the tested rice varieties. Meanwhile, the Sakha 104 was inferior, and a similar trend followed during the studied second season. The superiority of the studied plant characters for gypsum treatments is possibly due to more chances for released Ca^{2+} effect on soil improving as the time goes on (Zayed *et al*., 2017a). In addition, those plants of the control treatments recorded higher values in the second season, concerning the previously mentioned plant parameters, which seemed to be affected by the reduction in soil layers salinity. Moreover, the varietal differences in the concerned parameters may be because of the differences in the genetic structure among the rice cultivars related to the dry matter partitioning and salinity response (Kanawapee *et al*., 2013) besides the rice cultivar duration. Moreover, the results of Abd El-Megeed *et al*. (2016) and Shimizu *et al*. (2022) indicated that EHR1 and Giza 178 varieties of high performance even under high saline conditions (Zayed *et al*., 2013).

3.2. Photosynthetic pigments:-

Data in table 5 revealed a significant variation in the measurements values of photosynthetic pigments contents, which involved chlorophyll a and chlorophyll b besides carotenoids, within the rice genotypes during the studied periods. At 80 DAS, photosynthetic pigments content in leaves of EHR1, recorded the highest values over the other studied cultivars. Meanwhile, Sakha 107, Giza177 and

Table 4: Leaf area index (LAI), crop growth rate (CGR) and net assimilation rate (NAR) of rice cultivars as affected by gypsum application to salt affected soil during the studied seasons.

Treatments		**Leaf area index**						**CGR (g m^{-2}day^{-1})**				**NAR (g m^{-2}day^{-1})**			
		65 day		**80 day**		**95 day**		**(65-80 day)**		**(80-95 day)**		**(65-80 day)**		**(80-95 day)**	
		2018	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
Rice cultivars															
EHR1		2.98	3.10	3.56	3.65	3.45	3.49	27.8	28.6	30.8	31.4	11.5	11.6	11.6	11.6
Giza 178		2.69	2.8	3.37	3.58	3.27	3.47	25.6	26.5	28.3	29.4	11.3	11.5	11.2	11.4
Giza 177		2.43	2.61	2.86	3.02	2.66	2.77	25.0	26.1	28.3	28.8	10.9	11.1	11.0	11.1
Sakha 107		2.54	2.71	3.06	3.19	3.00	3.01	26.9	27.8	28.6	29.4	11.2	11.2	11.1	11.2
Sakha 106		2.40	2.55	2.77	2.96	2.72	2.83	24.8	25.2	27.5	28.1	10.6	10.9	10.7	10.3
Sakha 104		2.24	2.42	2.58	2.80	2.70	2.86	24.4	24.5	25.8	26.6	10.1	10.3	10.4	10.4
Sakha 101		2.28	-	2.72	-	3.04	-	23.8	-	26.2	-	9.8	-	10.2	-
Soil Amendment															
Control (C)		2.44	2.62	2.91	3.12	2.90	3.00	25.1	26.2	27.3	28.4	10.5	10.8	10.8	11.0
Gypsum (GY)		2.58	2.77	3.06	3.27	3.06	3.13	25.8	26.7	28.6	29.5	11.1	11.3	11.0	11.2
Interaction															
EHR1	**C**	2.91	3.02	3.48	3.55	3.38	3.44	27.42	28.38	30.23	30.99	11.33	11.49	11.50	11.54
	GY	3.05	3.19	3.65	3.75	3.53	3.54	28.10	28.77	31.41	31.73	11.68	11.76	11.64	11.68
Giza 178	**C**	2.62	2.73	3.30	3.50	3.20	3.41	25.39	26.04	27.43	28.65	11.18	11.26	11.13	11.34
	GY	2.75	2.87	3.43	3.65	3.33	3.54	25.90	26.90	29.23	30.18	11.46	11.66	11.30	11.51
Giza 177	**C**	2.36	2.54	2.78	2.94	2.60	2.72	24.64	25.98	27.78	28.39	10.43	10.77	10.83	10.96
	GY	2.5	2.67	2.94	3.10	2.74	2.81	25.43	26.32	28.84	29.18	11.28	11.40	11.07	11.16
Sakha 107	**C**	2.45	2.63	2.97	3.12	2.92	2.93	26.56	27.56	27.93	28.78	11.00	10.96	10.94	11.14
	GY	2.63	2.78	3.14	3.27	3.07	3.09	27.30	27.97	29.30	29.94	11.34	11.44	11.25	11.35
Sakha 106	**C**	2.33	2.49	2.69	2.90	2.64	2.76	24.39	24.83	26.79	27.39	10.21	10.51	10.49	10.81
	GY	2.46	2.61	2.84	3.02	2.80	2.91	25.13	25.66	28.16	28.83	11.07	11.22	10.91	11.06
Sakha 104	**C**	2.16	2.33	2.51	2.72	2.64	2.80	23.88	24.23	25.16	26.21	9.88	10.04	10.26	10.25
	GY	2.33	2.51	2.65	2.89	2.79	2.91	24.91	24.85	26.46	27.02	10.29	10.46	10.45	10.47
Sakha 101	**C**	2.23	-	2.64	-	2.94	-	23.43	-	25.74	-	9.37	-	10.13	-
	GY	2.33	-	2.80	-	3.13	-	24.08	-	26.59	-	10.23	-	10.25	-
LSD (0.05) V		**0.080**	**0.034**	**0.052**	**0.073**	**0.046**	**0.049**	**0.093**	**0.090**	**0.085**	**0.111**	**0.047**	**0.086**	**0.052**	**0.054**
LSD (0.05) A		**0.018**	**0.014**	**0.026**	**0.036**	**0.020**	**0.035**	**0.069**	**0.094**	**0.058**	**0.075**	**0.051**	**0.044**	**0.024**	**0.024**
LSD (0.05) V*A		**0.048**	**0.035**	**0.069**	**0.088**	**0.054**	**0.086**	**0.184**	**0.229**	**0.154**	**0.184**	**0.134**	**0.108**	**0.063**	**0.059**

relatively Giza 178 seemed to be; in general, close to each other's with the concerned parameters, the lowest values being shared with the cultivars Sakha 101 or Sakha 104. These results indicated that salt tolerant and moderately tolerant cultivars, opposite to moderately sensitive, sensitive and highly sensitive , were significantly higher in their chlorophyll under the stress conditions (Kanawapee *et al*., 2012). The relative variation among the tested varieties under salt affected soil stress may be account for their genetic backgrounds as reported by Zayed *et al*. (2017b) and Gerona *et al*. (2019) and findings of Shimizu *et al*., (2022).

Table 5: Photosynthetic pigments (chlorophyll a, chlorophyll b and carotenoids) content of some rice varieties leaves at 80 days as affected by gypsum application to salt affected soil during the studied seasons

		Photosynthetic pigments (mg g^{-1} FW)					
		Chl a		**Chl b**		**Carotenoids**	
Treatments		**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
Rice cultivars							
EHR1		0.463	0.482	0.179	0.188	0.109	0.114
Giza 178		0.452	0.476	0.173	0.184	0.102	0.107
Giza 177		0.444	0.457	0.162	0.171	0.099	0.104
Sakha 107		0.460	0.476	0.176	0.184	0.102	0.105
Sakha 106		0.427	0.448	0.154	0.164	0.088	0.092
Sakha 104		0.401	0.412	0.147	0.155	0.082	0.086
Sakha 101		0.392	-	0.150	-	0.084	-
Soil Amendment							
Control (C)		0.421	0.450	0.157	0.169	0.092	0.098
Gypsum (GY)		0.447	0.467	0.168	0.180	0.098	0.104
Interaction							
EHR1	**C**	0.451	0.473	0.173	0.180	0.106	0.110
	GY	0.475	0.490	0.184	0.195	0.112	0.117
Giza 178	**C**	0.441	0.470	0.167	0.179	0.099	0.105
	GY	0.462	0.482	0.178	0.189	0.104	0.109
Giza 177	**C**	0.436	0.444	0.157	0.166	0.096	0.101
	GY	0.451	0.470	0.166	0.177	0.102	0.107
Sakha 107	**C**	0.448	0.469	0.170	0.179	0.098	0.102
	GY	0.471	0.484	0.182	0.189	0.105	0.108
Sakha 106	**C**	0.413	0.441	0.149	0.158	0.084	0.088
	GY	0.442	0.454	0.160	0.170	0.091	0.096
Sakha 104	**C**	0.385	0.404	0.141	0.150	0.078	0.083
	GY	0.417	0.420	0.153	0.159	0.085	0.089
Sakha 101	**C**	0.372	-	0.144	-	0.081	-
	GY	0.411	-	0.155	-	0.088	-
LSD (0.05) V		**0.005**	**0.004**	**0.003**	**0.003**	**0.007**	**0.009**
LSD (0.05) A		**0.002**	**0.001**	**0.002**	**0.002**	**0.001**	**0.001**
LSD (0.05) V*A		**0.006**	**0.003**	**0.005**	**0.005**	**0.002**	**0.002**

Results also revealed that the amended treatment with gypsum application compared to the check treatment resulted in a significant variation in the all measurements of photosynthetic pigment contents during the studied seasons. Similar behavior was recorded as the interaction effect of between tested rice varieties and gypsum application are considered. These detectable results reflected the enhancement effect of Ca^{2+} released due to gypsum dissolution on retarding the Na^{+} destruction effect related to clay dispersion or that of the osmotic stress consequently reduced ROS production that resulted in significant increases in photosynthetic pigments functions (Rahman *et al*. 2016). In addition, enhancement in nutrients availability because of pH reduction by sulfate ions may be other possibility for enhancing physiological performance (Cha-um *et al*. 2011; Zayed *et al*. 2017b).

3.3. Relative water content, proline, Na^{+}, K^{+} and Na^{+}/K^{+} ratio

The values of RWC, proline, Na^{+}, K^{+}, and Na^{+}/K^{+} ratio, in general, significantly varied among the tested rice varieties during the first summer season (Table 6). Although Sakha 101 was not cultivated during the second summer season (2019), rice cultivars commonly followed a similar trend as those obtained during the first season. Giza 178 and EHR1, contrary to Sakha varieties 101, 104, and 106, recorded the highest values for RWC percentage and K^{+} content despite their inferiority for proline and

Na^+ content beside Na^+/K^+ ratio. These results indicated that both cultivars were more salinity tolerant, i.e., with a higher RWC percentage with a lower Na^+/K^+ ratio, and such parameters are predominantly used to assess salinity tolerance species (Suriya-arunroj *et al*., 2004). On the other hand, Sakha 101, 104, and 106 varieties seemed susceptible to experimental stress conditions with lower affinity for K^+ absorption and contained high Na^+ values (Mekawy *et al*. 2015; Abdelaziz *et al*. 2018). Therefore, increasing the Na^+/K^+ ratio resulted in rising proline content (Munns *et al*., 2002; Monsur *et al*. 2020). That is true since stressed plants revealed higher proline accumulation that plays a principal role in osmotic adjustment by maintaining protein and cellular structures and controlling free radical components. In addition, reduced ROS accumulation consequently enhances rice tolerance to abiotic stress (Nahar *et al*., 2016; Kibria *et al*., 2017). Zayed *et al*., (2017a) and Shimizu *et al*., (2022) found similar results.

Table 6: Relative water content, proline, sodium, potassium content and Na^+/K^+ ratio in leaves of some rice varieties at 80 days as affected by gypsum application to salt affected soil during the studied seasons

Treatments		Relative water content (%)		Proline ($\mu g\ g^{-1}$ FW)		Leaf Na^+content ($mmol\ kg^{-1}$)		Leaf K^+content ($mmol\ kg^{-1}$)		Na^+/K^+ ratio	
		2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Rice cultivars											
EHR1		87.5	88.8	104	100	206	197	323	331	0.64	0.60
Giza 178		88.6	89.4	100	95	178	171	322	327	0.55	0.52
Giza 177		81.5	82.6	117	113	227	216	304	310	0.75	0.70
Sakha 107		83.3	85.0	112	107	221	207	311	319	0.71	0.65
Sakha 106		79.6	80.3	121	119	241	228	289	295	0.84	0.77
Sakha 104		77.6	78.3	131	122	260	248	295	305	0.88	0.82
Sakha 101		83.1	-	127	-	251	-	282	-	0.89	-
Soil Amendment											
Control (C)		81.2	82.1	120	112	235	221	296	306	0.80	0.72
Gypsum (GY)		84.8	86.0	112	107	217	201	311	323	0.70	0.63
Interaction											
EHR1	**C**	85.2	86.7	107	103	218	208	314	321	0.69	0.65
	GY	89.8	90.9	101	97	193	185	331	342	0.58	0.54
Giza 178	**C**	86.5	87.4	103	98	189	184	315	319	0.60	0.58
	GY	90.7	91.3	97	92	166	158	328	335	0.51	0.47
Giza 177	**C**	79.4	80.5	120	115	236	225	297	303	0.79	0.74
	GY	83.5	84.7	114	112	218	206	310	317	0.70	0.65
Sakha 107	**C**	81.8	83.0	114	109	227	216	304	312	0.75	0.69
	GY	84.7	86.9	110	104	215	197	319	325	0.68	0.61
Sakha 106	**C**	77.8	78.7	124	121	248	234	280	287	0.88	0.82
	GY	81.5	82.0	118	116	234	223	297	304	0.79	0.73
Sakha 104	**C**	75.9	76.4	139	126	268	257	286	294	0.94	0.87
	GY	79.3	80.3	122	119	251	239	304	315	0.83	0.76
Sakha 101	**C**	81.8	-	130	-	261	-	274	-	0.95	-
	GY	84.4	-	123	-	242	-	290	-	0.83	-
LSD (0.05) V		**0.19**	**0.28**	**8.94**	**9.13**	**5.50**	**1.94**	**3.97**	**6.62**	**0.017**	**0.007**
LSD (0.05) A		**0.12**	**0.09**	**1.39**	**0.63**	**2.22**	**1.26**	**7.00**	**1.10**	**0.008**	**0.005**
LSD (0.05) V*A		**0.062**	**0.04**	**3.68**	**1.54**	**5.86**	**3.08**	**1.85**	**2.70**	**0.022**	**0.012**

Results also revealed that irrespective of rice varieties, the gypsum application significantly improves plant leaves water content and K content despite a remarkable significant reduction in proline, Na^+, and Na^+/K^+ ratio with the superiority of the second season. This behavior may account for the relative decrease in soil salt content (EC) and SAR values, compared to those of un-amended treatment, of the plant's root zone (soil parameters) under gypsum treatment resulting in enhanced physicochemical properties and reducing osmotic stress that facilitates plant water uptake. These results are in agreements with those found by Sheoran *et al*., (2021).

Concerning interaction effect, obtained results revealed that gypsum-treated plants significantly have higher RWC and K^+ content despite their inferiority regarding proline and Na^+ contents besides Na+/K+

ratio, compared to control treatment. Giza 178 and EHR1 surpass the tested rice cultivars for the concerned parameters, even under the control treatment. These may reveal their ability to prevent Na+ transport and accumulation in leaves (Munns and Tester, 2008). In contrast, salt-sensitive plants are more susceptible to growth reduction. These may be because of the energy spent on the production and proline storage (Chen *et al.* 2007).

However, the migration of hazardous salts in the soil after gypsum application and increased availability of the essential mineral ions particularly Ca^{2+} and K^{+} facilitate the adaptation of plants to salt stress, comparison with controls (Mann *et al.*, 2019). Moreover, soluble Ca^{2+} may contribute to reduce and regulate the binding Na^{+} to the cell wall and plasma membrane that helps to improve cell integrity and plasma membrane functions (Lauchli, 1990; Rengel, 1992). Accordingly, the soluble Ca^{2+} liberated from gypsum dissolution may be accounting for alleviating Na^{+} stressful effects on rice growth (Chi *et al.*, 2012).

3.4. Yield and yield components

Data in Table (7) reveal that EHR1 gave a significant increase in plant height, panicle length, panicle weight, grain yield and straw yield as compared with other rice cultivars under stress conditions during the two seasons, while Sakha 101 gave the highest 1000- grain weight in the 1st season and Sakha 106 gave a significant increase in 1000-grain weight in the 2nd season. These findings came in line with those of Zayed *et al.*, (2007); Aamer and Tabl (2019), who observed that rice cultivars significantly differed in their grain and straw yield as well as yield attributes. However, Zeng *et al.* (2003) stated that there were significant correlations between LAI and yield components in both salt-tolerant and sensitive genotypes and confirmed the significant contribution of LAI to grain yield.

Table 7: Yield and yield components of some rice varieties as affected by gypsum application to salt affected soil during the studied seasons.

		Plant height (cm)		**Panicle length (cm)**		**Panicle weight (g)**		**1000-grain weight (g)**		**Grain yield (t fed.$^{-1}$)**		**Straw yield (t fed.$^{-1}$)**	
Treatments		**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
Rice cultivars													
EHR1		102	105	24.9	25.0	3.56	3.80	29.2	30.1	4.62	4.70	5.33	5.38
Giza 178		98.5	99.2	23.0	23.7	2.99	3.15	23.3	23.8	4.23	4.29	5.31	5.35
Giza 177		96.7	97.7	22.8	23.4	3.07	3.20	31.0	32.3	3.95	4.06	5.12	5.19
Sakha 107		99.8	99.8	23.1	23.2	3.19	3.29	32.2	33.9	4.08	4.12	5.15	5.24
Sakha 106		95.5	96.3	22.3	22.4	3.09	3.26	33.5	34.5	3.74	3.82	5.10	5.17
Sakha 104		95.7	94.0	22.4	22.4	3.29	3.37	33.9	33.7	3.38	3.43	5.17	5.27
Sakha 101		94.3	-	21.6	-	3.20	-	34.7	-	4.19	-	5.14	-
Soil Amendment													
Control (C)		96.1	97.7	22.2	22.8	3.05	3.18	30.3	30.8	3.84	3.87	5.12	5.20
Gypsum (GY)		99.0	99.7	23.6	24.0	3.35	3.51	31.9	32.0	4.21	4.27	5.25	5.33
Interaction													
EHR1	**C**	101.3	103.3	24.00	24.17	3.41	3.65	28.0	29.5	4.37	4.43	5.27	5.33
	GY	103.3	107.0	25.83	25.83	3.71	3.94	30.3	30.7	4.88	4.97	5.38	5.42
Giza 178	**C**	97.7	98.7	22.17	23.00	2.83	2.96	22.5	23.0	3.99	4.08	5.24	5.27
	GY	99.3	99.7	23.83	24.33	3.15	3.33	24.0	24.5	4.46	4.50	5.38	5.43
Giza 177	**C**	95.7	96.7	22.17	23.00	2.91	3.05	30.0	31.6	3.75	3.83	5.04	5.12
	GY	97.7	98.7	23.50	23.83	3.24	3.36	32.0	33.1	4.15	4.29	5.19	5.26
Sakha 107	**C**	98.3	99.3	22.50	22.50	3.03	3.12	31.4	33.3	3.88	3.85	5.06	5.14
	GY	101.3	100.3	23.67	23.83	3.34	3.46	33.0	34.6	4.27	4.38	5.24	5.34
Sakha 106	**C**	94.3	95.3	21.83	22.00	2.95	3.09	32.8	34.0	3.45	3.64	5.07	5.11
	GY	96.7	97.3	22.67	22.83	3.23	3.42	34.2	34.9	4.02	3.99	5.14	5.23
Sakha 104	**C**	93.3	92.3	21.83	22.33	3.13	3.21	33.5	33.4	3.31	3.36	5.14	5.23
	GY	98.0	95.3	23.00	23.17	3.44	3.52	34.4	34.1	3.44	3.49	5.21	5.31
Sakha 101	**C**	92.3	-	20.67	-	3.08	-	34.1	-	4.10	-	5.05	-
	GY	96.3	-	22.67	-	3.31	-	35.3	-	4.29	-	5.22	-
LSD (0.05) V		0.718	1.097	0.408	0.136	0.017	0.015	0.523	0.402	0.037	0.025	0.028	0.022
LSD (0.05) A		0.468	0.453	0.198	0.148	0.015	0.015	0.345	0.219	0.015	0.012	0.011	0.013
LSD (0.05) V*A		1.238	1.109	0.523	0.363	0.041	0.037	0.914	0.535	0.040	0.028	0.028	0.031

With respect to the effect of gypsum application on plant height, panicle length, panicle weight, 1000-grain weight, grain yield and straw yield produced significant increase as compared with untreated control plants in the two seasons. This could be due to higher reclamation efficiency in terms of chemical soil properties and such progress in soil reclamation might resulted in an evident reduction in osmotic potential (Hafez *et al*., 2015; Murtaza *et al*. 2017). However, Saqib *et al*., (2020) concluded that under salt stressed gypsum application produced the favorable growth conditions for rice crop which was reflected by improved yield and yield components.

3.5. Soil characteristics and irrigation water Applied:

The total applied irrigation water, the water use efficiency in terms of water productivity (WP), and soil layers salt content of the cultivated rice varsities during the two-studied summer seasons are summarized in Table 8 and Figs. 1 and 2.

Table 8: The applied water, water productivity and soil layer salt content of the rice varieties under gypsum application during the studied seasons.

Treatments		Applied water (m^3)		WP (kg m^{-3})		Salt content (kg fad^{-1})					
						(0-20) cm		(20-40) cm		(40-60) cm	
		2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Rice cultivars											
EHR1		5848	5930	0.790	0.792	3116	2790	8454	5930	21354	11610
Giza 178		5649	5699	0.748	0.752	3250	3063	8825	5787	23833	13583
Giza 177		4953	5021	0.797	0.808	3712	3260	10101	6591	28234	15406
Sakha 107		4736	4744	0.861	0.867	4306	3789	11296	7243	32080	16223
Sakha 106		5205	5197	0.716	0.734	3504	3058	9993	6277	27564	14274
Sakha 104		5736	5698	0.589	0.601	3245	3266	10004	7792	24423	14259
Sakha 101		6823	-	0.614	-	3030	-	7481	-	19836	-
Soil Amendment											
Control (C)		5505	5334	0.703	0.728	3569	3068	10187	8139	26713	18929
Gypsum (GY)		5623	5429	0.758	0.790	3334	3341	8714	5068	23952	9523
Interaction											
EHR1	**C**	5780	5845	0.756	0.757	3231	2514	9034	6824	22791	14620
	GY	5917	6015	0.824	0.827	3001	3067	7873	5036	19916	8600
Giza 178	**C**	5610	5681	0.711	0.719	3326	2706	9385	6993	25800	17201
	GY	5688	5718	0.785	0.786	3173	3422	8264	4582	21867	9965
Giza 177	**C**	4910	5015	0.764	0.764	3726	3181	10803	8541	29898	21180
	GY	4995	5028	0.830	0.853	3699	3340	9399	4641	26571	9632
Sakha 107	**C**	4710	4689	0.824	0.821	4731	4037	12302	9735	33500	22144
	GY	4762	4800	0.897	0.913	3881	3540	10290	4752	30661	10302
Sakha 106	**C**	5030	5078	0.686	0.717	3586	3062	10628	8228	28494	20185
	GY	5380	5316	0.746	0.750	3422	3053	9358	4326	26633	8364
Sakha 104	**C**	5708	5697	0.580	0.590	3307	2907	10769	8514	25751	18242
	GY	5763	5699	0.597	0.612	3183	3625	9238	7070	23096	10275
Sakha 101	**C**	6789	-	0.604	-	3078	-	8386	-	20754	-
	GY	6857	-	0.625	-	2982	-	6576	-	18918	-
LSD (0.05) V		14.4	11.9	0.006	0.004	20.83	63.00	40.58	43.82	153.2	117.4
LSD (0.05) A		6.76	6.12	0.003	0.003	4.32	39.88	12.64	40.13	27.05	133.7
LSD (0.05) V*A		0.45	0.003	0.014	0.011	11.43	97.70	33.45	98.30	71.56	327.4

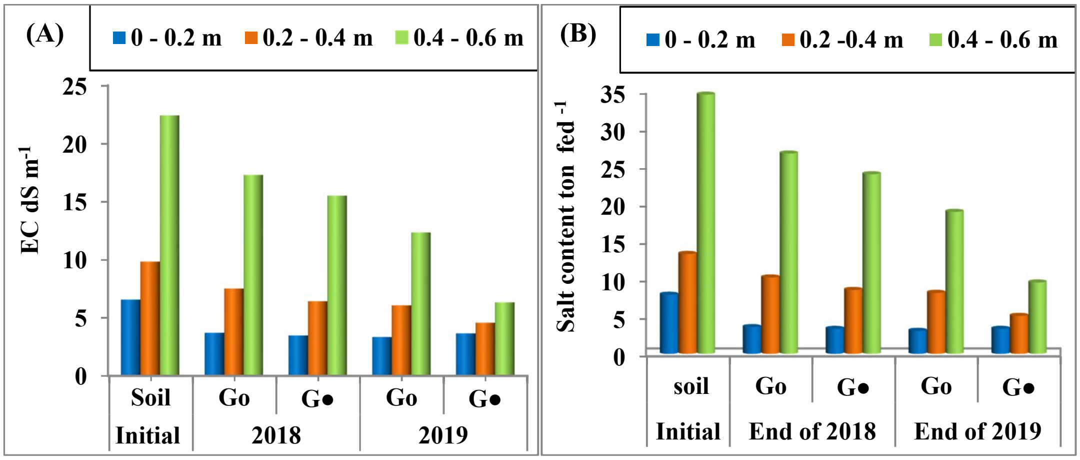


Fig. 1: Mean effect of the gypsum application, treated (G●) and untreated (Go), on the average EC values (A) and salt content (B) of different soil depths after rice harvesting of the studied summer seasons 2018 and 2019 as compared to the initial soil values.

In general, the average soil layers salinity (EC_e) values and their related salt layers content of the experimental area; were reduced, because of rice cultivation, in the first season (2018) as compared with the initial soil layers values (Table 1). In addition, gradual decreasing pattern by extending rice plantation for the second summer season, particularly with gypsum application Fig.1 (A and B). The reduction percentage in the EC_e values of the control treated soil (no gypsum application) was about 43.42, 23.55, and 22.72, compared to the initial soil values. These values are corresponding to 54.74, 23.57, and 22.72 % reduction in the salt content of different soil layers (0:20, 20:40, and 40:60 cm, respectively). The average reduction of soil layer salt content for the control treatment was 27.5% compared to an average of 35.8 % for gypsum application. Furthermore, the average accumulated reduction in soil layers salt content (0- 0.6 m depth) among the rice cultivars during the experimental period were about 46 and 68% for control and gypsum treatments, respectively, compared to the initial soil.

These results highlighted role of rice cultivation for the salt affected soils in particular combined with gypsum application to facilitate salt leaching efficiency. These findings closely agreed with those of Ismail *et al*. (2013) and in agreement with Hafez *et al*. (2015) and Aboelsoud *et al*. (2020) who supported the importance of gypsum application for north Delta clay salt affected soil of Egypt. Moreover, the above results also compatible with the two years field study in arid climate conditions by Chaganti *et al*. (2021) indicated that gypsum and sulfur application is significantly powerful for reducing soil sodicity irrigated with brackish water.

As to the effect of rice variety, the highest value of irrigation water applied was 6823 m^3 fed^{-1} in the first season when cultivating Sakha 101, vice versa Sakha 107, which has lower values of 4736 and 4744 m3 fed-1 under first and second growing seasons. Data also showed a considerable reduction in the applied water used for different rice cultivars compared with Sakha 101. The rice cultivars Sakha 107, Giza 177, Sakha 106, Giza 178, Sakha 104, and EHR1 saved water by about 30.6, 27.4, 23.7, 17.2, 15.9, and 14.3 % compared with Sakha 101 Table 8 and Fig 2. B. These variable behavior may account for the differences among rice varieties related to their vegetative and reproductive durations during the crop period (Abd El-Megeed *et al*., 2016). Despite this, the values of soil layers' salt content of Sakha 101 up to depths of 0.6 m were inferior compared to other rice cultivars Table 8 and Fig. 2 (A and B). These results may suggest that under control management of salt-affected soil conditions, the highest water applied variety is the lowest soil layers content. Concerning the effect of soil

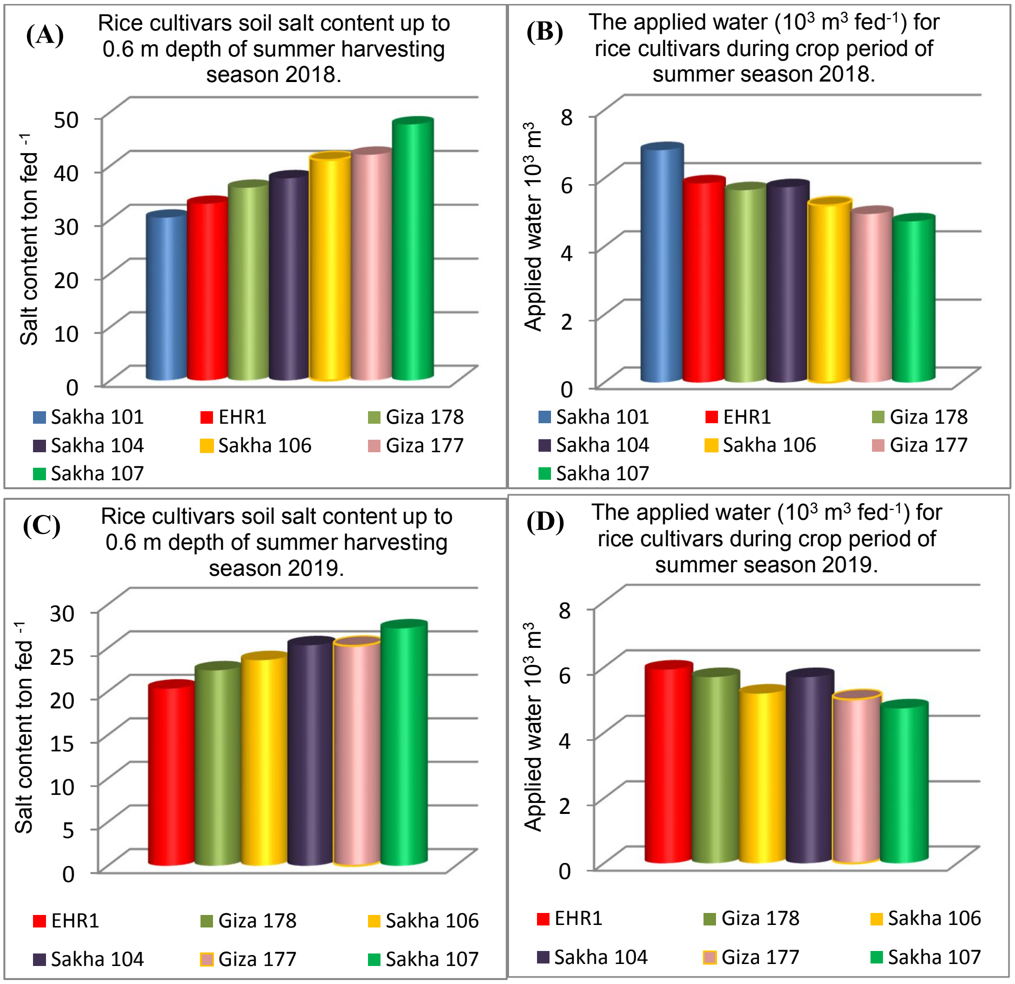


Fig. 2: Soil salt content ton fed^{-1} of 0.6 m soil depth (A and C) and the applied water (B and D) m^{3}fed^{-1} of rice cultivars during the studied summer seasons 2018 and 2019, respectively.

amendment application on the irrigation water applied, gypsum application increased the irrigation water added in the 1st and 2nd seasons by about 2.1 and 1.8% compared with control (untreated with gypsum). These results, as expected, revealed the role of released Ca^{2+} ions in reducing clay dispersion degree through Na^+ replacing and enhancing aggregate formation resulting in improved soil hydraulic properties that facilitated salt leaching (Skene and Oades, 1995; Xiao *et al*., 2022).

3.6. Water productivity and leaching efficiency:

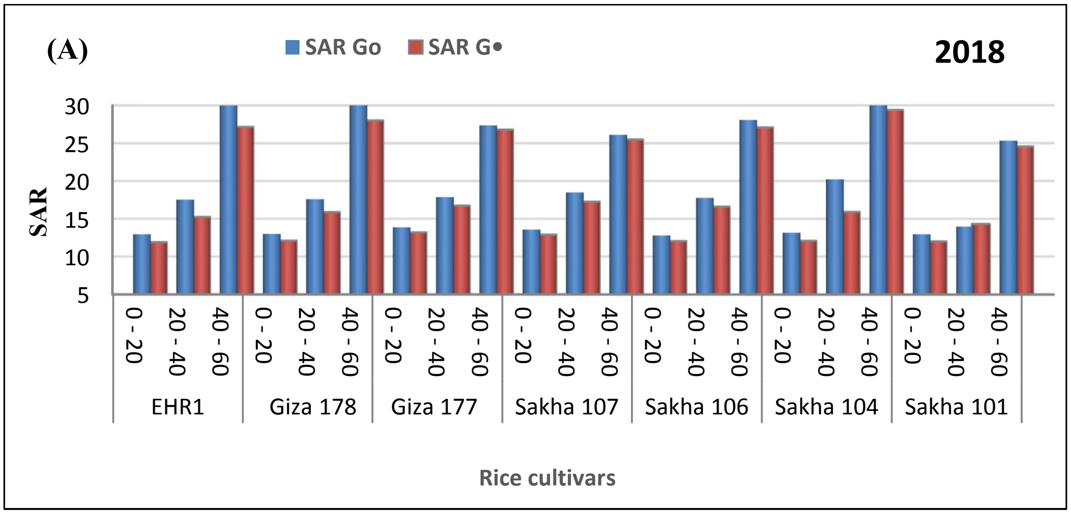
The amount of water applied to produce 1 kg of rice yield under the condition of this experiment is shown in Table (8). The lower the amount of water used to produce 1 kg, the higher the WP**.**

Considering the rice cultivars, regardless of gypsum treatment, results declared that WP values of the rice cultivars coincidentally behaved the corresponding order in the first and second seasons, the latter being superior. The results also indicated that Sakha 107 cultivar, followed by Giza 177, among the studied varieties ranked the first order for WP with values of 0.861 and 0.867 for the first and second seasons, respectively, meanwhile the lowest values of 0.589 and 0.601 were account for Sakha 104. These results could be a resultant of relative variations among rice cultivars in their crop duration (Abd El-Megeed *et al*. 2016; Abdallah *et al*., 2022). In addition, Mehana *et al*., (2021) reported that Giza 177 recorded the highest crop among Giza 178 and Sakha 104 as far as WP is concerned**.**

Concerning the effect of amending treatment, regardless rice cultivars varieties, data indicated that WP positively responded to gypsum application by an average relative increase of 7.82 and 8.5 % for the first and second summer seasons, respectively. These findings might be accountable for the relative salt content reduction under gypsum treatment and the principal role of released Ca^{2+} in improving plant capability to mitigate biotic stress along with enhancing its nutrient content, which led to increased crop productivity (Abdul Qadir *et al*., 2022; Liu *et al*., 2022). Furthermore, the interaction effect of Sakha 107, in contrast to Sakha 104, surpasses the other rice varieties for WP during the two-studied season, 2018 and 2019, with values of 0.897 and 0.913, respectively. Moreover, and despite the higher water applied under the experimental conditions, the WP values for the studied rice cultivars under gypsum treatment were relatively comparable with those reported by Mehana *et al*. (2021) and Abdallah *et al*. (2022) for Giza 177, Giza 178, Sakha 106 and 107, respectively, with the exception being obtained with Sakha 104. These findings may explore the role of gypsum application as far as WP is considered.

About the relation between the applied water and related soil salt content of 60 cm depth data (Table 8) declared that, with the first cropping season of 2018, gypsum application would improve salt removal by an average of 13% compared to control treatment that received no gypsum. Meanwhile, the second season of gypsum application contributes to salt leaching capacity by an average of 40% compared to the control treatment. These results may be because of the applied second gypsum doses at the beginning of the second season.

Concerning the SAR parameter as the indicator for soil sodium status, Fig. 3 (A and B) revealed, in general, a noticeable reduction in the surface soil layer 0 - 0.2 m with an almost gradual increase with subsequent soil layers for the tested rice varieties even those plots of the control treatment (not amended). These behaviors were observed also by the second summer season of 2019 with considerable inferiority as far as gypsum application is concerned. It may be worth to mention that the average reduction in SAR values for 0.6 m depth of plots that received gypsum treatment surpass those of the control treatment by about 8% during the first season. Meanwhile, with the second season the reduction was superior with an average of 30%. These results could be a result of accumulation of Na^{+} ions by the layer (40-60) and in relatively some layers of the tested rice varieties (Fig 3). Besides, using deep plowing (sub-soiler) during experimental set up facilitate water movement and gypsum losses from surface layer which seemed to be contribute for reduce SAR of second layer. These results in good agreement with those of Ryu *et al*., (2021) who found that sub-soiling treatment lead to enhance soil infiltration rate by about 150 and 49% for the shear point and 0.25m distance from the cutting point. Meanwhile, it rose up to 4% between the medial cut points. The results also declared that SAR values were reduced within the soil profile of 0.6 m. These results may be explained according to Luo *et al*. (2015) and Chaganti *et al*. (2021) on the base of Ca^{2+} supplemented by $CaCO_3$ dissolution that would enhance SAR of the soil profile and seemed to be also affected by water quality. In addition, biological reactions of rice root plants under flooding conditions led to an increasing redox system that resulted in the enhancement of $CaCO_3$ solubilization (Singh and Singh, 2022).



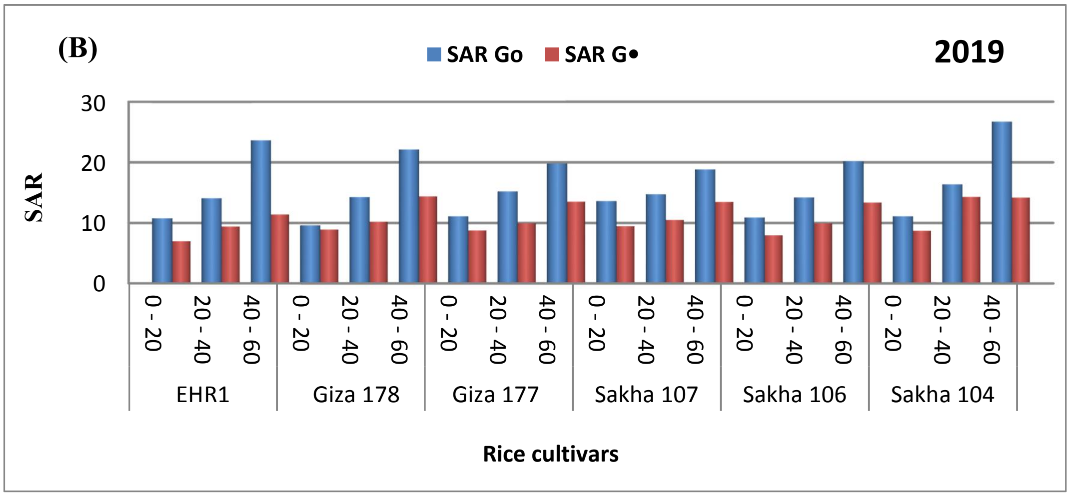


Fig. 3: Effect of the gypsum application, treated (G●) and untreated (Go), on the SAR values of different soil depths after rice harvesting of the studied summer seasons 2018 (A) and 2019 (B).

Conclusion

After two summer cropping seasons, among the new tested rice varieties Sakha 107, Giza 177, Sakha 106, Egyptian hybrid one (EHR1), and Sakha 104, EHR1 followed by Giza 178 outperformed the other tested cultivars for grain yield with corresponding values of 4.97 and 4.5 tone fed^{-1}, under gypsum application, and may be considered of the best varieties for maintaining self-sufficiency. Meanwhile, Sakha 107 and Giza 177 had considerable water productivity values of 0.913 and 0.853, respectively, and could be alternative varieties that encountered water scarcity. Gypsum treatment lowered soil salinity and SAR up to 0.6 m by more than 50%, and the removal efficiency increased by extending the cultivar period. Therefore, rice cultivation is a significant crop to maintain soil salinity-sodicity, particularly under conditions of using blended water. Adopting short-period rice varieties in the concerned area alternated with relatively long rice or medium crop periods may be helped in reducing soil profile salinization and support water saving.

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