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## Effect of Soil Salinity Improvers on Cotton Productivity on Land Reclamation

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SOIL salinity impairs plant productivity in Egypt due to immoderate accumulation of NaCl. To improve the productivity of saline-sodic soil via soil application of salinity improvers (SSI) to enhance the soil physical, biological and chemical properties and improve plant growth and productivity. Two field experiments were conducted at land reclamation at El Nobaria Research Station, Cotton Research Institute, Agricultural Research Center, El Beheira, Egypt, during 2020 and 2021 seasons, by using SSI (gypsum, sulfur and salinity correction) to study their effect on soil chemical properties and the leaves chemical constituents, growth, yield characters and fiber properties of Giza 94 cotton cultivar. A complete random design with four replicates was used as following: Control ($T_1$), gypsum ($T_2$), sulfur ($T_3$), salinity correction ($T_4$), gypsum + sulfur ($T_5$), gypsum + salinity correction ($T_6$), sulfur + salinity correction ($T_7$) and gypsum + sulfur + salinity correction ($T_8$). Results indicated that all SSI improved saline-sodic soil chemical properties by decreasing electrical conductivity (EC), sodium absorption ratio (SAR) and $Na^+$ content whereas increasing $Ca^{2+}$ content. All SSI applications individually or in combination significantly increased cotton leaves chemical constituents, growth, yield characters and fiber properties. The better performance for the individually application via $T_4$ gave higher seed cotton yield (9.334 and 9.46k/f) and the combination application via $T_8$ recorded the highest values of seed cotton yield (10.67 and 10.82k/f) compared to $T_1$ in both seasons, which SSI (calcium and sulfur-containing compounds) improved salinity soil effect by removing $Na^+$ cations, allowing nutrients uptake and improved productivity of cotton.

**Keywords:** Cotton, Gypsum, Saline-sodic soil, Salinity correction, Sulfur.

## Introduction

Soil decay resulting from salinity and sodicity is a main environmental menace to soil fecundity and crop productivity in arid and semiarid areas of the world. The increase of salinity in soil and groundwater is a major concern in Egyptian agriculture because of inadequate drainage conditions and the reduction in Nile demineralization of the soil owing to the deficiency of flooding. About 33% of total land area cropped is salt-affected land in Egypt, characterized as saline-sodic soils due to their poor physical and chemical properties (Mohamed et al., 2011). Saline–sodic soils tend to accumulate salts (high $Na^+$ concentrations) in the upper soil profile that alter the physical and chemical properties, including soil structure and hydraulic conductivity (Alcívar et al., 2018). High exchangeable soluble $Na^+$ at higher levels in the soil solution or at the cations exchange and pH reduced the dispersion of clays, soil permeability, slaking of soil aggregates, available water capacity and arise saline-sodic soil; thereby it caused to decrease the nutrients solubility in root zones and toxicity on plants (Andrade et al., 2018; Bello et al., 2021). Moreover, the negative effects of soil salinity properties include increased soil pH, sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP), while reduced cation exchange capacity (CEC) and soil microbial community (Zhang et al., 2019; Hammam & Mohamed, 2020). Salinity of soil has harmful effects on biochemical and physiological metabolism of plants due to osmotic and ionic stresses. The osmotic stress

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happens directly on the uptake of excess salt and leads to reduction in plant water uptake, leaves water content, production of pigments contents and plant growth. The ionic stress is characterized by salinity-induced accumulation of $Na^+$ and $Cl^-$, which due to ion imbalance (higher $Na^+/K^+$ ratio), leaf necrosis and plant senescence earlier than the attainment of physiological maturity (Ahmad et al., 2018). Salinity conditions significantly reduced growth characteristics, yield components and pigment contents, while increased significantly soluble sugars, phenols and free amino acids contents in cotton leaves and fiber quality properties (Ibrahim, 2022). Salinity stress caused to the osmotic effect that led to decrease water available, photosynthesis rate, increasing toxic ions accumulation, ionic imbalance, and stomatal closure, which that led to decrease the availability of assimilates and reduce number, weight of bolls and seed cotton yield (Zhang et al., 2014; Shehzad et al., 2019).

Gypsum ($CaSO_4.2H_2O$) is cheap and available, so it is a source for $Ca^{2+}$, sulfur and improves different properties of saline–sodic soil. It acts as a soil modifier by inhibiting the development of soil sodicity and directly enhances plant growth and productivity (Chintala et al., 2010). Gypsum has a positive role in the saline-sodic soils reclamation via replacement of the exchangeable $Na^+$ by $Ca^{2+}$ from the cation exchange sites and leaking $Na^+$ into groundwater out of root zone. Also, Gypsum immediately reduces the pH of sodic soils and allowed most plant nutrients to be absorbed by roots. Probably $Ca^{2+}$ reacts with bicarbonate to precipitate $CaCO_3$ and release protons which decreases the hydrolysis of clay to form hydroxides (Hafez et al., 2015). Gypsum application provision of $Ca^{2+}$ that acts as plant promoterto tolerance salinity conditions through increase the hydraulic conductivity and leaves surface area. $Ca^{2+}$ supports cell membrane solidity and selectivity that holding immoderate $Na^+$ and $Cl^-$ accumulation. Additionally, $Ca^{2+}$ adjustment participant proteins in $K^+$ and $Na^+$ transport support the motivation of $K^+$ against $Na^+$ flow, thereby raising the $K^+/Na^+$ ratio in plants under salinity conditions. Gypsum helps with reversing the negative impact of salinity on P uptake (Bello et al., 2021).

Sulfur (S) plays a vital role in the biosynthesis of protein, chlorophyll, and a few amino acids (Chowdhury et al., 2020). Application of inorganic sulfur is very essential for healthy growth and formation of protein and chlorophyll in plants. This important nutrient is available to plants only as sulfate; hence most sulfur fertilizers consist of sulfate salts. Plants need for sulfur is different from 0.1 to 0.5% of the dry biomass weight for optimum plant growth, because of its deficiency in soil due todecrease in crop yield and quality (Chan et al., 2019). Sulfur in plant tissues regulates chlorophyll content, electron transport system, activity of photosynthetic enzymes, C/N metabolism and protein synthesis. Application of sulfate may can overcome salinity problems, that because the important role of $SO_4^{2-}$ in formation $H_2SO_4$, which led to increase soil acidity, removal calcareous problem, which, is relation with salinity in soil (Mesbah, 2016). Sulfur adjusts plant stress mechanisms and physiological processes for improving plant salinity tolerance such as photosynthesis process regulated by the availability of S, which counters salt induced oxidative stress. Sulfur and its derivatives (e.g., glutathione) enhance the antioxidant defense pathway by scavenging excessive reactive oxygen species (ROS) under different stresses conditions (Hasanuzzaman et al., 2018) that led to oxidative stress, unbalanced nutrient and membrane instability on plants (Abd El-Mageed et al., 2020).

Desal is famous as saline soil and water corrector. It contains of calcium, nitrogen and carboxylic acids in liquid compound. It decreases $Na^+$ high toxic levels and increasing salt leaking. Desal has evolution product via high $Ca^{2+}$ cations exchange capacity, which allows $Na^+$ ions in sodic and sodic-saline soils to be removed from the clay-humic complicated and out in soil solution that led to decrease soil pH and release the absorption of nutrition by roots. Calcium supplied replaces sodium ions from the clay-humic complicated. The sodium ($Na^+$) that is subtracted reacts with the nitrate contributed ($NO_3^-$), thus forming sodium nitrate, which is very soluble in water [$NO_3^- + Na^+ \rightarrow NaNO_3$] and so it can be facilely removed by irrigation water, thus returning the clay-humic complicated (Hassan, 2016).

The objective of the current study was to investigate the effect of SSI applications (salinity correction, gypsum and sulfur) individually or in combination on salinity-sodic soil chemical properties and the leaves chemical constituents, growth, yield component and fiber properties of Giza 94 cotton cultivar in 2020 and 2021 seasons.

## Materials and Method

*Experimental design andtreatments*

The experiment was conducted in two successive seasons 2020 and 2021 at new land reclamation (salinity-sodic soil) at El Nobaria Research Station, Cotton Research Institute, Agricultural Research Center, El Beheira, Egypt. The experiment design was complete random design with three replications was adopted; the treatments of soil salinity improvers (gypsum, sulfur and salinity correction) were randomly assigned for eight treatments as follows:

- Control ($T_1$)

- Gypsum ($T_2$) is a commercial product from Afcomisr Co., Egypt. It is a naturally existing mineral that is consist of calcium sulfate and water ($CaSO_4.2H_2O$). By weight it is calcium sulfate 80% were added before planting 1kg/m$^2$.

- Sulfur ($T_3$) is a commercial product from Agrimisr Co., Egypt. It is a technologically advanced formulated with content of liquid sulfur 30% and calcium 6% completely water soluble. The amounts of liquid sulfur 400cm$^2$/100L water added through the irrigation water.

- Salinity correction (Desal) ($T_4$) is a commercial product from Agrolink Co., Egypt. It is evolution productmade up of calcium 15 %, nitrogen 12% and carboxyl acids 10% completely water soluble. The amounts of Desal 3L/fed added through the irrigation water one times per two weeks after planting and ended after flowering stage.

- Gypsum + sulfur ($T_5$)

- Gypsum +salinity correction ($T_6$)

- Sulfur + salinity correction ($T_7$)

- Gypsum + sulfur + salinity correction ($T_8$)

The experiment investigated the effect of SSI (gypsum, sulfur and salinity correction) applications individually or in combination on salinity-sodic soil chemical properties and the leaves chemical constituents, growth, yield and fiber properties of Giza 94 cotton cultivar. Seeds of cultivar Giza 94 were sown in saline-sodic soil on 12$^{th}$ of May 2020 in the first season and on the 10$^{th}$ May 2021 in the second one.The experimental plot consisted of 7 rows, 3.5m long and 0.6 m width (plot area= 14.70m$^2$) of the Agricultural Experimental El Nobari Station Farm of the Agriculture Research Center, El Beheira, Egypt. All experimental plots received irrigation, pesticide and fertilizer as recommended by the Egyptian Ministry of Agriculture for cotton cultivation. The chemical properties of the experimental fieldsoil are presented in Table 1. The soil analysis before and after SSI applications was conducted according to Rebecca (2004).

**TABLE 1. Chemical properties of experimental soil during 2020 and 2021 seasons**

| | 2020 | 2021 | | 2020 | 2021 |
|---|---|---|---|---|---|
| pH | 8.21 | 8.36 | **Soluble anions (meq/L)** | | |
| E.C. (dsm$^{-1}$) | 4.58 | 4.66 | $CO_3^{2-}$ | -- | -- |
| SAR | 23.42 | 24.10 | $HCO_3^-$ | 4.53 | 4.82 |
| **Available minerals (mg/kg soil)** | | | $Cl^-$ | 38.25 | 39.67 |
| N | 11.05 | 11.38 | $SO_4^{2-}$ | 0.75 | 0.81 |
| P | 8.20 | 8.46 | **Soluble cations (meq/L)** | | |
| K | 1.07 | 1.25 | $Ca^{2+}$ | 20.26 | 20.74 |
| Cu | 1.45 | 1.72 | $Mg^{2+}$ | 17.00 | 17.64 |
| Fe | 2.49 | 2.68 | $Na^+$ | 55.63 | 55.82 |
| Mn | 2.00 | 2.35 | $K^+$ | 1.07 | 1.16 |

*Chemical analysis*

Cotton leaves taken randomly after 60 days from planting to determine the chemical analysis as follows:

- Total chlorophyll assayed according to the method of Arnon (1949) and carotenoids of Robbelen (1957).

- Total soluble sugars determined by the phenol-sulfuric acid method in ethanol extract according to Cerning (1975). Reducing sugars assayed colormetrically by Folin and Wu method as reported in A.O.A.C. (1975). Non-reducing sugars calculated by the difference between total soluble sugars and total reducing sugars.

- Total free amino acids determined by ninhydrin method in ethanol extract according to Rosen (1957).

- Total phenols assayed by using Folin-Ciocalteau method in ethanol extract according to Simons & Ross (1971).

- Total antioxidant capacity assayed by the phosphomolybdenum method in ethanol extract as described by Kumaran & Karunakaran (2007).

*Growth characters*

Plant samples were taken after 60 days from sowing. In this stage, four plants were taken from each treatment. The growth characters of plants were recorded for this experiment as follows: plant height (cm), number of fruiting branches/ plant, plant dry weight (g), leaf area ($cm^2$) which is determined by leaf area meter Model L1 – 3100. In addition, relative water content was determined according to the method of Schonfeld et al. (1988).

*Yield and its components*

Three samples were taken from four plots at harvest stage. Yield and its components of number of open boll/plant, seed index (g), boll weight (g), lint percentage, and seed cotton yield (k/f) were recorded.

*Fiber technology properties*

According to A.S.T.M. (2012) fiber length, micronaire reading and fiber strength were determined fiber length, uniformity index, micronaire reading and fiber strength were recorded during data collection.

*Statistical analysis*

The measured variables were analyzed of variance (ANOVA) and Duncan test at 0.05 probability level by using M Stat-C statistical package (Freed, 1991). Standard error of means (S.E.M) was obtained from the analysis of variance using M Stat-C.

## Results

*Soil chemical properties*

Salinity and $Na^+$ ions removal affected by different SSI applications as demonstrated in Table 2. Generally, results revealed that all SSI treatments resulted in greater salinity removal compared with untreated soil ($T_1$), which they improved the chemical properties of salinity-sodic soil by decreasing pH, EC, SAR and $Na^+$ content, whereas increasing $Ca^{2+}$ content in both seasons.

**TABLE 2. Chemical analysis of soil treated with salinity soil improvers at harvesting during 2020 and 2021 seasons**

| Soil salinity improvers treatments | pH | | EC (ds $m^{-1}$) | | SAR | | $Ca^{2+}$ (meq/L) | | $Na^+$ (meq/L) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 |
| Control | 8.35 | 8.42 | 4.13 | 4.20 | 23.26 | 23.87 | 20.03 | 20.33 | 57.84 | 58.31 |
| Gypsum | 8.12 | 8.25 | 3.52 | 3.65 | 22.02 | 22.34 | 22.51 | 23.45 | 50.35 | 51.17 |
| Sulfur | 8.18 | 8.29 | 3.83 | 3.74 | 22.14 | 22.60 | 22.45 | 23.01 | 52.42 | 53.64 |
| Salinity correction | 8.09 | 8.22 | 3.10 | 3.16 | 21.97 | 22.14 | 23.28 | 23.86 | 48.70 | 49.18 |
| Gypsum + Sulfur | 8.03 | 8.14 | 2.84 | 2.89 | 21.94 | 21.99 | 23.63 | 24.12 | 47.51 | 48.73 |
| Gypsum + Salinity correction | 7.97 | 8.00 | 2..35 | 2.42 | 21.82 | 21.87 | 24.22 | 24.53 | 46.24 | 46.92 |
| Sulfur + Salinity correction | 8.00 | 8.07 | 2.62 | 2.70 | 21.88 | 21.92 | 23.91 | 24.29 | 46.83 | 47.36 |
| Gypsum + Sulfur + Salinity correction | 7.93 | 7.98 | 2.13 | 2.23 | 21.76 | 21.80 | 24.54 | 24.71 | 45.32 | 45.85 |
| S.E.M | 0.087 | 0.005 | 0.467 | 0.456 | 0.082 | 0.092 | 0.945 | 0.702 | 0.825 | 0.953 |

Note,.S.E.M = Standard error of means.

The individually applications of all SSI ameliorated the soil chemical properties, which salinity correction application ($T_4$) recorded higher significant results via decreased $Na^+$ content by 15.8 and 15.65%, pH by 3.11 and 2.37%, EC by 24.93 and 24.76% and SAR by 5.54 and 7.24%, whereas $Ca^{2+}$ content increased by 16.22 and 17.36%, respectively comparing with control plants ($T_1$) in both seasons.

All SSI combination applications enhanced the soil chemical properties. The main effect observed by the combination application of $T_8$ (gypsum + sulfur + salinity correction) gave the highest significant reducing in $Na^+$ content by 21.64 and 21.36%, pH by 5.02 and 5.22%, EC by 48.42 and 46.9%, SAR by 6.44 and 8.67%, while $Ca^{2+}$ content increasing by 22.51 and 21.54%, respectively comparing with control plants ($T_1$) in both seasons.

*Growth characteristics*

The data in Table 3 stated that, cotton plants sowed in saline-sodic soil ($T_1$) affected in growth characteristics of plant height, no. of fruiting branches/plant, plant dry weight, leave area and relative water content in both tested seasons. The untreated cotton ($T_1$) gave the lowest means of plant height (88.06 and 95.79cm), no. of fruiting branches/plant (8.31 and 9.33), plant dry weight (29.84 and 35.67g), leave area (799.71 and 809.94cm$^2$) and relative water content (40.22 and 41.37%) in both seasons, respectively.

All growth characteristics of cotton plant responded positively with all SSI applications (gypsum, sulfur and salinity correction) individually or in combination comparing with control plants $T_1$ in both tested seasons.

As for the individually application of salinity correction ($T_4$) gave significant higher values of plant height (109.91 and 119cm), no. of fruiting branches/plant (10.34 and 12.14), plant dry weight (41.84 and 46.33g), leave area (1131.61 and 1169.87cm$^2$) and relative water content (44.52 and 46.01%), then the application of gypsum ($T_2$) and sulfur ($T_3$) compared to control plants ($T_1$) in both seasons, respectively.

Considering the combination applications improved significantly all growth characteristics, which the best results recorded by the combination application of $T_8$ (gypsum + sulfur + salinity correction) then $T_6$ (gypsum + salinity correction) and $T_7$ (sulfur + salinity correction), respectively, compared to control plants $T_1$ in both tested seasons. The combination application of $T_8$ gave the highest significant means of plant height (123.25 and 130cm), no. of fruiting branches/plant (11.36 and 14.76), plant dry weight (57.13 and 67.03 g), leave area (1492.61 and 1501.79cm$^2$) and relative water content (52.61 and 54.72%) compared to control plants ($T_1$) in both seasons, respectively.

*Chemical constituents of cotton leave*

Data presented in Table 4 showed that the cotton plants in untreated soil ($T_1$) affected on the chemical constituents of cotton leaves, which $T_1$ application recorded the lowest contents of pigment (chlorophyll a, chlorophyll b and total chlorophyll, carotenoids) (2.56, 1.68, 4.24 and 0.791mg/g), carbohydrates of total soluble sugars, reducing sugars and non-reducing sugars (19.23, 11.12 and 8.11mg/g), total phenols (10.27mg/g), free amino acids (12.1mg/g) and total antioxidant capacity (0.706 $O.D_{695}$), respectively.

Table 4 stated that, all chemical constituents in cotton leaves increased significantly with all SSI applications individually or in combination than the control treatment.

With regard to the individually application of salinity correction ($T_4$) gave higher significant values of total chlorophyll, total soluble sugars, phenols, free amino acids contents and total antioxidant capacity (5.28, 24.04, 13.47, 14.58mg/g and 1.035O.D, respectively) then the application of gypsum ($T_2$) and the application of sulfur ($T_3$) compared to control plants ($T_1$), respectively.

As for the combination applications increased significantly cotton leaves chemical constituents, especially the combination application of $T_8$ (gypsum + sulfur + salinity correction) then $T_6$ (gypsum + salinity correction) and $T_7$ (sulfur + salinity correction), respectively, compared to control plants $T_1$. The combination application of $T_8$ gave the highest significantresults of total chlorophyll, total soluble sugars, phenols, free amino acids contents and total antioxidant capacity (7.58, 37.83, 16.41, 19.99mg/g and 1.313 O.D, respectively) compared to control plants ($T_1$).

**TABLE 3.Effect of soil salinity improvers (gypsum, sulfur and salinity correction) on growth characters of cotton plant during 2020 and 2021 seasons**

| Soil salinity improvers treatments | Plant height (cm) | | No. of fruiting branches/plant | | Plant dry Weight (g) | | Leave area ($cm^2$) | | Relative water content % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 |
| Control | $88.06^{d}$ | $95.79^{d}$ | $8.31^{c}$ | $9.33^{e}$ | $29.84^{f}$ | $35.67^{g}$ | $799.71^{e}$ | $809.94^{h}$ | $40.22^{e}$ | $41.37^{d}$ |
| Gypsum | $107.10^{bc}$ | $113.05^{c}$ | $10.33^{ab}$ | $11.75^{d}$ | $40.11^{e}$ | $43.91^{ef}$ | $1105.79^{d}$ | $1114.94^{f}$ | $41.49^{e}$ | $43.24^{d}$ |
| Sulfur | $101.49^{c}$ | $97.75^{d}$ | $9.35^{bc}$ | $11.38^{d}$ | $33.18^{f}$ | $39.87^{fg}$ | $855.47^{e}$ | $960.97^{g}$ | $41.15^{e}$ | $43.04^{d}$ |
| Salinity correction | $109.91^{b}$ | $119.00^{bc}$ | $10.34^{ab}$ | $12.14^{cd}$ | $41.84^{de}$ | $46.33^{de}$ | $1131.61^{d}$ | $1169.87^{e}$ | $44.52^{d}$ | $46.01^{c}$ |
| Gypsum + Sulfur | $119.85^{a}$ | $123.25^{ab}$ | $10.61^{ab}$ | $12.41^{bcd}$ | $44.71^{d}$ | $50.41^{cd}$ | $1144.99^{d}$ | $1252.29^{d}$ | $47.49^{c}$ | $48.65^{b}$ |
| Gypsum + Salinity correction | $122.66^{a}$ | $129.20^{a}$ | $11.08^{a}$ | $13.32^{b}$ | $55.94^{b}$ | $63.75^{b}$ | $1452.02^{b}$ | $1482.05^{b}$ | $51.47^{ab}$ | $52.78^{a}$ |
| Sulfur + Salinity correction | $120.37^{a}$ | $127.67^{a}$ | $10.82^{ab}$ | $12.90^{bc}$ | $51.28^{c}$ | $53.70^{c}$ | $1289.34^{c}$ | $1324.09^{c}$ | $50.30^{b}$ | $52.31^{a}$ |
| Gypsum + Sulfur + Salinity correction | $123.25^{a}$ | $130.00^{a}$ | $11.36^{a}$ | $14.76^{a}$ | $57.13^{a}$ | $67.03^{a}$ | $1492.61^{a}$ | $1501.79^{a}$ | $52.61^{a}$ | $54.72^{a}$ |
| LSD 0.05 | 6.787 | 8.459 | 1.500 | 1.070 | 4.239 | 5.708 | 75.440 | 48.915 | 2.221 | 2.430 |

**TABLE 4. Effect of soil salinity improvers (gypsum, sulfur and salinity correction) on Chl. a, b, total Chl., carotenoid, total soluble sugars, reducing, non- reducing sugars, total phenols, total free amino acids contents and total antioxidant capacity of cotton leaves**

| Soil salinity improvers treatments | Chlorophyll pigments (mg/g FW) | | | Carotenoids (mg/g FW) | Carbohydrate (mg/g FW) | | | Total phenols (mg/g FW) | Total free amino acids (mg/g FW) | Total antioxidant capacity (O.D 695nm) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Chl. a | Chl. b | Total Chl. | | Total soluble sugars | Reducing sugars | Non-reducing sugars | | | |
| Control | $2.56^{g}$ | $1.68^{g}$ | $4.24^{g}$ | $0.791^{g}$ | $19.23^{h}$ | $11.12^{g}$ | $8.11^{h}$ | $10.27^{g}$ | $12.10^{g}$ | $0.706^{f}$ |
| Gypsum | $3.22^{e}$ | $1.95^{f}$ | $5.17^{ef}$ | $0.910^{e}$ | $21.14^{f}$ | $12.22^{f}$ | $8.92^{f}$ | $12.92^{e}$ | $13.82^{e}$ | $0.866^{e}$ |
| Sulfur | $3.09^{f}$ | $1.91^{f}$ | $5.00^{f}$ | $0.856^{f}$ | $20.12^{g}$ | $11.88^{f}$ | $8.24^{g}$ | $12.04^{f}$ | $13.23^{f}$ | $0.850^{e}$ |
| Salinity correction | $3.27^{e}$ | $2.01^{e}$ | $5.28^{e}$ | $0.989^{d}$ | $24.04^{e}$ | $14.02^{e}$ | $10.02^{e}$ | $13.47^{de}$ | $14.58^{d}$ | $1.035^{d}$ |
| Gypsum + Sulfur | $3.75^{d}$ | $2.38^{d}$ | $6.13^{d}$ | $1.152^{c}$ | $25.58^{d}$ | $14.65^{d}$ | $10.93^{d}$ | $13.85^{d}$ | $14.71^{d}$ | $1.186^{c}$ |
| Gypsum + Salinity correction | $4.38^{b}$ | $2.81^{b}$ | $7.19^{b}$ | $1.294^{a}$ | $31.29^{b}$ | $18.25^{b}$ | $13.04^{b}$ | $15.65^{b}$ | $18.37^{b}$ | $1.304^{a}$ |
| Sulfur + Salinity correction | $4.07^{c}$ | $2.58^{c}$ | $6.65^{c}$ | $1.179^{b}$ | $29.13^{c}$ | $16.55^{c}$ | $12.58^{c}$ | $14.53^{c}$ | $16.70^{c}$ | $1.249^{b}$ |
| Gypsum + Sulfur + Salinity correction | $4.55^{a}$ | $3.03^{a}$ | 7.58a | $1.298^{a}$ | $37.83^{a}$ | $21.85^{a}$ | $15.98^{a}$ | $16.41^{a}$ | $19.99^{a}$ | $1.313^{a}$ |
| LSD 0.05 | 0.083 | 0.080 | 0.198 | 0.011 | 0.620 | 0.517 | 0.428 | 0.562 | 0.479 | 0.044 |

*Yield characteristics*

Results in Table 5 revealed that, the cotton plants in untreated soil ($T_1$) affected on yield and its components, which the application of $T_1$ gave the minimum means of no. of open bolls/plant (15.83 and 16.15), boll weight (2.24 and 2.26g), seed index (8.84 and 9.18g) and seed cotton yield (8.02 and 8.14k/f), while it gave the maximum means of lint % (40.32 and 40.35%) in both seasons, respectively.

The applications of SSI individually or combination significantly enhanced yield and its components including no. of open bolls/plant, seed index and seed cotton yield, whereas boll weight and lint % were insignificantly in both seasons.

The individually applications of salinity correction ($T_4$) gave higher significant values of yield and its components then the application of gypsum ($T_2$) and sulfur ($T_3$) comparing to control plants ($T_1$) in both tested seasons, respectively. The application of $T_4$ recorded best means of no. of open bolls/plant by 11.62 and 10.4%, boll weight by 3.57 and 3.53%, seed index by 12.33 and 10.34% and seed cotton yield by 16.45 and 16.21%, respectively, comparing with control plants ($T_1$) in both seasons.

All combination applications of SSI improving significantly cotton yield, which the combination application of $T_8$ (gypsum + sulfur + salinity correction) gave the best significant results then the applicant of $T_6$ (gypsum + salinity correction) and $T_7$ (sulfur + salinity correction) comparing with control plants $T_1$ in both seasons. The combinationapplication of $T_8$ recorded the maximum means of no. of open bolls/plant by 22.67 and 21.54%, boll weight by 8.48 and 8.4%, seed index by 25.9 and 23.31% and seed cotton yield by 33.04 and 32.92% as compared control plants ($T_1$) in both tested seasons, respectively.

*Fiber properties*

The data in Table 6 inducted that, SSI application (individually or in combination) gypsum, sulfur and salinity correction effected significantly on cotton fiber quality properties (uniformity index, micronaire reading and fiber strength), while fiber length insignificantly affected compared to the control ($T_1$) in 2020 and 2021 seasons. The individually applications of salinity correction ($T_4$) gave higher significantly values and the combination application of $T_8$ (gypsum + sulfur + salinity correction) gave the best significantly results on fiber properties comparing with control ($T_1$) in both tested seasons.

## Discussion

*Soil chemical properties*

Soil salinity result in high EC, SAR values and toxic accumulation of $Na^+$ (Table 2), which created osmotic stress in plants and led to low water uptake, cell death and plant wilting even under adequate soil moisture (Abdelhamid et al., 2013). Salinity has harmful impacts on soil biological characteristics, including soil microbial population, enzyme activity and biomass that due to decrease nutrient cycling, carbon fixing and soil productivity (Zhang et al., 2019). Therefore, crops productivity under salinity conditions significantly declines by decreasing plant growth, development and yield (Bello et al., 2021).

Salinity-sodic soil demands specific strategies such as SSI application (calcium and sulfur-containing compounds), including gypsum, sulfur and salinity correction to reduce pH, EC, SAR, $Na^+$ values and increase their reclamation role for long-term productivity (Lastiri-Hernández et al., 2019). SSI applications are foremost known methods of reclaiming salinity-sodic soils, which they can improve the soil's physical (aggregate stability, bulk density and water infiltration) and chemical (pH, EC, SAR, ESP, CEC, nutrients availability and organic carbon) characteristics, as well as biomass and crops production (Bello et al., 2021). SSI applications improve the availability of varied nutrients and enhance soil solution electrolytes in balanced concentration. Besides that, SSI applications stimulated soil microbial activity and biomass (Alcívar et al., 2018; Hammam & Mohamed, 2020). That might be related to the application of S in SSI reduces a plant's uptake of toxic elements, improves salt-soils' chemical properties and productivity. Sulfur contained in SSI is an acid former that allows decreasing the pH and EC of the soil in a fast way, which S speedy acidifies the soil as it oxidizes to a strong acid that reduces the soil pH and EC values. Likewise, application of SSI is provision of $Ca^{2+}$ in salinity-sodic soil that used to remove exchangeable $Na^+$, which the increasing of $Ca^{2+}$ and decreased $Na^+$ as due to the reduction in SAR value and reduced $Na^+$ uptake by plants. This replace of $Ca^{2+}$ for $Na^+$ in the soil colloids enhanced soil stabilization and permeability. An increase in $Ca^{2+}$ to $Na^+$ ratios on clay surfaces prohibits soil dispersion and improves a stable soil structure and makes more $Ca^{2+}$ available for plant uptake (Aboelsoud et al., 2020). Similar findings were deduced by Elazazi et al. (2017), who found that addition of gypsum + sulfur was more effective in reclaiming salinity-sodic soil than gypsum or sulfur alone.

TABLE 5. Effect of soil salinity improvers (gypsum, sulfur and salinity correction) on yield and its components of cotton plant during 2020 and 2021 seasons

| Soil salinity improvers treatments | No. of open bolls/plant | | Boll weight (g) | | Seed index (g) | | Lint % | | Seed cotton yield (k/f) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 |
| Control | 15.83$^{e}$ | 16.15$^{f}$ | 2.24$^{a}$ | 2.26$^{a}$ | 8.84$^{f}$ | 9.18$^{f}$ | 40.32$^{a}$ | 40.35$^{a}$ | 8.02$^{e}$ | 8.14$^{e}$ |
| Gypsum | 17.12$^{cd}$ | 17.38$^{de}$ | 2.30$^{a}$ | 2.3$^{a}$ | 9.72$^{de}$ | 9.92$^{de}$ | 40.24$^{a}$ | 40.32$^{a}$ | 8.93$^{cde}$ | 9.08$^{cde}$ |
| Sulfur | 16.55$^{de}$ | 16.72$^{ef}$ | 2.28$^{a}$ | 2.30$^{a}$ | 9.28$^{ef}$ | 9.45$^{ef}$ | 40.28$^{a}$ | 40.28$^{a}$ | 8.65$^{de}$ | 8.79$^{de}$ |
| Salinity correction | 17.67$^{bc}$ | 17.83$^{cd}$ | 2.32$^{a}$ | 2.34$^{a}$ | 9.93$^{cd}$ | 10.13$^{cd}$ | 40.16$^{a}$ | 40.24$^{a}$ | 9.34$^{bcd}$ | 9.46$^{bcd}$ |
| Gypsum + Sulfur | 17.91$^{bc}$ | 18.16$^{bcd}$ | 2.34$^{a}$ | 2.36$^{a}$ | 10.04$^{cd}$ | 10.56$^{bc}$ | 40.11$^{a}$ | 40.19$^{a}$ | 9.55$^{abcd}$ | 9.73$^{abcd}$ |
| Gypsum + Salinity correction | 18.82$^{ab}$ | 19.00$^{ab}$ | 2.40$^{a}$ | 2.41$^{a}$ | 10.60$^{b}$ | 11.04$^{ab}$ | 39.90$^{a}$ | 39.96$^{a}$ | 10.26$^{ab}$ | 10.41$^{ab}$ |
| Sulfur + Salinity correction | 18.14$^{bc}$ | 18.45$^{bc}$ | 2.36$^{a}$ | 2.37$^{a}$ | 10.35$^{bc}$ | 10.73$^{b}$ | 40.04$^{a}$ | 40.12$^{a}$ | 9.81$^{abc}$ | 9.96$^{abc}$ |
| Gypsum + Sulfur + Salinity correction | 19.42$^{a}$ | 19.63$^{a}$ | 2.43$^{a}$ | 2.45$^{a}$ | 11.13$^{a}$ | 11.32$^{a}$ | 39.73$^{a}$ | 39.85$^{a}$ | 10.67$^{a}$ | 10.82$^{a}$ |
| LSD 0.05 | 1.232 | 0.987 | N.S | N.S | 0.513 | 0.548 | N.S | N.S | 1.138 | 1.129 |

TABLE 6. Effect of soil salinity improvers (gypsum, sulfur and salinity correction) on fiber properties of cotton plant during 2020 and 2021 seasons

| Soil salinity improvers treatments | Fiber length (mm) | | Uniformity index | | Micronaire reading | | Fiber strength | |
|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 |
| Control | 34.05$^{a}$ | 34.16$^{a}$ | 85.87$^{d}$ | 85.95$^{d}$ | 3.93$^{b}$ | 3.91$^{c}$ | 10.42$^{c}$ | 10.54$^{b}$ |
| Gypsum | 34.22$^{a}$ | 34.30$^{a}$ | 86.21$^{bcd}$ | 86.34$^{bcd}$ | 4.03$^{ab}$ | 4.21$^{ab}$ | 10.60$^{abc}$ | 10.62$^{ab}$ |
| Sulfate | 34.18$^{a}$ | 34.23$^{a}$ | 86.09$^{cd}$ | 86.17$^{cd}$ | 3.98$^{b}$ | 4.15$^{bc}$ | 10.58$^{bc}$ | 10.58$^{b}$ |
| Salinity correcting | 34.46$^{a}$ | 34.44$^{a}$ | 86.52$^{abc}$ | 86.64$^{abc}$ | 4.06$^{ab}$ | 4.33$^{ab}$ | 10.61$^{abc}$ | 10.73$^{ab}$ |
| Gypsum + Sulfate | 34.53$^{a}$ | 34.67$^{a}$ | 86.76$^{ab}$ | 86.92$^{ab}$ | 4.14$^{ab}$ | 4.36$^{ab}$ | 10.72$^{abc}$ | 10.76$^{ab}$ |
| Gypsum + Salinity correcting | 34.68$^{a}$ | 34.81$^{a}$ | 87.00$^{a}$ | 87.06$^{a}$ | 4.31$^{a}$ | 4.44$^{a}$ | 10.87$^{ab}$ | 10.87$^{ab}$ |
| Sulfate + Salinity correcting | 34.54$^{a}$ | 34.75$^{a}$ | 86.94$^{a}$ | 86.93$^{ab}$ | 4.28$^{ab}$ | 4.40$^{a}$ | 10.76$^{abc}$ | 10.83$^{ab}$ |
| Gypsum + Sulfate + Salinity correcting | 34.71$^{a}$ | 34.86$^{a}$ | 87.08$^{a}$ | 87.20$^{a}$ | 4.36$^{a}$ | 4.48$^{a}$ | 10.92$^{a}$ | 10.92$^{a}$ |
| LSD at 0.05 of | N.S | N.S | 0.567 | 0.644 | 0.391 | 0.282 | 0.391 | 0.305 |

*Growth characteristics*

The salinity-sodic soil (untreated soil) reduced all growth characteristics of cotton plants ($T_1$) in both seasons as showed in Table 3. The decline in growth characteristics in response to salinity may be related to a combination of osmotic stress and increasing $Cl^-$ and $Na^+$ ions concentration due to a decrease in the water availability, increase sodium chloride toxicity and growth inhibition cause to use energy instead of growth to tolerate salinity (Ahmad et al., 2018). Salinity conditions reduced turgor pressure and leaf area which caused to inhibition of cell division, expansion, stomata closure, decrease photosynthesis rate and altered metabolism (Bello et al., 2021). These results are in line with Ibrahim (2022) and Shehzad et al. (2019) on cotton.

Regarding applications of SSI have a positive effect on the salinity-sodic soil especially in land reclamation, which SSI contain $Ca^{2+}$ cation and sulfur that decreased soil pH, EC, SAR, $Na^+$ and allowed the nutrient uptake from soil to the cotton plants and improving the growth and development of plants. Also, SSI replaced $Na^+$ cations on the surface and surplus irrigation water leaked the replaced $Na^+$ out of the upper-layer, so that gypsum could reducein $Na^+$ ions form the soil and improved plant root growth. In addition, calcium enhancesN, K and P elements absorption in roots, promotes photosynthesis rate, augments the plant growth and productivity. Similar finding are illustrated by Chandrakar et al. (2018), who stated that the plant height increased with the gypsum treatment might be due to its role in chlorophyll synthesis. Moreover, sulfur treatment is necessary for better plant biosynthesis and growth, which it enters intoa few amino acids, proteins and chlorophyll biosynthesis and forming in plants. Additionally, sulfur application at high levels increases nutrients uptake which might have affected on the stored materials synthesis and translocation. The results obtained by Eisa et al. (2016) and Chowdhury et al. (2020) who found that the application of sulfur significantly increased the plant height and leaf area compared to control plants.

*Chemical constituents of cotton leave*

Salinity-sodic soil (untreated soil) affected on cotton leaves chemical constituents ($T_1$) of pigments, carbohydrates, phenols, amino acids and antioxidant capacity (Table 4). That might be attended to the negative effect of salinity and high levels of soluble $Na^+$ that due to decrease photosynthesis rate, repressed the responsible enzymes for chlorophyll synthesis, decreased pigments content and reduction in stomatal conductance. Cotton plants under salinity conditions activated metabolic and defense system like increasing leaves chemical constituents' of soluble sugars, phenols and free amino acids that act as protective osmolytes allowing plants to keep tissue water stations. These results are in agreement with Alcívar et al. (2018), Shehzad et al. (2019), and Ibrahim (2022) on cotton.

Cotton leaves chemical constituents (photosynthetic pigments, carbohydrates, total phenols, total free amino acids contents and total antioxidant capacity) increased significantly with SSI either individually or in combination application as comparing to untreated plants ($T_1$). The increment in pigments content might be related to SSI being major source of calcium and sulfur for the plant, which calcium enhances phosphorus, potassium and ammonium absorption. Calcium and sulfur have a positive interaction, which increases $Ca^{+2}$ ions and S levels due to redouble carbon dioxide amounts fixation from the air, increase photosynthesis rate, plant growth, nitrogen uptake and plant's carbohydrates biosynthesis (Pradhan & Patnaik, 2015; Chandrakar et al., 2018). Also, calcium effect cellular pH and a regulate carbohydrates translocation in the source-sink via its effects on cells and cell walls that improvement plant carbohydrates contents (Hafez et al., 2015; Hassan, 2016). In addition, $CaSO_4$ might have been increased sulfur amount with increasing $SO_4^{-2}$ levels that increasing sulfur-containing amino acids production by increasing sulfur and pyruvic acid contents was led to increase crop uptake of sulfur by sulfur soil application cause to improve volatile sulfur compounds synthesis and production of more pungency in the plant (Chattopadhyay et al., 2015). These results are in line with Navaldey (2014), who found that photosynthesis pigments content increased in response to application of gypsum and sulfur. That might be due to high sulfur fertilization increasing rubisco chlorophyll and protein content the regulatory function of the calcium transport from the cytosol into the chloroplast illumination. Likewise, Khalil et al. (2015) and Mesbah (2016) reported the important role of $SO_4^{-2}$ in formation $H_2SO_4$ that increase soil acidity, remove calcareous problems because of salinity, sulfur role in mineralization process from via chemotrophic sulfur bacteria and formation some of the amino acids (cysteine, biotin and thiamine), sulfur is essential element information of glycosides (chloroplasts, which, contain chlorophyll).

*Yield characteristics*

The results in Table 5 revealed that yield and its components of cotton affected by saline-sodic soil in both seasons. That might be related to salinity conditions reduced the nutrition availability from the soil to the plant that finally due to decrease plant growth, development, reduced number, weight of bolls and seed cotton yield. These results are agreement with Alcívar et al. (2018), Shehzad et al. (2019), and Ibrahim (2022) on cotton.

The study indicated that the application of SSI individually or combination had strong positive effect on cotton yield and its components compared to the control ($T_1$) in both tested seasons. The positive effect of SSI applications might be attributed to the important role of $CaSO_4$ in alleviates the adverse effect of soil salinity and decreased soil pH, EC on the soil from by exchanging $Na^+$ with $Ca^{+2}$cations, thus, removed $Na^+$ and $Cl^-$ out the cell or exile on root system range (Mesbah, 2016). Besides that, sulfur is a limitation factor for leaves biomass yield in crops ecosystems (Pareek et al., 2012). The yield improvement might be related to the efficient sulfur availability exploit and metabolism, which sulfur has a synergistic relationship with many essential plant nutrients especially nitrogen that its uptake and absorption become limited in sulfur deficient soils. The growth and yield improvements obtained from sulfur application, might affect the synthesis and translocation of stored materials and pigments content (Pradhan & Patnaik, 2015; Chandrakar et al., 2018). Results can be supported with the findings of Eisa et al. (2016) and Chowdhury et al. (2020), who observed the favorable effect of sulfur application on the plant growth and yield.

*Fiber properties*

The finding in Table 6 showed that SSI application affected significantly on fiber quality properties in both seasons. That might be related to the positive effect of SSI application on soil properties and cotton plants during growth and productivity stages that led to improve chlorophyll, carbohydrates contents, number, weight of bolls, lint%, seed cotton yield and finally fiber quality properties (uniformity index, micronaire reading and fiber strength).

## Conclusion

Saline-sodic soil affects the biochemical, physiological and morphological processes of plants that due to osmotic and ionic stresses. Exchangeable soluble $Na^+$ at higher levels in the soil solution or at the cations exchange site that arise saline-sodic soil, which causing loss of inherent soil quality, deficiency of some nutrients by reducing their solubility in root zone and toxicity on plants. The application of SSI (calcium and sulfur-containing compounds) such as gypsum, sulfur and salinity correction individually or/and combination improved the chemical properties of saline-sodic soil in new land reclaimed by removing $Na^+$ cation and increasing $Ca^{2+}$ and sulfur of the soil that caused a significant decreasing in soil alkalinity and salinity. A significant enhancement in leaves chemical constituents, growth, yield and fiber properties of cotton were obtained when salinity correction ($T_4$) applied individually into clay alkalinity-salinity soil. Also, the combination application of $T_8$ (gypsum + sulfur + salinity correction) is considered as the effective application to remove the salts for reclamation of salinity-sodic soil and improved chemical constituents, plant growth, yield and fiber properties of cotton.

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## تأثير إستخدام محسنات ملوحة التربة علي إنتاجية القطن في الأراضي المستصلحة

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ملوحة التربة تضعف إنتاجية النباتات في مصر نتيجه للتراكم المفرط لكلويد الصوديوم في التربة. تم استخدام مواد محسنات ملوحة التربة لتحسين إنتاجية التربة الملحيه- القلويه عن طريق زياده الخصائص الفيزيائية والكيمياتيه والحيويه للتربة لتحسين نمو وإنتاجية النباتات. أجريت التجربه خلال موسمين 2020 و2021 لصنف جيزه 94 بمحطة بحوث النوبارية التابعة لمعهد بحوث القطن – مركز البحوث الزراعية لمعرفة تأثير محسنات التربة (الجبس الزراعي- الكبريت الزراعي – مصحح الملوحه) في التربة الملحية-القلويه للأراضي المستصلحة ودراسة تأثيرها منفرده ومتجمعه علي الخصائص الكيميائية للتربة والمكونات الكيميائيه للأوراق (الصبغات – الكربوهيدرات– الفينولات– الاحماض الامينيه الحرة- محتوي مضادات الاكسدة) وخصائص النمو والمحصول ومكوناته وصفات جوده ألياف لصنف جيزة 94. استخدام تقييم القطع الكاملة العشوائيه في ثلاث مكررات، حيث احتوت علي ثمانية معاملات وهي الكنترول، الجبس الزراعي، الكبريت الزراعي، مصحح الملوحة، الجبس+الكبريت، الجبس+مصحح الملوحة، الكبريت+مصحح الملوحة، الجبس+الكبريت+مصحح الملوحة. أوضحت النتائج المتحصل عليها أن استخدام محسنات التربه أدى إلى تحسين الخصائص الكيميائية للتربة الملحية-القلوية عن طريق تقليل كمية الصوديوم والتوصيل الكهربائي (EC) ونسبة إمتصاص الصوديوم (SAR) وزياده كميه الكالسيوم بها. أدى إستخدام كل محسنات التربة منفرده أو متجمعه إلى زياده معنويا في المحتوي الكيميائي للأوراق ويحسن معنويا خصائص النمو والمحصول ومكوناته وجوده الألياف، حيث أعطى استخدام محسن الملوحة منفردا أفضل النتائج يليها إستخدام الجبس الزراعي ثم الكبريت الزراعي مقارنه بالكنترول في الموسمين، بينما أعطى إستخدام المتجمع للجبس+الكبريت+مصحح الملوحة معا أعلى النتائج معنويا يليها استخدام الجبس+مصحح الملوحة معا ثم استخدام الكبريت+مصحح الملوحة معا مقارنه بالكنترول في الموسمين. وذلك يرجع إلى إحتواء محسنات التريه على الكالسيوم والكبريت التي تعمل على إنخفاض حموضة التربة والتخلص من ايونات الصوديوم وتقليل ملوحة التربة مما يسمح بانتقال المغذيات من التربة للنبات فيحسنمن نمو وانتاجية نبات القطن.