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# EFFECT OF SOME SOIL AMENDMENTS ON SALINE-SODIC SOILS RECLAMATION

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**ABSTRACT:** A leaching experiment was conducted to asses efficiency of gypsum solely or in combination with sulfuric acid and/or botanical compost on saline-sodic soils reclamation. Soil samples were collected from El-Hossainia plain, El-Sharkia Governorate, Egypt. The following treatments were designed in a randomized complete block design and performed in 8 replicates:T1: non-treated soil "NTS", T2: full gypsum requirements "FGR", T3: FGR + sulfuric acid "SA", T4: FGR + SA + botanical compost 1% "BC-1%", T5: FGR + SA + botanical compost 2% "BC-2%", T6: FGR + BC-1%, T7: FGR + BC-2%, T8: ½ gypsum requirements "½ GR", T9: ½ GR + SA, T10: ½ GR + SA + BC-1%, T11: ½ GR + SA + BC-2%, T12: ½ GR + BC-1% and T13: ½ GR + BC-2%. Leaching was done using the intermittent method so as to add portions to the already saturated soil columns, and obtain leachates equal to the added portions. Amounts of water were calculated to reduce the initial $EC_e$ from 66 to 4-$dSm^{-1}$ for 20-cm soil according to Reeve equation. All treatments decreased soil EC, soil pH and soil sodicity expressed as SAR and ESP. Results showed that ½ GR + SA + BC-2% treatment was more effective in decreasing the pH, EC and soil sodicity than the other treatments. Efficiency of treatments were T11 < T5 < T4 < T3 < T10 < T7 < T9 < T6 < T2 < T8 < T13 < T12 < T1. This study suggests that leaching using gypsum in combination with sulfuric acid and/or botanical compost on saline-sodic soils reclamation is reliable on ameliorating salinity and sodicity or such soils.

**Key words:** Saline, sodic, soils, reclamation, gypsum, sulfuric acid and compost.

## INTRODUCTION

Soil degradation, which can be caused by salinity and sodicity, is considered an environmental impairment problem causing severe adverse effects on agricultural productivity, particularly in arid and semi-arid regions (Qadir *et al.*, 2006). Salt-affected soils have become a serious problem of land degradation all around the world (Vanessa *et al.*, 2004). The total global area of salt-affected soils including saline soudic, saline and sodic soils was 831 M ha (Martinez-Beltran and Manzur, 2005). Soil salinity and/or sodicity is a global problem posing major threat to sustainable agriculture in the world. Globally, > 8 × $10^8$ ha of land are affected, either by salinity (3.97 × $10^8$ ha) or sodicity (4.34 × $10^8$ ha) (FAO, 2000), both constitutes about 6% of the world's total land area. Salinity or sodicity in profile layers are major abiotic environmental stresses to crop production (Grewal, 2010). Degradation of soil caused by salinity/sodicity is problematic in modern world (Sadiq *et al.*, 2007).

Salinization is the increase of the total soluble salts in the root zone of a soil profile whereas; sodication or alkalization is the increase of exchangeable sodium percentage in the root zone of a soil profile. Both processes occur naturally but they may be accelerated by adverse human activities. Furthermore, the two processes may operate simultaneously and form saline sodic soils. The three types of soils occur in all continents and under almost all climatic conditions. There are many procedures and strategies that can be used to improve salt

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affected cropland. The chemical remediation is one of these reclamation strategies (Sharma and Minhas, 2005). The application of $Ca^{2+}$ amendments can improve different properties of soil and act as soil modifiers that can prevent development of sodicity which is directly related to plant growth, crop productivity and crop yields (Wong *et al.*, 2009; Chintala *et al.*, 2010).

Saline-sodic and sodic soils need a source of soluble calcium ($Ca^{2+}$) to replace excess $Na^{+}$ from cation exchange sites. Chemical amendments have a long history of usage for soil amelioration (Qadir *et al.*, 2001). Gypsum is the most extensively used amendment for the reclamation of saline-sodic soils because of its low cost, general availability, and rich supply of ($Ca^{2+}$) Ghafoor and Muhammad, 1981; Hanay *et al.*, 2004; Ardakani and Zahirnia, 2006,Tuna *et al.*, 2007; Murtaza *et al.*, 2009; Wong *et al.*, 2009). Gypsum plays a significant role in the reclamation of saline-sodic soils by providing a $Ca^{2+}$ cation to replace the exchangeable Na+ from the colloid's cation exchange positions and leaching it out from the root zone into groundwater (Oster, 2002; Sharma and Minhas, 2005; Qadir and Horneck *et al.*, 2007). Efficiency of gypsum in the reclamation of saline-sodic and sodic soils varies considerably depending upon the type of the soil to be reclaimed, the method of gypsum application, the fineness of the gypsum particles, combination of gypsum with other amendments and breaking of the soil hard pan, if exists (Chaudhry, 2001).

However, although gypsum amendment has a marled impact on the chemical properties of the soil yet it has minimum impact on the soil biological properties (Clark *et al.*, 2009).

Addition of gypsum at different rates to saline sodic soils then leaching led to increase sodium, chloride, zinc and manganese concentrations in leached water and at the same time soil salinity, soil pH, dissolved and exchangeable sodium and dissolved chloride decreased with increase in gypsum applied rate (Sahin *et al.*, 2003; Makoi and Ndakidemi, 2007).

Khan *et al.* (2010) found a positive significant improvement in saline-sodic soil properties, *i.e.*, EC, SAR and pH in response to applied gypsum. Abdel-Fattah (2011 and 2012) detected pronounced decreases in EC, pH, SAR, ESP and bulk density and, on the other hand, increases in hydraulic conductivity and infiltration rate in saline-sodic soil due to the application of gypsum and two types of compost either applied solely or in combination, compared with the control and added that the combined treatments were more efficient. These results are similar to those obtained by Abou Youssef (2001) and Manzoor *et al.* (2001).The main objective of this study was evalution of the efficiency of leaching using gypsum soley or in combinations with sulfuric acid and/or botanical compost at different rates on saline-sodic soils reclamation.

## MATERIALS AND METHODS

### Soil Location, Preparation of Pots and Application of Soil Amendments

Soil samples were collected from the surface layers (0-30 cm) of El-Hossainia plain, El-Sharkia Governorate, Egypt; air-dried, crushed, mixed thoroughly passed through a 2-mm sieve and analyzed for their physical and chemical properties. Table 1 shows the physical and chemical properties of the soil.

Polyvinyl chloride cubic pots of 30-cm height, 25-cm length and 25-cm width were used. The bottom of each pot was pierced and sealed with a perforated nylon screen and glass wool. Acid-washed inert sand (pre-washed with HCl then water) was placed on the pot bottom to make a 5-cm layer of sand. Soil was packed uniformly in pots to a hight of 20-cm to maintain a soil bulk density of 1.35-$Mgm^{-3}$, this required a quantity of soil of 16.88-kg of crushed air-dried soil per pot. The top 5-cm of the pot was left to give a sufficient space for addition of water used for leaching process.

The soil amendments used in this experiment were, gypsum (85% purity), sulfuric acid and compost of plant residues. Gypsum "G" amount (28.11 Mg $ha^{-1}$) was calculated based on the gypsum requirement (GR) equation (USDA, 1954) taking into consideration reducing the exchangeable sodium percentage ($ESP_i$) of soil to a final exchangeable sodium percentage ($ESP_f$) of 10% using the equation:

$$GR = \frac{ESP_i - ESP_f}{100} \times CEC \times 1.14$$

**Table 1. Physical and chemical properties of studied soil**

| Soil property | Value |
|---|---|
| - Particle size distribution (%) | |
| - Clay | 53.79 |
| - Silt | 29.56 |
| - Sand | 16.52 |
| - Textural class | Clay |
| - Saturation percent | 43.75 |
| - Bulk density, $Mgm^{-3}$ | 1.35 |
| - Total porosity [%] | 52.83 |
| Organic matter [g $kg^{-1}$] | 3.80 |
| $CaCO_3$ [g $kg^{-1}$] | 52.5 |
| - EC ($dSm^{-1}$) [Soil paste extract] | 66.00 |
| - pH [Soil suspension 1:2.5] | 8.36 |
| - Soluble ions ($mmol_c$ $l^{-1}$) | |
| ▪ $Na^+$ | 587.88 |
| ▪ $K^+$ | 3.81 |
| ▪ $Ca^{2+}$ | 63.46 |
| ▪ $Mg^{2+}$ | 137.40 |
| ▪ $Cl^-$ | 526.00 |
| ▪ $HCO_3^-$ | 26.00 |
| ▪ $SO_4^=$ | 240.55 |
| ▪ SAR | 58.66 |
| Exchangeable cations, CEC and ESP | |
| ▪ $Na^+$ ($cmol_c$ $kg^{-1}$) | 12.21 |
| ▪ $K^+$ ($cmol_c$ $kg^{-1}$) | 5.56 |
| ▪ $Ca^{2+}$ ($cmol_c$ $kg^{-1}$) | 7.87 |
| ▪ $Mg^{2+}$ ($cmol_c$ $kg^{-1}$) | 8.93 |
| ▪ CEC ($cmol_c$ $kg^{-1}$) | 34.57 |
| ▪ $ESP_i$ | 35.32 |

Where:

GR: gypsum requirement (Mg $fad^{-1}$.), $ESP_i$: initial ESP of the soil (actual ESP of the soil), $ESP_f$: final ESP of the soil (ESP required to be reached by reclamation) and CEC: cation exchange capacity ($cmol_c\ kg^{-1}$ soil).

The equivalent amount for sulfuric acid "SA" was calculated according to FAO (1988) as follows: amount of sulfuric acid = GR × 0.57 (16.03 Mg $ha^{-1}$). Botanical compost "BC" was added at a rate of 1% or 2% by weight. All former amendments and their combinations were mixed homogeneously with soil before being packed in pots. The G was of 85% purity and its addition rate was 175.74-g per pot. The SA (concentration 98%, specific weight 1.84 Mg $m^{-3}$ and normality 36.7N) was added at a rate of 0.06-ml per pot (8.89 liter per ha). The BC was added at a rate of 156 or 312 g. $pot^{-1}$. Table 2 shows some properties of the BC. The following treatments were designed in a randomized complete block design and performed in 8 replicates:T1: non-treated soil "NTS", T2: full gypsum requirements "FGR", T3: FGR + sulfuric acid "SA", T4: FGR + SA + botanical compost 1% "BC-1%", T5: FGR + SA + botanical compost 2% "BC-2%", T6: FGR + BC-1%, T7: FGR + BC-2%, T8: ½ gypsum requirements "½ GR", T9: ½ GR + SA, T10: ½ GR + SA + BC-1%, T11: ½ GR + SA + BC-2%, T12: ½ GR + BC-1% and T13: ½ GR + BC-2%.

## Experiment Execution

After mixing amendments with soil, the soils were leached with water having EC 1.00-$dSm^{-1}$. Leaching was done using intermittent method so as to add water portions to the already saturated soil; and obtain leachates equal to the added portions. Amounts of water (43.12 liter per pot) were calculated to reduce the initial $EC_e$ from 66 to 4-$dSm^{-1}$ for 20-cm soil according to Reeve equation (Reeve, 1975). as follows:

$$\frac{D_{iw}}{D_s} = \frac{(EC_e)_i}{5(EC_e)_f} + 0.15$$

Where:

$D_{iw}$ is the depth of the applied leaching water (cm), Ds is the depth of soil (cm), $(EC_e)_i$ is the soil salinity($dSm^{-1}$) before leaching and $(EC_e)_f$ is the soil salinity ($dSm^{-1}$) after leaching. Calculated $D_{iw}$ (equal to 69-cm water depth) was divided into about 14 leachates; each one was 5-cm water depth (3.03.125 L of water leaching). Leachates were collected and analyzed for EC, pH, Soluble cations and anions.

At end of the experiment, soil was analyzed according to the methods described by the USDA (1954), Jackson (1967), Page *et al.* (1982) and Baruah and Barthakur (1997).

# RESULTS AND DISCUSSION

## Chemical Composition of Leachates

Salt and ion removal as affected by leaching and different treatments are shown in Fig. 1. Generally, results show that all treatments resulted in greater salt removal compared with untreated soil (*i.e.*, leaching alone). The main effect shows that T5 treatment "FGR + SA + BC-2%" gave the highest salt removal (170.68 $dS.m^{-1}$) whereas the control (*i.e.*, leaching alone) treatment resulted in the lowest (135.83$dS.m^{-1}$). This shows the superiority of gypsum as full requirements combined with both sulfuric acid and botanical compost at a rate of 2% (*i.e.*, FGR + SA + BC-2%) in salt removal from the studied soil. Treating soil with amendments resulted in salt removal efficiencies of by 21.19, 22.49, 25.56, 25.66, 21.37, 21.66, 20.70, 21.97, 25.21, 25.00, 17.60 and 19.87 for T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12 and T13, respectively. Salt removal by treatments was in the following order: T5 > T4 > T10 > T11 > T3 > T9 > T7 > T6 > T2 > T8 > T13 > T12 > T1, respectively.

The main effect shows that the 1st leachate was of the highest salinity (319.20 $dS.m^{-1}$) whereas 14th leachate gave the lowest (34.57 $dS.m^{-1}$). Soluble salts removed in leachates depended on the number of leachates. There was a considerable decrease in EC particularly following the 1st leachate. From the 8th leachate (152.06 $dSm^{-1}$) onwards, the decrease was rather moderate. This shows that the amount of added water leaching portion was capable of removing the majority of the readily soluble salts and mobile ions such as $Cl^-$ and $Na^+$, whether the soils were amended or not.

Dissolution of the slightly soluble salts (such as $CaSO_4$ and $CaCO_3$) and desorption of the exchangeble ions from the exchange complex would further supply the soil solution with soluble

Table 2. Physical and chemical properties of botanical compost

| Property | Value |
|---|---|
| Moisture (%) | 27 |
| EC, $dSm^{-1}$ | 2.1 |
| Organic matter, $gkg^{-1}$ | 321 |
| Organic carbon, $gkg^{-1}$ | 187 |
| Total nitrogen, $gkg^{-1}$ | 13 |
| C:N ratio | 14 : 1 |
| $N\text{-}NO_3$, $mgkg^{-1}$ | 113 |
| N-NH4, $mgkg^{-1}$ | 558 |
| Total phosphorus, $gkg^{-1}$ | 0.5 |
| Total potassium, $gkg^{-1}$ | 2.4 |

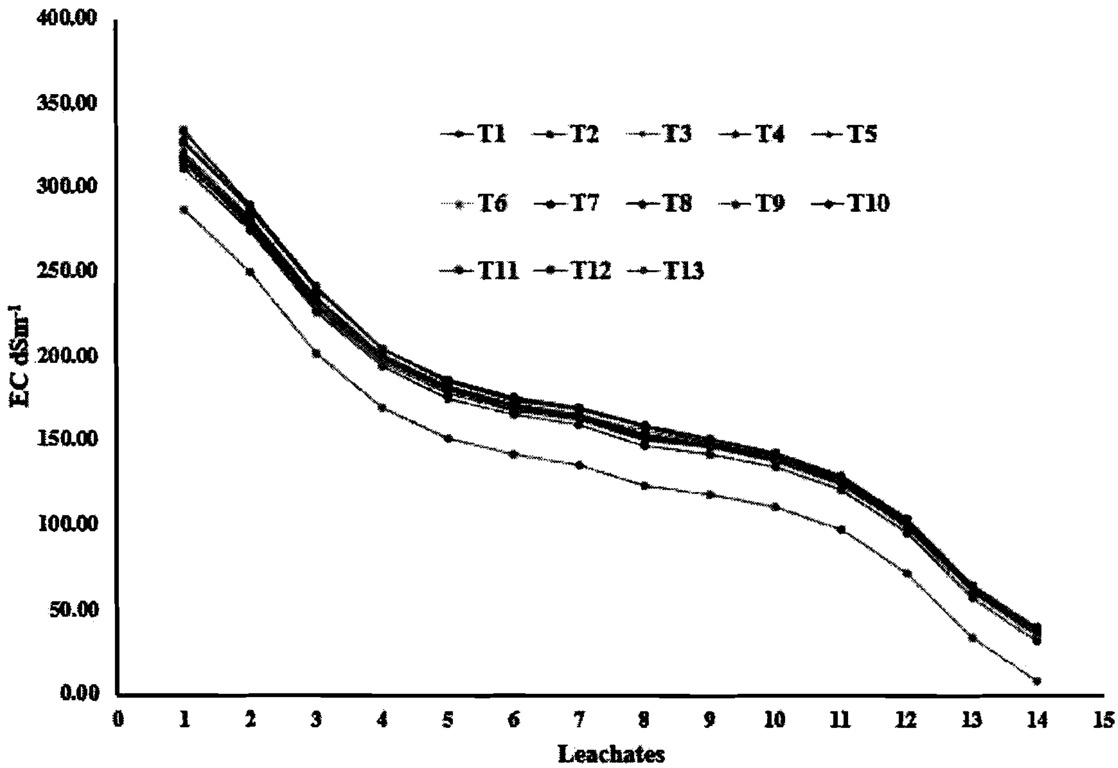


Fig 1. EC values in fourteen leachates as affected by different treatments

ions especially, $Ca^{2+}$, $SO_4^{-2}$, $HCO_3^-$ and $CO_3^=$. During the first period of leaching, the soluble salts leached from the soil column were mainly NaCl and $Na_2SO_4$ causing a high EC values while during the second period, the leached salts would include $NaHCO_4$ and finally $Na_2CO_3$. The decreasing salinity was less considerable from the 8[th] leachate onwards. Amended treatments caused greater rates of decrease in salinity than non-amended ones. This indicates a favorable effect of amendments on the leach ability through improving the physical properties of the soil.

## Soil pH

Concerning soil pH as affected by soil depth, as shown in Table 3, soil pH was significantly affected by soil depths ($p \leq 0.05$), where the soil pH values decreased in all soil depths compared with initial value (8.36). The highest soil pH value (8.06) was obtained in the first depth (0-10-cm), while the lowest one (8.04) was recorded with the second depth (10-20-cm). The relative decreases in soil pH compared to the initial soil pH was 3.59 and 3.83% for the first and the second depths, respectively.

Regarding to soil pH as affected by the different treatments, results in Table 3 clearly show that soil pH was significantly affected by the different treatments ($p \leq 0.05$), where the soil pH values decreased due to all the tested treatments compared with initial value (8.36). The highest soil pH (8.33) of leached soil was attained for the untreated soil (*i.e.* leaching alone), while the lowermost one (7.93) was recorded with the T11 (*i.e.*, ½ GR + SA + BC-2%). In addition, data show that there were no significant differences between T7 (*i.e.* FGR + BC-2%) and T9 (*i.e.*, ½GR + SA) as well as between T3 (*i.e.*, FGR + SA) and T10 (*i.e.*, ½ GR + SA + BC-1%). The results presented in Table 3 cleared also that the tested treatments could be arranged ascendingly in the following order according to their effects on soil pH, T11 < T5 < T4 < T3 < T10 < T7 < T9 < T6 < T2 < T8 < T13 < T12 < T1. The relative decreases in soil pH compared to the initial soil one were 0.36, 3.71, 4.19, 4.31, 4.67, 3.83, 4.07, 3.59, 4.07, 4.19, 5.14, 2.63 and 3.23% due to T1, T2, T3 T4, T5, T6, T7, T8, T9, T10, T11, T12 and T13, respectively.

Results presented in Table 3 shows that the interaction between treatment and depth of soil negatively and significantly decreased soil pH as compared to the initial soil pH (8.36). The highest value of soil pH was 8.35 achived due to T1 (untreated soil) at the first depth of soil (0-10 cm), while the lowest one was 7.92. achived due to T11 (½ GR + SA + BC-2%) at second depth (10-20 cm). In addition, results show that there were no significant differences between the first and second depths of soil with T2, T3, T4, T8 and T13. On the other hand, there were no significant differences between T2 at 1[st] depth and T8 at 2[nd] depth, T2 at 2[nd] depth and T6 at 1[st] depth, T6 at 2[nd] depth and T7 at 1[st] depth, T7 at 2[nd] depth and T9 1[st] depth, T9 at 2[nd] depth and T10 at 1[st] depth and T4 at 1[st] depth and T10 at 2[nd] depth.

The reduction in pH value in sodic or saline sodic soil due to use of gypsum as inorganic amendment has been reported by many researchers (Mahmoud *et al.*, 1969; Sunar and Chohan, 1971). FYM improves the efficiency of gypsum and releases organic acids and $CO_2$, both help reduce soil pH. Similar findings were also reported by Mehta (1986). According to (Udayasoorian *et al.*, 2009; Pagaria and Totawat, 2011; Prapagar *et al.*, 2012). This reduction in pH soil could be due to acidifying effect of organic and inorganic acids produced during the process of decomposition of organic amendments and solubilized native calcium carbonate (Rai *et al.*, 2010; Behzad, 2011; Abdel-Fattah 2012) reported that ameliorative role of organic matter amendments is due to releas of $CO_2$ and organic and acids during decomposition process which solubilize $CaCO_3$ and neutralize sodicity. Marked effect of gypsum and FYM as a combination with $H_2SO_4$was detected because addition of $H_2SO_4$ with that of gypsum and/or FYM might enhancing the solubilization process (Chaudhry and Ullah, 1982). Niazi *et al.* (2001) reported that the lowest pH was recorded with gypsum and FYM. Worku *et al.* (2016) observed a significant decrease in pH with the application of 50% gypsum and 50% $H_2SO_4$acid where a maximum of 9.4% decrease in pH was detected by application 50% gypsum and 50% $H_2SO_4$ acid.

**Table 3. Soil reaction, salinity and soluble ions of soil at the end of leaching process as affected by different treatments**

| Factor of study | | pH | EC $dSm^{-1}$ | Soluble cations ($mmolc\ l^{-1}$) | | | | Soluble anions ($mmolc\ l^{-1}$) | | | SAR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | $HCO_3^{-}$ | $Cl^{-}$ | $SO_4^{=}$ | |
| **Effect of soil depth** | | | | | | | | | | | |
| **0-10 cm (1st depth)** | | 8.06 | 6.26 | 24.13 | 13.91 | 22.80 | 1.76 | 0.78 | 9.71 | 52.11 | 5.03 |
| **10-20 cm (2nd depth)** | | 8.04 | 6.70 | 23.70 | 15.85 | 25.57 | 1.85 | 0.85 | 10.73 | 55.38 | 5.42 |
| **Effect of treatments** | | | | | | | | | | | |
| **T1** | | 8.33 | 16.43 | 21.80 | 48.75 | 89.29 | 4.47 | 1.80 | 25.70 | 136.81 | 15.05 |
| **T2** | | 8.05 | 5.96 | 23.31 | 12.98 | 21.58 | 1.70 | 0.64 | 8.74 | 50.19 | 5.07 |
| **T3** | | 8.01 | 5.32 | 24.06 | 11.34 | 16.26 | 1.50 | 0.50 | 7.83 | 44.83 | 3.87 |
| **T4** | | 8.00 | 4.82 | 24.90 | 10.83 | 11.06 | 1.39 | 0.40 | 7.30 | 40.47 | 2.62 |
| **T5** | | 7.97 | 4.74 | 25.26 | 10.48 | 10.30 | 1.33 | 0.40 | 7.10 | 39.87 | 2.44 |
| **T6** | | 8.04 | 5.82 | 23.46 | 12.58 | 20.48 | 1.64 | 0.60 | 8.43 | 49.14 | 4.82 |
| **T7** | | 8.02 | 5.67 | 23.61 | 12.03 | 19.47 | 1.59 | 0.60 | 8.11 | 47.99 | 4.61 |
| **T8** | | 8.06 | 6.17 | 23.10 | 13.51 | 23.33 | 1.77 | 1.26 | 9.25 | 51.21 | 5.45 |
| **T9** | | 8.02 | 5.57 | 23.87 | 11.71 | 18.55 | 1.54 | 0.60 | 8.00 | 47.07 | 4.40 |
| **T10** | | 8.01 | 4.95 | 24.48 | 11.05 | 12.58 | 1.44 | 0.40 | 7.54 | 41.61 | 2.98 |
| **T11** | | 7.93 | 4.63 | 27.46 | 9.63 | 8.07 | 1.18 | 0.40 | 6.69 | 39.24 | 1.88 |
| **T12** | | 8.14 | 7.70 | 22.69 | 14.65 | 37.64 | 2.05 | 1.59 | 17.96 | 57.46 | 8.71 |
| **T13** | | 8.09 | 6.45 | 22.91 | 13.93 | 25.77 | 1.86 | 1.40 | 10.26 | 52.80 | 6.00 |
| **Effect of interaction** | | | | | | | | | | | |
| **0-10 cm** | **T1** | 8.35 | 14.55 | 22.38 | 37.89 | 81.04 | 4.15 | 1.60 | 23.79 | 120.06 | 14.76 |
| | **T2** | 8.06 | 5.92 | 23.40 | 12.83 | 21.26 | 1.68 | 0.60 | 8.65 | 49.92 | 5.00 |
| | **T3** | 8.01 | 5.20 | 24.13 | 11.23 | 15.12 | 1.49 | 0.40 | 7.73 | 43.84 | 3.60 |
| | **T4** | 8.00 | 4.80 | 25.00 | 10.78 | 10.88 | 1.37 | 0.40 | 7.20 | 40.43 | 2.57 |
| | **T5** | 7.99 | 4.71 | 25.42 | 10.38 | 10.03 | 1.31 | 0.40 | 7.00 | 39.74 | 2.37 |
| | **T6** | 8.04 | 5.78 | 23.53 | 12.48 | 20.19 | 1.63 | 0.60 | 8.40 | 48.83 | 4.76 |
| | **T7** | 8.03 | 5.63 | 23.63 | 11.88 | 19.26 | 1.58 | 0.60 | 8.00 | 47.74 | 4.57 |
| | **T8** | 8.07 | 6.11 | 23.20 | 13.40 | 22.80 | 1.75 | 1.17 | 9.05 | 50.93 | 5.33 |
| | **T9** | 8.02 | 5.53 | 23.94 | 11.63 | 18.19 | 1.53 | 0.60 | 8.00 | 46.69 | 4.31 |
| | **T10** | 8.01 | 4.89 | 24.55 | 11.00 | 11.95 | 1.43 | 0.40 | 7.48 | 41.05 | 2.83 |
| | **T11** | 7.94 | 4.58 | 28.79 | 9.30 | 6.66 | 1.08 | 0.40 | 6.58 | 38.86 | 1.53 |
| | **T12** | 8.16 | 7.31 | 22.80 | 14.28 | 34.03 | 1.99 | 1.59 | 14.58 | 56.93 | 7.90 |
| | **T13** | 8.10 | 6.36 | 23.00 | 13.83 | 24.96 | 1.83 | 1.40 | 9.80 | 52.42 | 5.82 |
| **10-20 cm** | **T1** | 8.30 | 18.32 | 21.23 | 59.61 | 97.54 | 4.79 | 2.00 | 27.61 | 153.56 | 15.34 |
| | **T2** | 8.05 | 6.00 | 23.23 | 13.13 | 21.89 | 1.72 | 0.68 | 8.83 | 50.46 | 5.14 |
| | **T3** | 8.01 | 5.44 | 24.00 | 11.45 | 17.40 | 1.51 | 0.60 | 7.93 | 45.83 | 4.13 |
| | **T4** | 8.00 | 4.83 | 24.80 | 10.88 | 11.23 | 1.41 | 0.40 | 7.40 | 40.52 | 2.66 |
| | **T5** | 7.96 | 4.76 | 25.10 | 10.58 | 10.58 | 1.35 | 0.40 | 7.20 | 40.00 | 2.50 |
| | **T6** | 8.03 | 5.85 | 23.40 | 12.68 | 20.77 | 1.65 | 0.60 | 8.45 | 49.44 | 4.89 |
| | **T7** | 8.02 | 5.71 | 23.60 | 12.18 | 19.67 | 1.61 | 0.60 | 8.23 | 48.23 | 4.65 |
| | **T8** | 8.06 | 6.23 | 23.00 | 13.63 | 23.87 | 1.79 | 1.34 | 9.45 | 51.49 | 5.58 |
| | **T9** | 8.02 | 5.61 | 23.80 | 11.80 | 18.91 | 1.55 | 0.60 | 8.00 | 47.45 | 4.48 |
| | **T10** | 8.00 | 5.02 | 24.40 | 11.10 | 13.21 | 1.45 | 0.40 | 7.60 | 42.16 | 3.13 |
| | **T11** | 7.92 | 4.68 | 26.13 | 9.95 | 9.48 | 1.27 | 0.40 | 6.80 | 39.63 | 2.23 |
| | **T12** | 8.12 | 8.09 | 22.58 | 15.03 | 41.24 | 2.10 | 1.60 | 21.34 | 57.99 | 9.51 |
| | **T13** | 8.09 | 6.53 | 22.83 | 14.03 | 26.58 | 1.88 | 1.41 | 10.73 | 53.18 | 6.19 |
| **LSD 5%** | **SD** | 0.002 | 0.07 | 0.12 | 0.33 | 0.47 | 0.02 | 0.01 | 0.31 | 0.65 | 0.07 |
| | **TRT** | 0.005 | 0.18 | 0.29 | 0.85 | 1.21 | 0.06 | 0.03 | 0.31 | 1.65 | 0.19 |
| | **SD×TRT** | 0.008 | 0.26 | 0.41 | 1.21 | 1.71 | 0.08 | 0.05 | 0.55 | 2.34 | 0.26 |

Notes: SD and TRT refer to soil depth and treatments, respectively. T1 to T13 refer to non-treated soil, full gypsum requirements "FGR", FGR + SA, FGR + SA + botanical compost 1% "BC-1%", FGR + SA + botanical compost 2% "BC-2%", FGR + BC-1%, FGR + BC-2%, ½ gypsum requirements "½ GR", ½ GR + SA, ½ GR + SA + BC-1%, ½ GR + SA + BC-2%, ½ GR + BC-1% and ½ GR + BC-2%, respectively.

### Soil electric conductivity (EC)

As shown in Table 3, soil EC was significantly affected by soil depths ($p \leq 0.05$), where the soil EC values decreased at all soil depths compared with initial value (66.00 $dSm^{-1}$). The highest soil EC value (6.70 $dSm^{-1}$) was obtained in the lowest depths of soil (10-20 cm), while the lowest one (6.26 $dSm^{-1}$) was recorded with the surface layer (0-10 cm). Efficiencies of first and second depths of soil in decreasing soil EC in comparison with initial soil EC were 90.52 and 89.85% for the first and the second depths of soil, respectively.

Concerning effect of different treatments on soil EC, results in Table 3 clearly show that soil EC was significantly affected by the different treatments ($p \leq 0.05$), where the soil EC values were decreased in all tested treatments compared with initial value (66.00 $dSm^{-1}$). The highest soil EC (16.43 $dSm^{-1}$) was gained by non-treated soil (*i.e.*, leaching alone), while the lowest one (4.63 $dSm^{-1}$) was recorded with the T11 (*i.e.*, ½ GR + SA + BC-2%) with non-significant differences between T11 and T4 (*i.e.*, FGR + SA + BC-1%) and T5 (*i.e.*, FGR + SA + BC-2%). In addition, results show that there were no significant differences between the T2 (*i.e.*, FGR) and T6 (*i.e.*, FGR + BC-1%) as well as between T6 (*i.e.* FGR + BC-1%) and T7 (*i.e.*, FGR + BC-2%), T7 (*i.e.*, FGR + BC-2%) and T9 (*i.e.*, ½ GR + SA) and T4 (*i.e.*, FGR + SA + BC-1%) and T10 (*i.e.*, ½ GR + SA + BC-1%). The results presented in Table 3 clear also that the tested treatments could be arranged in the following order according to their effects on soil EC, T11 < T5 < T4 < T10 < T3 < T9 < T7 < T6 < T2 < T8 < T13 < T12 < T1. The relative decreases in soil EC compared to the initial soil were 75.11, 90.97, 91.94, 92.70, 92.82, 91.18, 91.41, 90.65, 91.56, 92.50, 92.98, 88.33 and 90.23% for the T1, T2, T3 T4, T5, T6, T7, T8, T9, T10, T11, T12 and T13, respectively.

The results presented in Table 3 show that application different treatments at different depths of soil significantly decreased soil EC in comparison with initial soil EC (66.00 $dSm^{-1}$). The highest value of soil EC was 18.32 $dSm^{-1}$ due to T1 (untreated soil) in second depth of soil (10-20 cm), while the lowest one (4.58 $dSm^{-1}$) was observed with T11 (½ GR + SA + BC-2%) in first depth (0-10 cm). In addition, results show that there were no significant differences between the first and second depths of soil with T2, T3, T4, T5, T6, T7, T8, T9, T10, T11 and T13.

However, results of Table 3 shows a highly significant correlation coefficient of $EC_e$ with soluble ions (*i.e.* $Na^+$, $K^+$, $Ca^{++}$, $Mg^{++}$, $Cl^-$, $HCO_3^=$ and $SO_4^=$). (r = 0.62, 0.98, 0.99, 0.996, 0.76, 0.94 and 0.997) for $Ca^{++}$, $Mg^{++}$, $Na^+$, $K^+$, $HCO_3^-$, $Cl^-$, $SO_4^=$, respectively.

### Sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP)

Tables 3 and 4 shows that SAR and ESP were significantly affected by soil depths ($p \leq 0.05$), where the SAR and ESP values were decreased in all soil depths compared with initial values (58.66 and 35.32), respectively. The highest SAR and ESP values (5.42 and 11.05%) were obtained at (10-20 cm) soil depth, while the lowest values (5.03 and 10.46%) were recorded for the first depth (0-10 cm). Superiorities of first and second depths of soil in decreasing SAR in comparison with initial soil were (91.43, 80.76% and 70.39, 68.71%) for the first and the second soil, respectively.

Results in Tables 3 and 4 clearly show that SAR and ESP were significantly affected by the different treatments ($p \leq 0.05$), where the SAR and ESP values were decreased due to all the tested treatments compared with initial value (58.66 and 35.320%, respectively). The highest SAR (15.05) was gained by untreated soil (*i.e.*, leaching alone), while the lowest one (1.88 and 7.92%) was recorded with the T11 (*i.e.*, ½ GR + SA + BC-2%). Moreover there were no significant differences between the T4 (*i.e.*, FGR + SA + BC-1%) and T5 (*i.e.*, FGR + SA + BC-2%). However, the tested treatments could be arranged in the following order according to their effects on soil SAR and ESP, T11 < T5 < T4 < T10 < T3 < T9 < T7 < T6 < T2 < T8 < T13 < T12 < T1. The relative decreases in SAR compared to the initial soil were 74.34, 91.36, 93.40, 95.53, 95.84, 91.78, 92.14, 90.71, 92.50, 94.92, 96.80, 85.15 and 89.77%. Mean while the relative decreases in ESP compared with initial soil were 55.75, 69.20, 70.64, 72.17, 73.73, 69.25, 69.62, 68.69, 70.07, 71.07, 71.52, 77.58, 67.50 and 68.37 for the T1, T2, T3 T4, T5, T6, T7, T8, T9, T10, T11, T12 and T13, respectively.

**Table 4. Exchangeable cations of soil at the end of leaching process as affected by different treatments**

| Factor of study | | Exchangeable cations ($cmol_c\ kg^{-1}$ soil) | | | | CEC | ESP |
|---|---|---|---|---|---|---|---|
| | | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | | |
| **Effect of soil depth** | | | | | | | |
| **0-10 cm (1st depth)** | | 13.58 | 9.10 | 6.32 | 3.63 | 34.62 | 10.46 |
| **10-20 cm (2nd depth)** | | 13.36 | 9.43 | 6.53 | 3.89 | 35.05 | 11.05 |
| **Effect of treatments** | | | | | | | |
| **T1** | | 6.09 | 14.65 | 8.51 | 5.66 | 35.91 | 15.63 |
| **T2** | | 13.42 | 9.37 | 6.48 | 3.82 | 35.09 | 10.88 |
| **T3** | | 14.19 | 8.44 | 6.16 | 3.56 | 34.34 | 10.37 |
| **T4** | | 14.89 | 8.13 | 5.95 | 3.38 | 34.35 | 9.83 |
| **T5** | | 15.82 | 7.96 | 5.79 | 3.23 | 34.80 | 9.28 |
| **T6** | | 13.55 | 9.03 | 6.35 | 3.77 | 34.70 | 10.86 |
| **T7** | | 13.64 | 8.84 | 6.23 | 3.69 | 34.40 | 10.73 |
| **T8** | | 13.14 | 9.54 | 6.60 | 3.89 | 35.16 | 11.06 |
| **T9** | | 13.95 | 8.67 | 6.16 | 3.64 | 34.42 | 10.57 |
| **T10** | | 14.61 | 8.24 | 6.06 | 3.45 | 34.35 | 10.06 |
| **T11** | | 16.65 | 7.23 | 5.54 | 2.71 | 34.13 | 7.92 |
| **T12** | | 12.35 | 10.48 | 6.94 | 4.12 | 35.88 | 11.48 |
| **T13** | | 12.79 | 9.87 | 6.75 | 3.95 | 35.37 | 11.17 |
| **Effect of interaction** | | | | | | | |
| **0-10-cm** | **T1** | 6.30 | 13.65 | 7.69 | 4.47 | 34.11 | 13.10 |
| | **T2** | 13.53 | 9.23 | 6.39 | 3.82 | 34.96 | 10.92 |
| | **T3** | 14.26 | 8.39 | 6.16 | 3.53 | 34.34 | 10.29 |
| | **T4** | 15.09 | 8.09 | 5.94 | 3.36 | 34.48 | 9.74 |
| | **T5** | 15.83 | 7.95 | 5.76 | 3.18 | 34.72 | 9.17 |
| | **T6** | 13.55 | 8.94 | 6.31 | 3.73 | 34.53 | 10.80 |
| | **T7** | 13.72 | 8.84 | 6.19 | 3.65 | 34.41 | 10.61 |
| | **T8** | 13.22 | 9.52 | 6.60 | 3.87 | 35.21 | 10.98 |
| | **T9** | 14.06 | 8.57 | 6.16 | 3.64 | 34.43 | 10.56 |
| | **T10** | 14.68 | 8.17 | 6.04 | 3.45 | 34.34 | 10.06 |
| | **T11** | 16.94 | 6.93 | 5.36 | 2.47 | 33.70 | 7.33 |
| | **T12** | 12.44 | 10.29 | 6.85 | 4.05 | 35.62 | 11.36 |
| | **T13** | 12.90 | 9.74 | 6.71 | 3.91 | 35.26 | 11.09 |
| **10-20-cm** | **T1** | 5.87 | 15.66 | 9.33 | 6.85 | 37.71 | 18.17 |
| | **T2** | 13.31 | 9.51 | 6.58 | 3.82 | 35.22 | 10.84 |
| | **T3** | 14.12 | 8.48 | 6.16 | 3.59 | 34.35 | 10.45 |
| | **T4** | 14.70 | 8.16 | 5.97 | 3.40 | 34.23 | 9.92 |
| | **T5** | 15.81 | 7.97 | 5.83 | 3.27 | 34.89 | 9.38 |
| | **T6** | 13.55 | 9.12 | 6.38 | 3.81 | 34.86 | 10.92 |
| | **T7** | 13.55 | 8.84 | 6.27 | 3.73 | 34.39 | 10.84 |
| | **T8** | 13.06 | 9.55 | 6.60 | 3.91 | 35.12 | 11.13 |
| | **T9** | 13.83 | 8.78 | 6.16 | 3.64 | 34.41 | 10.57 |
| | **T10** | 14.53 | 8.30 | 6.07 | 3.45 | 34.36 | 10.05 |
| | **T11** | 16.36 | 7.53 | 5.72 | 2.94 | 34.56 | 8.51 |
| | **T12** | 12.26 | 10.66 | 7.02 | 4.19 | 36.13 | 11.60 |
| | **T13** | 12.69 | 10.01 | 6.79 | 4.00 | 35.49 | 11.26 |
| **LSD 5%** | **SD** | 0.03 | 0.05 | 0.06 | 0.02 | 0.11 | 0.04 |
| | **TRT** | 0.07 | 0.13 | 0.16 | 0.05 | 0.30 | 0.10 |
| | **SD×TRT** | 0.10 | 0.18 | 0.23 | 0.07 | 0.42 | 0.13 |

Notes: SD and TRT refer to soil depth and treatments, respectively. T1 to T13 refer to non-treated soil, full gypsum requirements "FGR", FGR + SA, FGR + SA + botanical compost 1% "BC-1%", FGR + SA + botanical compost 2% "BC-2%", FGR + BC-1%, FGR + BC-2%, ½ gypsum requirements "½ GR", ½ GR + SA, ½ GR + SA + BC-1%, ½ GR + SA + BC-2%, ½ GR + BC-1% and ½ GR + BC-2%, respectively.

The interaction results presented in Table 3 show that application of the different treatments at different depths of soil significantly decreased SAR and ESP in comparison with initial soil (58.66 and 35.32%, respectively). The highest value of soil SAR and ESP (15.34 and 18.17), were obtained with T1 (untreated soil) at the second depth of soil (10-20 cm), while the lowest one (1.53 and 7.33) were resulted with T11 (½ GR + SA + BC-2%) at the first depth (0-10 cm).

The reduction in SAR and ESP may be the results of increased $Ca^{2+}$ + $Mg^{2+}$ and decreased $Na^{+}$ as a results of amendments application. Similar findings were reported by Shad and Hashmi (1970); and Ghafoor and Muhammad (1981) they showed that addition of gypsum + manure was more effective in reclaiming calcareous saline sodic soils than gypsum or manure alone. This addition of gypsum and/or FYM may enhanced the SAR and ESP values. The current results are similar to those of (Niazi *et al.*, 2001; Abdel-Fattah, 2012).

**Bulk density and total porosity**

Table 5 shows that bulk density values were decreased in all soil depths compared with initial value (1.35 $Mgm^{-3}$). The highest bulk density value (1.21 $Mgm^{-3}$) was obtained at the second depth (10-20-cm), while the lowest one (1.20 $Mgm^{-3}$) was recorded with the first depth (0-10-cm). The relative decreases in bulk density compared to the initial soil were 11.11 and 10.37% for the first and the second depths, respectively.

Results in Table 5 clearly show that bulk density was significantly affected by the different treatments ($p \leq 0.05$), where the bulk density values were decreased due to all the tested treatments compared with initial value (1.35 $Mgm^{-3}$). The highest bulk density (1.26 $Mgm^{-3}$) was gained by untreated soil (*i.e.* leaching alone), while the lowest one (1.15 $Mgm^{-3}$) was recorded with the T11 (*i.e.*, ½ GR + SA + BC-2%). Tested treatments could be arranged in the following order according to their effects on bulk density, T11 < T5 < T4 < T3 < T10 < T7 < T9 < T6 < T2 < T8 < T13 < T12 < T1. The relative decreases in bulk density compared to the initial soil one were 6.67, 8.89, 11.85, 13.33, 14.07, 9.63, 10.37, 8.89, 11.11, 12.59, 14.81, 7.41 and 8.15% for the T1, T2, T3 T4, T5, T6, T7, T8, T9, T10, T11, T12 and T13, respectively.

The results presented in Table 5 show that application of the different treatments at different depths of soil significantly decreased bulk density as compared to initial bulk density of soil (1.35 $Mgm^{-3}$).The highest value of bulk density 1.28 $Mgm^{-3}$ was obtained with T1 (untreated soil) at the first depth of soil (0-10 cm), while the lowest one (1.15 $Mgm^{-3}$) was observed with T11 (½ GR + SA + BC-2%) at the second depth (10-20 cm). In addition, results show that there were no significant differences between the first and second depths of soil with T3, T4, T5, T10, T12 and T13.

Concerning total porosity as affected by soil depth, as shown in Table 5, total porosity was significantly affected by soil depths ($p \leq 0.05$), where the total porosity values decreased at all soil depths compared with the initial value (52.83%). The highest total porosity value (54.54%) was obtained at the first depth (0-10-cm), while the lowest one (53.93%) was recorded for the second depth (10-20-cm). The relative decreases in total porosity compared to the initial soil one were 3.24 and 2.08% for the first and the second depths, respectively.

Results in Table 5 clearly show that total porosity was significantly affected by the different treatments ($p \leq 0.05$), where the total porosity values increased due to all tested treatments compared with initial value (52.83%). The lowermost total porosity (49.17%) was gained by untreated soil (*i.e.* leaching alone), while the highest one (56.70%) was recorded with T11 (*i.e.*, ½ GR + SA + BC-2%). The results presented in Table 5 cleared also that the tested treatments could be arranged in the following order owing to their effects on total porosity, T11 > T5 > T4 > T10 > T3 > T9 > T7 > T6 > T2 > T8 > T13 > T12 > T1. The relative increases in total porosity compared to the initial soil were 6.93, 1.74, 4.33, 5.58, 6.30, 2.46, 3.22, 1.25, 3.88, 5.00, 7.33, 0.09 and 0.59 % for the T1, T2, T3 T4, T5, T6, T7, T8, T9, T10, T11, T12 and T13, respectively.

**Table 5. Bulk density and total porosity of soil at the end of leaching process as affected by different treatments**

| SD (cm) | TRT | Bulk density ($Mgm^{-3}$) | Total porosity (%) |
|---|---|---|---|
| **0-10-cm** | | 1.20 | 54.54 |
| **10-20-cm** | | 1.21 | 53.93 |
| | T1 | 1.26 | 49.17 |
| | T2 | 1.23 | 53.75 |
| | T3 | 1.19 | 55.12 |
| | T4 | 1.17 | 55.78 |
| | T5 | 1.16 | 56.16 |
| | T6 | 1.22 | 54.13 |
| | T7 | 1.21 | 54.53 |
| | T8 | 1.23 | 53.49 |
| | T9 | 1.20 | 54.88 |
| | T10 | 1.18 | 55.47 |
| | T11 | 1.15 | 56.70 |
| | T12 | 1.25 | 52.78 |
| | T13 | 1.24 | 53.14 |
| **0-10-cm** | T1 | 1.28 | 51.89 |
| | T2 | 1.22 | 53.92 |
| | T3 | 1.19 | 55.14 |
| | T4 | 1.17 | 55.85 |
| | T5 | 1.16 | 56.23 |
| | T6 | 1.21 | 54.29 |
| | T7 | 1.20 | 54.72 |
| | T8 | 1.23 | 53.58 |
| | T9 | 1.19 | 55.05 |
| | T10 | 1.18 | 55.47 |
| | T11 | 1.14 | 56.89 |
| | T12 | 1.25 | 52.83 |
| | T13 | 1.24 | 53.21 |
| **10-20-cm** | T1 | 1.25 | 46.46 |
| | T2 | 1.23 | 53.58 |
| | T3 | 1.19 | 55.09 |
| | T4 | 1.17 | 55.71 |
| | T5 | 1.16 | 56.08 |
| | T6 | 1.22 | 53.96 |
| | T7 | 1.21 | 54.34 |
| | T8 | 1.24 | 53.40 |
| | T9 | 1.20 | 54.72 |
| | T10 | 1.18 | 55.47 |
| | T11 | 1.15 | 56.51 |
| | T12 | 1.25 | 52.74 |
| | T13 | 1.24 | 53.07 |
| **LSD5%** | SD | 0.001 | 0.32 |
| | TRT | 0.004 | 0.82 |
| | SD×TRT | 0.005 | 1.16 |

Notes: SD and TRT refer to soil depth and treatments, respectively. T1 to T13 refer to non-treated soil, full gypsum requirements "FGR", FGR + SA, FGR + SA + botanical compost 1% "BC-1%", FGR + SA + botanical compost 2% "BC-2%", FGR + BC-1%, FGR + BC-2%, ½ gypsum requirements "½ GR", ½ GR + SA, ½ GR + SA + BC-1%, ½ GR + SA + BC-2%, ½ GR + BC-1% and ½ GR + BC-2%, respectively.

The results presented in Table 5 show that application of the different treatments at different depths of soil significantly increased total porosityas compared to initial soil one (52.83%). The lowest value of total porosity was 46.46% and it was obtained with T1 (untreated soil) at the second depth of soil (10-20 cm), while the highest one was 56.89% and it was observed with T11 (½ GR + SA + BC-2%) at the second depth (10-20 cm). In addition, results showed that there were no significant differences between the first and second depths of soil with T3, T4, T5, T6, T7, T9, T10, T11, T12 and T13.

These results are in agreement with that obtained by El-Shanawany (1985), who reported that applied gypsum, particularly at high rates gave the highest values of total soil porosity. Calcium accumulations on the exchange sites have improved soil aggregation thus reduced the bulk density.

In this context (Qadir and Oster, 2004; Oo *et al.*, 2013) reported that combinations of organic amendments resulted in substantial flocculation and formation of a large number of soil aggregates. In a referent word Worku *et al.* (2016) reported that a mixture of organic wastes decreased bulk density, EC and ESP by 11%, 78% and 96%, respectively compared with control.

## Conclusion

A leaching experiment was conducted to asses efficiency of gypsum solely or in combination with sulfuric acid and/or botanical compost on saline-sodic soils reclamation. Soil samples were collected from El-Hossainia plain, El-Sharkia Governorate, Egypt. Results showed that ½ gypsum requirements + sulfuric acid + botanical compost at rate 2% by weight treatment was more effective in decreasing the pH, EC and soil sodicity than the other treatments.

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# تأثير بعض محسنات التربة على استصلاح الأراضي الملحية الصودية

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أجريت تجربة غسيل لتقييم كفاءة الجبس مخلوطا مع حامض الكبريتيك و/أو الكمبوست النباتي علي استصلاح الأراضي الملحية الصودية، جمعت عينات التربة من سهل الحسينية، محافظة الشرقية، مصر، تم تصميم المعاملات التالية بأسلوب القطاعات تامة العشوائية فى ثمانية مكررات: T1 أرض غير معاملة، T2 احتياجات جبسيه كاملة، T3 احتياجات جبسيه كاملة + حامض كبريتيك، T4 احتياجات جبسيه كاملة + حامض كبريتيك+ كمبوست نباتي بنسبة 1% وزنا، T5 احتياجات جبسيه كاملة + حامض كبريتيك + كمبوست نباتي بنسبة 2% وزنا، T6 احتياجات جبسيه كاملة + كمبوست نباتي بنسبة 1% وزنا، T7 احتياجات جبسيه كاملة + كمبوست نباتي بنسبة 2% وزنا، T8 نصف الاحتياجات الجبسيه، T9 نصف الاحتياجات الجبسيه + حامض كبريتيك، T10 نصف الاحتياجات الجبسيه + حامض كبريتيك + كمبوست نباتي بنسبة 1% وزنا، T11 نصف الاحتياجات الجبسيه + حامض كبريتيك + كمبوست نباتي بنسبة 2% وزنا، T12 نصف الاحتياجات الجبسيه + كمبوست نباتي بنسبة 1% وزنا، T13 نصف الاحتياجات الجبسيه + كمبوست نباتي بنسبة 2% وزنا، تم إجراء الغسيل باستخدام النظام المتقطع حيث تم إضافة أجزاء من ماء الغسيل للتربة المشبعة بالفعل ثم تم الحصول علي غسلات مساوية للأجزاء المضافة، تم حساب كمية الماء المضاف طبقا لقانون Reeve بحيث تخفض الأملاح من 66 إلى 4 ملليموز/سم لعمق 20 سم، أوضحت النتائج أن كل المعاملات خفضت من درجة التوصيل الكهربي للتربة، درجة تفاعل التربة وصوديتها، كما أوضحت أن T11 كانت أكثر المعاملات تأثيرا من المعاملات في خفض الصفات سالفة الذكر، ويمكن ترتيب المعاملات حسب تأثيرها كما يلي: T11 > T5 > T4 > T3 > T10 > T7 > T9 > T6 > T2 > T8 > T13 > T12 > T1

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