

**EFFICIENCY OF SOME SOIL AMENDMENTS FOR
RECLAMATION OF A SALT-DEGRADED SOIL
USING CONTINUOUS LEACHING**

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ABSTRACT: A soil columns experiment was run to investigate the prospective efficiency of some amendments (phosphogypsum "PG", normal gypsum "NG", sulfuric acid "SA" and rice straw "RS") used for reclamation of a degraded salt affected clay soil taken from Sahl El-Tina in the northeast Mediterranean sea coast of Egypt, North-Sinai, using continuous leaching.

There was a decrease in pH, EC and ESP values for the degraded soil reclaimed using all amendments. Also, infiltration rate of water increased due to amendments through enhancement of soil aggregation. Incorporation of chemical amendments NG and PG within the whole of soil column was more efficient than application within the surface 10 cm of the column.

All amendments proved of greater efficiency as compared with the control. The efficiency of soil amendments used in this study followed the descending order: PG mixed with the soil column > NG mixed with the soil column > PG applied within the top 10 cm of the column > NG applied within the top 10 cm of the column > SA in one dose \geq SA in split doses > rice straw (RS).

Key words: Reclamation, leaching, amendments, gypsum, sulfuric acid, and rice straw

INTRODUCTION

Irrigation-based agriculture comprises a significant part of arable lands in many areas of the world and accounts for one-third

the world food production, with about three quarters of the irrigated land being located in developing countries (Umali, 1993). Salinization is one of most serious problems confronting sustainable

agriculture in irrigated arable lands in semi-arid regions. This problem may be caused by the importation of dissolved salts in irrigation water or existing high salt levels in the soil due to ancient marine deposits or a combination of the two. The most appropriate reclamation procedure depends on the nature of the ionic chemistry affecting the soil. A different approach is necessary to reclaim each category. Low sodium water would adequately leach the salts from saline non-sodic soils, but in the case of saline-sodic soils, which are characterized by high exchangeable sodium percent (ESP) there is a need for application of appropriate amendments to aid their reclamation (Richards, 1954).

The desired effect of the amendments is exchanging the cation of calcium for that of sodium, followed by a subsequent leaching of sodium through the application of leaching water. Therefore, the amendments must supply calcium, either directly or indirectly. The most effective and economical means of doing this depends on the soil chemistry. If the soil is low in carbonate content, then the calcium must be supplied directly. The most common amendment in this case is

agricultural gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), although in some cases (generally those of low pH), lime may also be used (Abdel-Salam *et al.*, 2002). If the soil has sufficient calcium carbonate, acid-forming substances (e.g. sulfur) or acids (e.g. sulfuric acid) may be applied. The acid reacts with calcium carbonate to form calcium salts, more soluble than calcium carbonate, which then supplies Ca^{++} which replaces Na^+ on the soil exchange complex. Elemental sulfur must be incorporated into the soil and then oxidized by sulphur-oxidizing micro-organisms to form sulfuric acid; sulfuric acid in turn reacts to form gypsum (Rhoades *et al.*, 1988, 1997; Mitchell *et al.*, 2000)

Gypsum is commonly applied as a soil amendment in combination with leaching for sodic soils. It may also be used periodically, e.g. as annual application to maintain adequate infiltration of irrigation water in heavy textured soils of sodic or non-sodic nature. Suarez (2001) found that placement depth of gypsum affects the sodicity distribution in the soil after 70 cm of leaching; mixing it within the 80 to 100 cm was optimal for reclamation of sodic soil where the objective was to remove sodium

from the profile. However, surface application was most efficient when irrigating with waters where the objective was to keep the SAR low in the surface and maintain the existing SAR at depth.

For efficient crop production salts must be leached from the root zone. Leaching may be problematic because irrigation water is scarce in most regions where these soils occur. A further problem arises if the irrigation water is itself saline. Drainage of the irrigation water always has to be ensured. After the initial application of irrigation water for leaching of salts a regular water supply has to be maintained in order to sustain intensive cropping. Generally sodic soils give much lower returns per unit irrigation water than saline soils because they require more water for their reclamation.

Karimpour (2002) pointed out that the problem of salinity and sodicity in all the basic problems in soils of arid lands. Sodicity damages the soil structure particularly clayey soils by clay dispersion. Understanding the damage process of soil structure due to Na accumulation will help in reconstructing the structure and render the soil more suitable

for plants in soils of arid and semi arid zones.

Shahid (2002) described recent technological advances in the reclamation of salt affected soils in arid zones. There are four approaches to reclamation, physical, biological, hydraulic and chemical properties.

Miyamoto and Enriquez (1990) pointed out that gypsum application provided low ratios of sodicity to salinity in percolating solution and relatively uniform hydraulic gradient throughout the soil profile. Abdurrahman et al. (2004) showed that the sequential application of gypsum followed by matured mixed municipal solid waste compost can effectively restore degraded soils suffering from high soluble salts and exchangeable sodium content. Laboratory experiments by Khamraev et al., (1992) showed that the application of phosphogypsum (a by-product of Ca-phosphate fertilizer manufacture, is calcium sulfates rich in phosphate) to saline soils lowered pH values and increased the infiltration rate, thus contributing to accelerated removal of salts from the soil. Siyal et al.

(2002) reported that soil amendments of (gypsum, sulfur or sulfuric acid) are usually used for the reclamation of soil with high sodium content. Abdel-salam *et al.* (2002) in a field experiment used gypsum, sulfur, manured lime and non-manured lime to reclaim a saline sodic clay soil. They found that mixing lime (CaCO_3) with organic manure rendered it nearly as efficient as gypsum.

There are 2 principal methods of reclamation of salt-affected soils (FAO, 1980 and Tanji, 1990), the continuous leaching (continuous ponding) and the intermittent leaching. The former involves maintaining a constant head of water above the soil surface (usually allowing a constant depth of water of up to 10 cm above the soil surface). The latter method involves application of water in cycles, each cycle consists of 2-water applications firstly an application of enough water to dissolve salts and attain some equilibrium (particularly when using amendments); secondly and following some days, application of water in excessive amount to remove

salts from the required soil depth to the drainage system. The first method is more efficient but requires more water.

Habib *et al.* (1994) found that gypsum was equally efficient in reducing soil sodicity when it was applied using ponding and intermittent methods.

Ramirez *et al.* (1999) found that addition of phosphogypsum to the soil led to increasing the rate of water infiltration into the furrows as well as increasing onion yield.

The main aim of this investigation is to assess the efficiency of some soil amendments i.e. phosphogypsum (PG), normal gypsum (NG), sulfuric acid (SA) and rice straw (RS) for reclamation of degraded salt affected clay soil taken from Sahl El-tina area in northeast Mediterranean Sea Coast of Egypt. Salts removal from the soil was carried out by using continuous leaching.

MATERIALS AND METHODS

Soil sample was collected from the 0-30 cm top segment Sahl El-Tina area and used for this study. Soil

was air dried, crushed, mixed thoroughly and passed through a 2 mm sieve. Polyvinyl chloride (PVC) cylinders of 75 cm height and 16 cm inside diameter were filled with the soil to be used as leaching columns. The bottom of each column was fitted with a mesh nylon screen and glass wool. Acid-washed coarse sand was placed in the bottom 5 cm segment of each column to regulate the flow of water and to prevent plugging the lower part of columns with the immigrating fine materials. About 13 Kg. of air-dried soil was carefully and gradually packed to give a height of 50 cm soil matrix above the bottom segment and obtain a bulk density of about 1.30 Mg m^{-3} . The top 20 cm of the column was left free to give sufficient space for application of water used for leaching. Four different sources of soil amendments were used in this experiment; normal gypsum (NG), phosphogypsum (PG), sulfuric acid (SA) and rice straw (RS); the chemical amendments of NG, PG and SA were applied in terms of gypsum requirement. The amount of each of these amendments (except rice straw) was equivalent to pure gypsum was calculated to reduce the average initial ESP from 29.8 to a final ESP of 12, and for 50 cm soil thickness according

to USDA (1954) as follows: 1. NG (purity 59.5%) was added at a rate of 136 g per column (16.56 ton/fed/30cm), 2. PG (purity 73.9%) was added at a rate of 110 g per column (13.33 ton /fed /30 cm) and 3. SA (98%) was added at a rate of 45 ml per column (16.67 ton /fed) (Richard's 1954). The calculated amounts of NG and PG were applied to soil columns either mixed thoroughly with the 50 cm soil matrix or mixed with the upper 10 cm of soil matrix at the beginning of the experiment. SA was applied either in one dose on the surface of soil at the beginning of leaching process or divided to four equal doses during the leaching process.

Air-dried rice straw (RS) was chopped into shredded pieces less than 5 cm long using a hand chopper. The shredded straw was added at a rate of 125 g per column (15.75 ton/fed) were thoroughly incorporated into the soil before the beginning of the leaching process.

Water used in leaching was collected from El-Sallam water canal used for irrigating the area where the soil was collected. The chemical properties of the water are shown in Table 1. The leaching water increments were applied

taking into of consideration pore volume (PV) basis, which equals to the volume of pore space of the soil at saturation. The volume of water used to saturate one soil column was 7000 cm³ (34.82 cm) which is equivalent to one pore volume (1 PV). Leaching was performed by continuous ponding (i.e. continuous leaching). The amount of water was supplied using rubber tube to keep a constant head of 36 mm water on the soil surface. The leachate was periodically collected in volume increment of 728cm³/column (equivalent to 0.1PV). Twenty leachates were collected throughout the duration of the experiment.

The leachates were analyzed for the total soluble salts and soluble ions. At end of leaching process, the soil columns were separated into 3 segments 0-15, 15-30 and 30-50 cm respectively. Each segment was air-dried, crushed, thoroughly mixed and passed through a 2 mm sieves and analyzed for the EC, pH, soluble ions and exchangeable cations follows:

Mechanical analysis was determined according to the international pipette method. Sodium hexametaphosphate was

used for dispersion after leaching the soluble salts (Piper, 1950).

Calcium carbonate was determined using a calcimeter and calculated as CaCO₃ % (Jackson, 1967).

Organic matter content was determined using Walkley and Black method (Jackson, 1967). Total soluble salts, were determined conductometrically in the saturated soil extract using a conductivity meter according to Richards (1954) and Jackson (1967). The pH was measured using a pH-meter with a combined glass / reference. (Ag/AgCl) electrode in the soil suspension (1:2.5) soil-water ratio (Richards, 1954). Carbonate and bicarbonate ions, were determined by titration with a standard solution of sulfuric acid using phenolphthalein as an indicator for CO₃⁻ and methyl-orange for HCO₃⁻ (Jackson, 1967).

Chloride ions were determined by titration with silver nitrate using potassium chromate as an indicator according to Mohr's method (Jackson, 1967).

Sulfates ions were determined by difference between total cations and total anions.

Calcium and magnesium ions were determined by titration with versinate using Eriochrom Black T (EBT) as an indicator for Ca + Mg and using murexide indicator powder for Ca determination (Richards, 1954).

Sodium and potassium ions were determined by flame photometer (Jackson, 1967).

Extraction of exchangeable calcium and magnesium was done, and the two cations were determined by titration with versinate along with extract of exchangeable sodium and potassium using 1 M ammonium acetate solution and the two cations was determined flame photo metrically (Piper 1950). Stability of wet stable aggregates was determined by using the wet sieving technique described by Yoder (1936) and modified by Ibrahim (1964). The method in brief consists of placing a sample on a set sieves oscillated vertically under water. The sieves have opening of 10, 2, 1, 0.5, 0.25 and 0.125 mm. the determination was made in duplicate by using 100 g of soils aggregates having diameter between 0.8 and 0.25 mm. The sample was placed on the top sieve and wetted to saturation by capillary. The sieves were oscillated for 30 min. with a stroke

length of 3.8 cm and a frequency of fifty cycles per minute. The amount of soil remaining on each sieve was weighted. Then the aggregates separated were combined, dispersed by sodium hexametaphosphate and washed through the next sieves. The remaining primary separates on each sieve were used for analysis and to calculate the water stable aggregates size distribution and wet sieving stability. The wet sieving stability (WSS) was calculated by using the following equation:

$$W.S.S = \frac{\sum m}{M} \times 100$$

Where: m = weight of the wet sieving fraction (in g) and M = weight of soil sample used (in g).

RESULTS AND DISCUSSION

Soil Properties

Physical and chemical properties of the soil and the water used for leaching are presented in Table 1. According to the U.S. Salinity Laboratory Staff (Richards, 1954) the investigated soil would be classified as "saline-sodic" where its EC exceeds $4dSm^{-1}$ and the exchangeable sodium

Table 1. Physical and chemical properties of studied soil and chemical properties of water used for leaching.

Property	Soil	water
<u>A- Physical properties</u>		
1- Particle size distribution (%)		
• Clay	45.40	
• Silt	26.82	
• Fine sand	17.59	
• Coarse sand	10.19	
• Texture class	Clayey	
2- Porosity (%)	50.59	
3- Soil moisture characteristics (%)		
• Saturation percent (SP %)	58.3	
• Field capacity (FC %)	29.14	
• Wilting point (W.P %)	14.60	
4- Density (Mg. m⁻³)		
• Real density	2.53	
• Bulk density	1.30	
<u>B- Chemical properties</u>		
1- EC (dSm⁻¹)	57.58	3.18
2- pH	8.99	8.72
3- soluble ions (mmol L⁻¹)		
• Na ⁺	287.2	19.8
• K ⁺	16.1	2.4
• Ca ⁺⁺	63.8	3.8
• Mg ⁺⁺	208.8	5.8
• Cl ⁻	502.2	17.2
• HCO ₃ ⁻	4.8	13.6
• CO ₃ ⁻	0.0	0.0
• SO ₄ ⁻	68.9	1.0
• SAR	24.6	9.1
4- Exchangeable cations (cmol. kg⁻¹ soil)		
• Na	9.60	
• K	2.18	
• Ca	13.28	
• Mg	7.12	
5- Cation exchangeable capacity (CEC)	32.18	
6- Exchangeable sodium percent (ESP)	29.8	
7- CaSO₄ (%)	0.29	
8- CaCO₃ (%)	1.08	
9- Organic matter (%)	0.55	

percentage (ESP) exceeds of 15. Its pH exceeds 8.5 despite its very high salt contents. Such high pH may be due to the extremely highly soluble Mg content along with the very high soluble Na contents relative to Ca.

Soluble sodium was the dominant soluble cation, constituting nearly half of the soluble cations. The SAR is also extremely high to 25 which exceed the 13 level considered sodicity threshold. On the other hand, chloride represents the major anions followed by sulfate and bicarbonate in the following descending order: $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^-$. However, calcium was the dominant exchangeable cation; the cations are generally arranged in the following descending order: $\text{Ca} > \text{Na} > \text{Mg} > \text{K}$.

The soil is heavy clayey with a high clay content, low in organic matter and CaCO_3 content

Leaching Soluble Salts Pattern

The ion concentration in the leachates as a function of leachates volume is presented in Table 2. Generally, results show that the salt removal by leaching depends mainly on the leachates volume. A very sharp decrease in the EC values were observed for all

treatments, particularly when a volume of leaching water equal to 1.0 pore volume (PV) had percolated through the soil column. The EC value showed a sharp decrease at the beginning of the leaching process, Thereafter it slightly decreased until the end of the experiment.

Following the first four leachates increments (0.4 PV) of water, EC was reduced to 37.15, 27.00, 45.25, 28.15, 26.25, 26.15, 39.05, 32.9 dSm^{-1} for the control (leaching alone), NG^+ , NG^{++} , PG^+ , PG^{++} , SA^+ , SA^{++} and RS, respectively. (The symbol "+" denotes application with thorough mixing within the whole soil column or one dose for SA; and "++" denotes application within the upper 10 cm of the soil column or two split doses of SA)

Following the eight increments (0.8 PV) of water, EC was reduced to 19.25, 13.85, 12.00, 13.15, 11.50, 16.00, 15.65 and 19.15 dSm^{-1} for the control (leaching alone), NG^+ , NG^{++} , PG^+ , PG^{++} , SA^+ , SA^{++} and RS, respectively. Following the twelve increments (1.2 PV) of water, EC was reduced to 9.90, 9.65, 9.65, 9.40, 9.10, 13.23, 13.35 and 14.65 dSm^{-1} for the control (leaching alone), NG^+ , NG^{++} , PG^+ , PG^{++} , SA^+ , SA^{++} and RS, respectively.

Following the sixteen increments (1.6 PV) of water, EC was reduced to 7.35, 7.50, 7.90, 7.45, 6.96, 10.22, 11.15 and 10.12 dSm^{-1} for the control (leaching alone), NG^+ , NG^{++} , PG^+ , PG^{++} , SA^+ , SA^{++} and RS, respectively.

Following the twenty increments (2 PV) of water, EC was reduced to 6.15, 6.2, 6.2, 6.45, 6.05, 7.65, 8.65 and 6.78 dS/m for the control (leaching alone), NG^+ , NG^{++} , PG^+ , PG^{++} , SA^+ , SA^{++} and RS, respectively. Effect of treatments on EC values during continuous leaching illustrated in Fig. (1).

There was considerable decrease in salinity, the effect was more pronounced where the chemical amendments were added. So the replacement of exchangeable sodium by calcium took place during the percolation resulting in formation of sodium sulfate. Sodium and sulfates ions make up a markedly high concentration during the first 10 increments while most of the chlorides have been removed with the 1.5 PV leachates. The sodium and chloride ions took the same trend as EC values are similar in all treatments; these ions concentrations showed a

decrease as the collection leachates progressed. The chloride decreased drastically with the 1.5 pore volume for the chemical and organic treatments.

On the above-mentioned basis, data in Table 2 clarifies that the majority of salts removed out of the soil columns were sodium chloride and sodium sulfate.

Sodium Adsorption Ratio (SAR)

Adding the four increments (0.4 PV) of water reduced the SAR values to 4.87, 26.08, 29.67, 31.13, 16.19, 19.31, 14.11 and 4.59 $\text{mmol}_e\text{L}^{-1}$ for the control (leaching alone), NG^+ , NG^{++} , PG^+ , PG^{++} , SA^+ , SA^{++} and RS, respectively.

Adding the eight increments (0.8 PV) of water reduced the SAR values to 3.65, 7.58, 5.43, 8.59, 5.50, 2.81, 3.41 and 3.71 $\text{mmol}_e\text{L}^{-1}$ for the control (leaching alone), NG^+ , NG^{++} , PG^+ , PG^{++} , SA^+ , SA^{++} and RS, respectively.

Adding the twelve increments (1.2 PV) of water reduced the SAR values to 2.92, 4.76, 3.58, 3.89, 3.45, 1.94, 1.48 and 3.12 $\text{mmol}_e\text{L}^{-1}$

Table 2. Salinity, ion composition, SAR of water leached from soil columns and average hydraulic conductivity (HC) of soil following successive stages of leaching of soil columns treated with normal gypsum (NG), phosphogypsum (PG), sulfuric acid (SA) and rice straw (RS)

Treatments	PV	EC	Cations mmol.L ⁻¹				Anions mmol.L ⁻¹			SAR	HC
			Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻		
Cont.	0.4	37.15	101.60	200.76	59.94	9.77	310.69	1.94	59.44	4.87	0.0003
	0.8	19.25	58.64	99.94	32.53	1.38	137.10	1.04	54.35	3.65	0.0006
	1.2	9.90	36.24	43.49	18.45	0.77	26.48	1.32	71.81	2.92	0.0008
	1.6	7.35	33.42	32.09	6.87	1.13	18.77	0.91	53.83	1.20	0.0013
	2.0	6.15	28.35	27.22	4.97	0.96	15.92	0.44	45.13	0.94	0.0042
NG ⁺	0.4	27.00	8.96	73.17	167.1	17.42	139.03	2.98	108.6	26.08	0.0036
	0.8	13.85	29.97	47.42	47.13	14.00	27.99	1.85	108.7	7.58	0.0050
	1.2	9.65	31.54	32.33	26.90	5.53	17.94	1.29	77.07	4.76	0.0056
	1.6	7.50	25.05	24.54	18.92	6.95	13.68	0.84	60.49	3.80	0.0092
	2.0	6.20	20.70	19.84	15.65	5.75	11.31	0.70	50.01	3.48	0.0182
NG ⁺⁺	0.4	45.25	18.55	131.65	257.1	45.21	248.94	1.30	202.2	29.67	0.0025
	0.8	12.00	21.87	55.83	33.84	8.28	19.43	1.05	99.23	5.43	0.0036
	1.2	9.65	22.38	46.71	21.06	6.47	14.59	0.55	81.38	3.58	0.0046
	1.6	7.90	18.47	39.23	16.42	4.88	5.45	0.35	73.21	3.06	0.0075
	2.0	6.20	14.51	30.60	12.68	3.83	4.27	0.27	57.47	2.71	0.0125
PG ⁺	0.4	28.15	20.44	25.60	149.4	67.08	46.21	1.30	238.6	31.13	0.0058
	0.8	13.15	28.92	41.81	51.09	9.68	22.37	0.99	106.9	8.59	0.0071
	1.2	9.40	31.38	32.63	22.03	8.22	18.48	0.87	74.03	3.89	0.0094
	1.6	7.45	24.87	25.86	15.77	6.52	14.92	0.69	58.68	3.13	0.0124
	2.0	6.45	21.53	22.38	14.96	5.63	13.11	0.59	50.79	3.19	0.0182
PG ⁺⁺	0.4	26.25	19.60	59.04	101.5	82.36	65.73	1.44	195.3	16.19	0.0020
	0.8	11.50	26.87	49.85	34.08	4.58	27.16	1.07	87.15	5.50	0.0045
	1.2	9.10	30.74	36.01	19.93	4.32	19.32	0.51	71.17	3.45	0.0055
	1.6	6.96	23.62	30.33	13.82	1.83	12.74	0.40	56.46	2.66	0.0093
	2.0	6.05	20.51	26.34	12.00	1.59	11.07	0.34	49.04	2.48	0.0099
SA ⁺	0.4	26.15	26.20	80.73	141.2	13.37	81.69	1.86	177.9	19.31	0.0025
	0.8	16.00	22.70	108.99	22.83	5.48	15.72	0.86	143.4	2.81	0.0031
	1.2	13.23	20.51	93.48	14.85	3.62	14.24	0.27	117.8	1.94	0.0045
	1.6	10.22	15.27	75.90	6.87	3.37	11.19	0.21	90.75	1.02	0.0065
	2.0	7.65	11.42	56.85	4.32	2.55	8.38	0.17	67.96	0.74	0.0087
SA ⁺⁺	0.4	39.05	38.20	177.54	146.5	28.23	249.10	2.25	139.2	14.11	0.0024
	0.8	15.65	29.93	96.20	27.09	3.32	27.74	1.23	127.6	3.41	0.0039
	1.2	13.35	21.38	98.32	11.46	2.35	13.68	0.38	119.5	1.48	0.0049
	1.6	11.15	20.52	80.28	8.65	2.05	11.45	0.22	99.83	1.22	0.0058
	2.0	8.65	15.94	62.28	6.71	1.55	8.89	0.16	77.44	1.07	0.0095
R.S	0.4	32.90	89.98	177.79	53.09	8.66	275.14	1.73	52.65	4.59	0.0010
	0.8	19.15	55.00	100.98	32.75	3.24	41.86	1.02	147.8	3.71	0.0013
	1.2	14.65	41.52	77.27	24.04	2.50	32.26	0.84	113.2	3.12	0.0019
	1.6	10.12	45.99	44.16	9.46	1.56	25.83	1.27	74.10	1.41	0.0024
	2.0	6.78	30.82	29.61	6.08	1.04	17.28	0.85	49.70	1.11	0.0036

Notes: +: applied with thorough mixing in soil column (for NG and PG) or one dose (for SA)
 ++: applied on surface within top 10 cm of column (for NG and PG) or split doses of SA.

for the control (leaching alone), NG^+ , NG^{++} , PG^+ , PG^{++} , SA^+ , SA^{++} and RS, respectively.

Adding the sixteen increments (1.6 PV) of water reduced the SAR values to 1.20, 3.80, 3.06, 3.13, 2.66, 1.02, 1.22 and $1.41 \text{ mmol}_e\text{L}^{-1}$ for the control (leaching alone), NG^+ , NG^{++} , PG^+ , PG^{++} , SA^+ , SA^{++} and RS, respectively.

Adding the twenty increments (2 PV) of water reduced the SAR values to 0.94, 3.48, 2.71, 3.19, 2.48, 0.74, 1.07, $1.11 \text{ mmol}_e\text{L}^{-1}$ for the control (leaching alone), NG^+ , NG^{++} , PG^+ , PG^{++} , SA^+ , SA^{++} and RS, respectively. Effect of treatments on SAR values during continuous leaching illustrated in Fig. 2.

Hydraulic Conductivity and Aggregates

The values of hydraulic conductivity are shown in Table 2. The hydraulic conductivity (HC) of the soil increased with time, except when treated with rice straw. This could be explained by the fact that, at the beginning the high electrolyte concentration of the soil solution brings about a reversible flocculation of the primary

particles, which remain stable only above a certain electrolyte concentration (threshold limit) below which dispersion occurs to cemented particles. Consequently, the HC of highly saline soil would be relatively high, but during the leaching the electrolyte concentration falls below a threshold concentration, so the flocculating effect of a high salinity becomes negligible.

The amendment of sulfuric acid, normal gypsum and phosphogypsum resulted in an increase in the HC with time. This could be due to the CaCO_3 dissolution which supplies the soil solution gradually with soluble calcium. So, the replacement of exchangeable sodium by calcium takes place during the percolation, hence, improving the soil structure and the HC. In case of rice straw and the control (untreated soil) treatments there was a limited supply of soluble calcium to replace the exchangeable sodium. Due to the high hydration of adsorbed sodium and the presence of high clay content, which must

have been dominated by expanding clay minerals, swelling and pore size redistribution would take place with leaching, leading to a possible increase in small intra-aggregate pores and total pore volume. A considerable part of the water would be present in fine pores, bounded strongly to the solid particles and would show special semi-solid state "dead water". Consequently, this water cannot be removed below a certain hydraulic gradient. Thus a decrease in hydraulic conductivity with time was obtained. Effect of treatments on HC values during continuous leaching illustrated in Fig. 3.

Table 3 shows the values of wet sieving stable aggregates (WSA, %) as well as distribution of aggregate size fraction. The average value of WSA % was 22.42 % initially. At end of the experiment was for the upper segments ranged has 28.5 to 49.40%; ranges for the middle and lower segments were 25.60-48.91% and 13.24-23.30% respectively. This indicates a distribution of aggregates size fraction in the upper, middle and lower segments of the soil columns.

The content of aggregates having diameter between 0.5 – 0.25 mm, 0.25 – 0.125 mm and 0.125 – 0.062 mm were higher than the other aggregate fraction. This may due to the high content of clay fraction together with other colloidal materials.

The obtained data of Table 3 reveal that percentage of WSA fractions decreased with increasing the sampling depth in almost all profile this may due to increasing exchangeable sodium with increasing the sampling depth. The values of mean weight diameter (M.W.D) are also shown in Table 3.

Residual Soil Salinity and Soluble Ions at the End of Reclamation

The high initial soil salinity (57.58 dS/m) was sharply reduced to values average of the 3 segments of soil columns of 8.37, 4.73, 5.33, 4.69, 5.24, 5.42, 5.46 and 6.87 dS/m for the control (leaching alone), NG^+ , NG^{++} , PG^+ , PG^{++} , SA^+ , SA^{++} and RS, respectively. As observed from the data, the EC increased with soil depth since, the lowest EC was found in the upper segment (0 – 15 cm) and

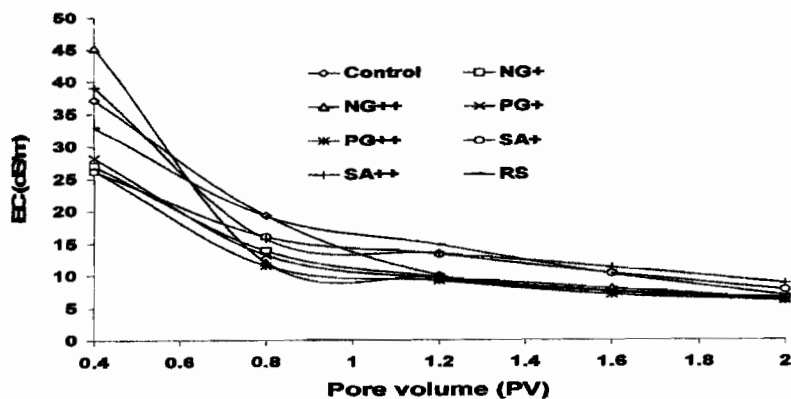


Fig. 1. Effect of treatments on EC values during continuous leaching

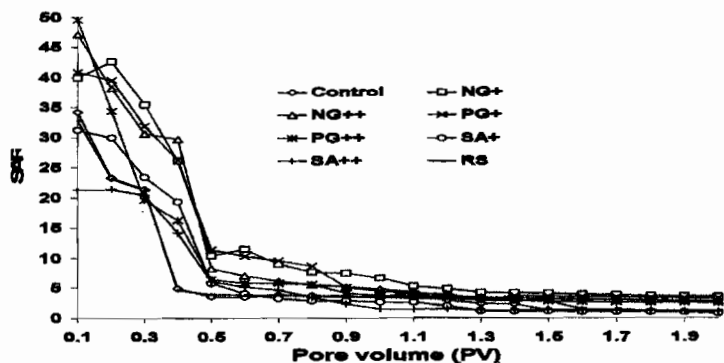


Fig. 2. Effect of treatments on SAR values during continuous leaching

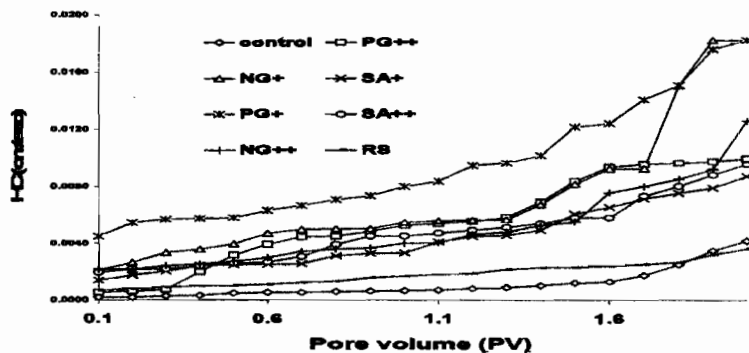


Fig. 3. Effect of treatments on HC values during continuous leaching

Notes: NG: normal gypsum, PG: phosphogypsum, AS: sulphuric acid, RS rice straw, +: applied with thorough mixing in soil column (for NG and PG) or one dose (for SA) and ++: applied on surface within top 10 cm of column (for NG and PG) or split doses of SA.

Table 3. The distribution of water stable aggregated (%) in the different treatments.

Treat-ments	Soil depth	Sieves diameter (mm)						W.S.A %	MWD mm
		10-2	2-4	1-0.5	0.5-0.25	0.25-0.125	0.125-0.062		
	initial	0.19	0.73	2.02	6.22	13.97	1.67	24.80	0.112
Cont.	0-15	0.22	0.84	2.31	7.13	16.00	1.91	28.41	0.124
	15-30	0.20	0.75	2.09	6.43	14.43	1.70	25.60	0.114
	30-50	0.10	0.39	1.08	3.33	7.47	0.87	13.24	0.07
Aver.	0-50	0.17	0.66	1.83	5.63	12.63	1.49	22.42	0.103
NG ⁺	0-15	0.41	1.50	4.03	12.35	27.84	0.33	49.46	0.201
	15-30	0.37	1.44	3.98	12.27	27.56	3.29	48.91	0.197
	30-50	0.18	0.69	1.90	5.84	13.12	1.57	23.30	0.106
Aver.	0-50	0.32	1.21	3.30	10.15	22.84	1.73	40.56	0.198
NG ⁺⁺	0-15	0.38	1.44	3.99	12.29	27.61	3.31	49.02	0.198
	15-30	0.30	1.14	3.14	9.67	21.72	2.60	38.57	0.160
	30-50	0.16	0.60	1.66	5.11	11.49	1.37	20.39	0.095
Aver.	0-50	0.28	1.06	2.93	9.02	20.27	2.43	35.99	0.151
PG ⁺	0-15	0.38	1.49	4.02	12.38	27.80	3.32	49.39	0.199
	15-30	0.36	1.40	3.85	11.87	26.56	3.19	47.23	0.191
	30-50	0.16	0.63	1.74	5.35	12.03	1.44	21.35	0.098
Aver.	0-50	0.30	1.14	3.20	9.87	22.13	2.65	39.32	0.127
PG ⁺⁺	0-15	0.38	1.43	3.99	12.29	27.60	3.30	48.99	0.197
	15-30	0.16	1.13	3.12	9.61	21.58	2.58	38.18	0.151
	30-50	0.15	0.57	1.58	4.87	10.93	1.31	19.41	0.092
Aver.	0-50	0.23	1.04	2.90	8.92	20.04	2.40	35.53	0.147
SA ⁺	0-15	0.30	1.14	3.14	9.67	21.72	2.60	38.57	0.160
	15-30	0.21	0.80	2.21	6.80	15.27	1.83	27.12	0.119
	30-50	0.14	0.56	1.54	4.74	10.65	1.27	18.90	0.090
Aver.	0-50	0.22	0.83	2.30	7.07	15.88	1.90	28.53	0.123
SA ⁺⁺	0-15	0.30	1.14	3.16	9.73	21.85	2.61	38.79	0.161
	15-30	0.20	0.77	2.12	6.52	14.65	1.75	26.01	0.115
	30-50	0.15	0.59	1.62	4.99	11.22	1.34	19.91	0.093
Aver.	0-50	0.22	0.83	2.30	7.08	15.91	1.90	28.24	0.123
R.S	0-15	0.25	0.87	2.32	7.14	16.03	1.92	28.53	0.126
	15-30	0.20	0.79	2.18	6.70	15.05	1.80	26.72	0.118
	30-50	0.20	0.44	1.08	3.33	7.49	0.89	13.43	0.076
Aver.	0-50	0.22	0.70	1.89	5.72	12.86	1.54	22.89	0.107

Notes: +: applied with thorough mixing in soil column (for NG and PG) or one dose (for SA)

++: applied on surface within top 10 cm of column (for NG and PG) or split doses of SA.

the highest EC was found in lower segment (30 – 50 cm). Residual Soluble salts in the soil after leaching is illustrated in Fig. 4. Such considerable decrease in soil salinity as compared with the initial amount reached to 85.46, 91.79, 90.74, 91.85, 90.90, 90.59, 90.52 and 88.07 % due to leaching alone, leaching with NG⁺, NG⁺⁺, PG⁺, PG⁺⁺, SA⁺, SA⁺⁺ and RS, respectively.

The overall average of the decrease is 89.99%. The lowest average of the EC were found in PG⁺ and NG⁺ treatments, while the highest ones were found in RS and the control treatments.

Regarding the chloride ions, it is of interest to notice that the distribution of residual Cl through soil segments at end of leaching is rather similar in the treatments receiving chemical amendments; and greater in the control treatments followed by the RS treatment. Its concentration in the soil column was reduced sharply in upper segment (0 – 15 cm) particularly in the PG⁺ and NG⁺ treatments.

There was a considerable decrease in soluble Cl⁻ in soil. The initial contents were 502.20 mmol

L⁻¹. Leaching caused decreases of 85.24, 96.46, 95.83, 97.04, 96.45, 95.52, 95.35 and 92.49 % for the control (leaching alone), NG⁺, NG⁺⁺, PG⁺, PG⁺⁺, SA⁺, SA⁺⁺ and RS, respectively. The overall average decrease was 94.30% of the initial content of chloride.

The residual soluble sulfates content was also decreased. The reduction was more pronounced in the upper segments. The results revealed that 52.37 to 55.12 % of the initial content of sulfate ions was leached out of the soil column.

The Bicarbonate ion content was decreased in all soil segments with decreases of 21.19, 44.49 and 65.02 % of the initial content of HCO₃ for control, RS and average of the chemical amendments, respectively.

Concerning residual soluble sodium the results reveal that values of soluble sodium decreased to 41.03, 17.70, 20.27, 14.80, 19.66, 20.92, 21.24 and 28.96 mmol L⁻¹ (average of soil columns) for the control (leaching alone), NG⁺, NG⁺⁺, PG⁺, PG⁺⁺, SA⁺, SA⁺⁺ and RS, respectively with an average value of 23.07 mmol L⁻¹. The highest value of residual soluble sodium was found in the control treatment

(leaching alone). This could be attributed to the limited supply of soluble Ca required for exchangeable sodium replacement. A pronounced relative reduction was found in the top segments of soil columns. This finding indicates that the easily soluble sodium salts are translocated from the upper segment to the lower ones and the percolating saline solution carried the soluble Na^+ resulting from the exchangeable reaction.

The data presented in Table 4 show the contents of remained soluble (Ca + Mg) contents in the soil columns. There were high values in the upper segment and increased higher by going down in the soil columns. The values (average of all segments) 39.40, 28.32, 31.57, 30.85, 31.32, 31.81, 31.88 and 38.50 $\text{mmol}_e\text{L}^{-1}$ for the control (leaching alone), NG^+ , NG^{++} , PG^+ , PG^{++} , SA^+ , SA^{++} and RS, respectively, as compared with 274.6 $\text{mmol}_e\text{L}^{-1}$ in the initial soil

Regarding, SAR values results reveal that values of SAR decreased to 9.46, 4.70, 5.10, 3.77, 4.96, 5.24, 5.31 and 6.53 mmol L^{-1} (average of soil columns) for the control (leaching alone), NG^+ , NG^{++} , PG^+ , PG^{++} , SA^+ , SA^{++} and RS respectively. The highest value

of SAR was found in the control. Generally, the SAR values were higher in the lower segment, i.e. increased by going down in the soil columns. Residual SAR in the soil segments during continuous leaching is illustrated in Fig. 5.

Exchangeable Cations

Data presented in Table 5 show the contents of exchangeable cations ($\text{cmol}_e\text{ kg}^{-1}$ soil). The obtained data reveal that leaching the treated soil markedly increased the exchangeable calcium and decreased the exchangeable sodium and magnesium in the three soil segments of columns.

Generally, it could be notice of that, the decrease in the exchangeable sodium was approximately equal to the increase in exchangeable calcium. Also, the exchangeable magnesium has followed the same pattern such as that of exchangeable sodium.

Results also reveal that values of exchangeable sodium decreased to 6.35, 3.76, 3.96, 3.64, 3.86, 4.75, 4.59 and 5.91 $\text{cmol}_e\text{ kg}^{-1}$ soil (average of soil columns) for the control (leaching alone), NG^+ , NG^{++} , PG^+ , PG^{++} , SA^+ , SA^{++} and RS,

respectively. Values of calcium increased to 14.50, 20.55, 20.06, 20.74, 20.13, 18.39, 19.23 and 15.24 $\text{cmol}_c \text{kg}^{-1}$ soil (average of columns) for the control (leaching alone), NG^+ , NG^{++} , PG^+ , PG^{++} , SA^+ , SA^{++} and RS, respectively.

Data reveal that the exchangeable potassium slightly increased in the soil columns in all treatments.

Data presented in Table 5 show that leaching of soil treated with various amendments considerably decreased the ESP values. This drop was more pronounced in the upper segments than in the lower ones. Values of ESP in the soil segments at end of leaching are illustrated in Fig. 4.

To have a more realistic approach to the leaching of various soluble salts out of the soil columns as related to the effective leaching water depth, desalinization leaching curves were constructed to relate the residual soil salinity to the effective leaching water. A correlation was constructed between the soluble salts remaining in each soil segment and the amount of water

passing through it. The residual salinity was expressed as C/C_0 fraction, where C_0 refers to the initial salt concentration in soil saturation extract of each segment before leaching and C refers to the corresponding concentration after passing of certain amount of leaching water through it. The effective leaching water was expressed as D_w/D_s ; where D_w represent the depth of effective leaching (drainage) water, which can be obtained by adding the total depth of percolated water to the depth of water needed for moistening the soil segment (or segments beneath); D_s is the depth of leached soil segment. An attempt was made to fit an empirical relationship to the experimental data. The closest fit regression equation was found as: $C/C_0 = A + B (D_w/D_s)$. Where; C , C_0 , D_w and D_s are as defined above, A and B are empirical constant. The obtained results are tabulated in Table 6.

Effect of Different Treatments on the Reclamation Time

The time required to complete the reclamation was calculated upon the end of experiment. The results are

Table 4. Soil salinity, pH, and soluble ions of the soil columns at the end experiment after completion of leaching

Treat- ments	Soil depth (cm)	EC dS/m	pH	Soluble cations mmol.L ⁻¹				Soluble anions mmol.L ⁻¹			SAR
				Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl	HCO ₃	SO ₄ ⁻	
	initial	57.58	8.99	63.80	208.8	287.20	16.06	502.2	4.75	68.85	24.60
Cont.	0-15	7.84	8.45	8.55	28.37	39.35	2.14	43.56	3.57	31.28	9.16
	15-30	8.29	8.42	9.04	30.00	41.61	2.26	45.53	3.88	33.50	9.42
	30-50	8.97	8.51	9.78	32.46	45.03	2.45	52.33	3.78	33.60	9.80
Aver.	0-50	8.37	8.46	9.12	30.28	42.00	2.28	47.14	3.74	32.79	9.46
NG ⁺	0-15	4.51	8.32	11.15	16.32	16.41	1.23	14.72	1.60	28.79	4.43
	15-30	4.68	8.35	10.82	16.90	17.71	1.28	18.11	1.37	27.22	4.76
	30-50	5.01	8.45	11.64	18.13	18.98	1.36	20.51	1.67	27.92	4.92
Aver.	0-50	4.73	8.37	11.20	17.12	17.70	1.29	17.78	1.55	27.98	4.70
NG ⁺⁺	0-15	4.75	8.35	11.44	17.19	17.58	1.29	16.69	1.91	28.91	4.65
	15-30	5.46	8.38	12.35	19.76	21.01	1.49	22.41	1.88	30.32	5.25
	30-50	5.77	8.47	13.08	20.88	22.23	1.52	23.79	2.09	31.82	5.40
Aver.	0-50	5.33	8.40	12.29	19.28	20.27	1.43	20.96	1.96	30.35	5.10
PG ⁺	0-15	4.22	8.31	14.39	15.27	11.39	1.15	12.66	1.00	28.55	2.96
	15-30	4.67	8.34	12.26	16.90	16.29	1.27	17.17	1.05	28.48	4.27
	30-50	5.17	8.41	17.05	16.69	16.71	1.26	14.78	1.27	35.66	4.09
Aver.	0-50	4.69	8.35	14.57	16.29	14.80	1.23	14.87	1.11	30.90	3.77
PG ⁺⁺	0-15	4.67	8.34	11.67	16.90	16.86	1.28	14.74	1.64	30.33	4.46
	15-30	5.36	8.36	12.40	19.40	20.36	1.46	20.93	1.64	31.03	5.11
	30-50	5.69	8.46	12.97	20.62	21.77	1.55	17.86	1.78	37.22	5.31
Aver.	0-50	5.24	8.39	12.35	18.97	19.66	1.43	17.84	1.69	32.86	4.96
SA ⁺	0-15	4.85	7.63	11.43	17.55	18.21	1.32	18.06	2.10	28.35	4.78
	15-30	5.56	8.12	12.18	20.12	21.78	1.52	24.38	2.09	29.14	5.42
	30-50	5.85	8.17	12.97	21.17	22.77	1.60	25.05	2.27	31.19	5.52
Aver.	0-50	5.42	7.97	12.19	19.61	20.92	1.48	22.50	2.15	29.56	5.24
SA ⁺⁺	0-15	4.86	7.52	11.24	17.59	18.45	1.33	18.93	1.40	28.28	4.86
	15-30	5.60	8.11	12.22	20.27	21.99	1.52	24.75	1.53	29.72	5.46
	30-50	5.92	8.15	12.89	21.42	23.28	1.61	26.45	1.62	31.14	5.62
Aver.	0-50	5.46	7.93	12.12	19.76	21.24	1.49	23.38	1.52	29.71	5.31
R.S	0-15	6.80	8.41	14.09	24.61	27.46	1.84	34.77	2.68	30.55	6.24
	15-30	6.29	8.42	11.77	22.77	26.65	1.71	35.65	2.42	24.84	6.41
	30-50	7.54	8.44	14.98	27.29	31.97	1.17	42.74	2.81	29.86	6.95
Aver.	0-50	6.88	8.42	13.61	24.89	28.69	1.57	37.72	2.64	28.42	6.53

Notes: +: applied with thorough mixing in soil column (for NG and PG) or one dose (for SA)

++: applied on surface within top 10 cm of column (for NG and PG) or split doses of SA.

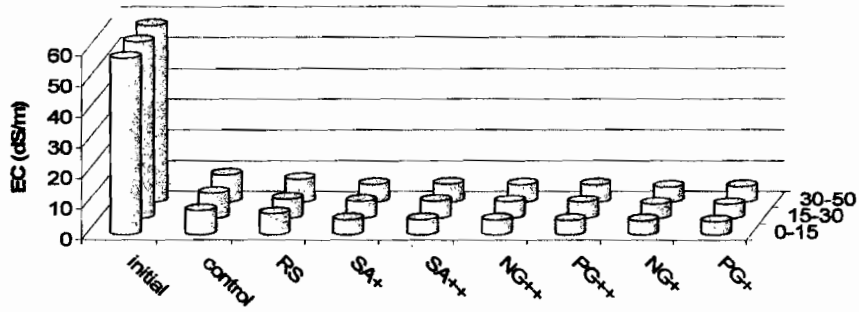


Fig. 4. Residual soluble salts in the soil segments after continuous leaching

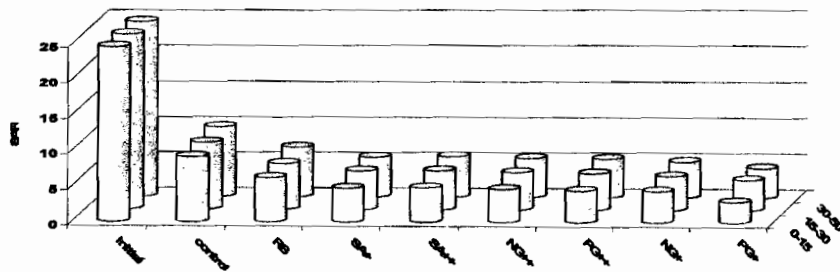


Fig. 5. Residual SAR in the soil segments after continuous leaching

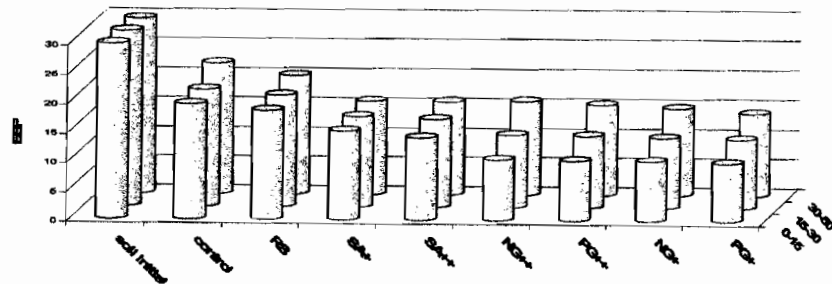


Fig. 6. Residual ESP in the soil segments after continuous leaching

Notes: NG: normal gypsum, PG: phosphogypsum, AS: sulphuric acid, RS rice straw, +: applied with thorough mixing in soil column (for NG and PG) or one dose (for SA) and ++: applied on surface within top 10 cm of column (for NG and PG) or split doses of SA

Table 5. Exchangeable cations, cation exchange capacity (CEC), exchangeable sodium percentage (ESP) and exchangeable calcium percentage (ECaP) at end of leaching processes.

Treatments	Soil depth (cm)	Exchangeable cations cmol. kg ⁻¹ soil				CEC	ESP	ECaP
		Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺			
	initial	13.28	7.12	9.60	2.18	32.18	29.80	41.27
Cont.	0-15	15.09	6.55	5.90	2.58	30.12	19.59	50.11
	15-30	13.86	7.22	5.99	3.08	30.15	19.89	46.00
	30-50	13.85	7.79	7.16	3.34	32.14	22.25	43.10
Aver.	0-50	14.27	7.19	6.35	3.00	30.80	20.58	46.40
NG ⁺	0-15	21.62	3.25	3.14	3.00	31.01	10.12	69.72
	15-30	21.06	3.51	3.64	2.10	30.31	12.01	69.48
	30-50	18.98	4.95	4.51	2.00	30.44	14.83	62.31
Aver.	0-50	20.55	3.90	3.76	2.37	30.59	12.32	67.17
NG ⁺⁺	0-15	21.20	3.61	3.21	3.11	31.13	10.31	68.10
	15-30	20.60	3.68	3.78	2.40	30.46	12.41	67.63
	30-50	18.39	5.15	4.89	2.27	30.70	15.93	59.90
Aver.	0-50	20.06	4.15	3.96	2.59	30.76	12.88	65.21
PG ⁺	0-15	21.80	3.11	3.05	3.08	31.04	9.83	70.23
	15-30	21.35	3.46	3.62	2.20	30.63	11.82	69.71
	30-50	19.06	4.92	4.26	2.10	30.34	14.04	62.82
Aver.	0-50	20.74	3.83	3.64	2.46	30.76	11.90	67.59
PG ⁺⁺	0-15	21.29	3.45	3.16	3.21	31.11	10.16	68.44
	15-30	20.68	3.66	3.75	2.45	30.54	12.28	67.71
	30-50	18.41	4.99	4.67	2.30	30.37	15.38	60.62
Aver.	0-50	20.13	4.03	3.86	2.65	30.76	12.61	65.59
SA ⁺	0-15	18.76	3.89	4.57	2.98	30.20	15.13	62.12
	15-30	18.59	3.95	4.68	3.12	30.34	15.43	61.27
	30-50	17.81	5.60	5.01	3.14	31.56	15.88	56.41
Aver.	0-50	18.39	4.48	4.75	3.08	30.70	15.48	59.93
SA ⁺⁺	0-15	19.95	3.75	4.36	3.01	31.07	14.03	64.21
	15-30	19.58	3.71	4.56	2.52	30.37	15.01	64.47
	30-50	18.16	5.34	4.86	2.38	30.74	15.80	59.08
Aver.	0-50	19.23	4.27	4.59	2.64	30.73	14.95	62.59
R.S	0-15	16.09	5.67	5.61	2.83	30.20	18.56	53.29
	15-30	15.28	6.46	5.81	3.07	30.62	18.97	49.90
	30-50	14.34	6.92	6.32	3.73	31.31	20.18	45.81
Aver.	0-50	15.24	6.35	5.91	3.21	30.71	19.24	49.67

Notes: +: applied with thorough mixing in soil column (for NG and PG) or one dose (for SA)

++: applied on surface within top 10 cm of column (for NG and PG) or split doses of SA.

Table 6. Empirical constant A and B of the regression equation relating the residual salinity fraction (EC/EC₀) to the effective leaching water (Dw/Ds)

Treatment	Equation	r
Control	$y = 0.6747e^{-0.337x}$	0.989 ^{***}
NG ⁺	$y = 0.4408e^{-0.3524x}$	0.991 ^{***}
NG ⁺⁺	$y = 0.379e^{-0.3319x}$	0.989 ^{***}
PG ⁺	$y = 0.4335e^{-0.3524x}$	0.991 ^{***}
PG ⁺⁺	$y = 0.3834e^{-0.3484x}$	0.900 ^{***}
SA ⁺	$y = 0.4482e^{-0.3514x}$	0.992 ^{***}
SA ⁺⁺	$y = 0.4523e^{-0.3533x}$	0.992 ^{***}
RS	$y = 0.5585e^{-0.3437x}$	0.988 ^{***}

Note: y refer to (Dw/Ds) and x refer to (EC/Eco)

***: Significant at 0.001 levels

Table 7. Effect of different treatments on the reclamation time.

Treatment	Time (day)
Cont.	208.83
NG ⁺	48.65
NG ⁺⁺	69.95
PG ⁺	36.69
PG ⁺⁺	53.77
SA ⁺	84.23
SA ⁺⁺	91.25
R.S	175.05

Notes: +: applied with thorough mixing in soil column (for NG and PG) or one dose (for SA)

++: applied on surface within top 10 cm of column (for NG and PG) or split doses of SA.

presents in Table 7. The data reveal that the treatments used in the current study could be arranged according to their efficiencies in reducing the time required for reclamation in the following descending order: NG⁺, NG⁺⁺, PG⁺, PG⁺⁺, SA⁺, SA⁺⁺ and RS > control (leaching alone).

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كفاءة بعض محسنات التربة لا ستصلاح أرض ملحية متدهورة باستخدام
الغسيل المستمر

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اقامت تجربة معملية لتقييم كفاءة بعض المصلحات الكيميائية والعضوية (الجبس الزراعي العادي والجبس المفسفر وحامض الكبريتيك وقش الأرز) وطريقة اضافتها في استصلاح الأراضي المتأثرة بالأملاح في منطقة سهل الطينة ومدى تأثيرها على خواص التربة الطبيعية (التوصيل الهيدروليكي و التجمعات الأرضية) والكيميائية (درجة التوصيل الكهربى والأيونات الذائبة والمتبادلة ونسبة ادمصاص الصوديوم) وذلك باستخدام أعمدة بلاستيكية تم فيها غسيل عمود التربة باتباع نظام الغسيل المستمر للتربة.

تم اضافة الجبس العادي والمفسفر بطريقتين الأولى اضافة سطحية للتربة حيث تم خلط الكمية المحسوبة مع الطبقة السطحية أما الثانية فتم خلط كمية الجبس المحسوبة مع عمود التربة بينما في حالة حامض الكبريتيك تم اضافة الكمية المحسوبة مع ماء الغسيل بطريقتين الأولى اضافة الكمية المحسوبة جرعة واحدة (اضافة كاملة) والثانية تم تقسيم الكمية المحسوبة الي اربع جرعات (اضافة متقطعة) أما في حالة قش الأرز فتم خلط الكمية (١٢٥ جرام) مع عمود التربة بنسبة ١%

اظهرت النتائج ان اضافة هذه المصلحات أدى الي تحسين الخواص الطبيعية والكيميائية للتربة مقارنة بالكنترول (الغسيل بالماء فقط) ويمكن ترتيب هذه المصلحات تنازليا حسب تأثيرها في عملية الإستصلاح كما يلي : الجبس المفسفر المخلوط مع عمود التربة <الجبس الزراعي العادي المخلوط مع عمود التربة <الجبس المفسفر المخلوط مع الطبقة السطحية للتربة <الجبس الزراعي العادي المخلوط مع الطبقة السطحية للتربة <حامض الكبريتيك اضافة كاملة <حامض الكبريتيك اضافة متقطعة <قش الأرز > الكنترول (الغسيل فقط)