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OPTIMAL USE OF COMBINED SOIL AMENDMENTS FOR RECLAIMING AND RESTORING SALT-AFFECTED SOILS

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ABSTRACT

A leaching column experiment techniques was carried out to evaluate the optimal combination of gypsum, sulfuric acid, limestone, and organic compost as soil reclamation amendments for a saline-sodic soil taken from Sahl El Tina, Egypt. After termination of leaching, the soil columns were planted with the halophyte plant, *Atriplex halimus*. Leaching as well as irrigation was done using El-Salam canal water of 1.72 dSm^{-1}. All of the amendments, singly or in combination decreased EC, pH, SAR and ESP soil properties and increased exchangeable calcium. Initial values being 28.8 dSm^{-1}, 8.40, 12.96 and 38.01 for soil EC, pH, SAR and ESP, respectively, decreased upon leaching to 5.80, 7.99, 6.05 and 12.40; then to 2.10, 7.7, 4.06 and 8.80 after harvesting, respectively, as general means. The obtained data showed that there is no one combination fitting for all soil properties of EC, pH, SAR, ESP and bulk density although using a mixture of the 4 amendments instead of one kind may be recommended. Growing the halophyte plant increased the effectiveness of amendments.

Keywords: Reclamation, Gypsum, Sulfuric acid, Limestone, Compost, Computer model.

INTRODUCTION

Reclaiming saline and particularly sodic soil is a recurring and challenging problem. A general rule was to apply a given depth of water to remove 80% of the soluble salt from the same depth of the soil. Early, Carter and Robbins (1978) reported that essentially all of the residual salt could be removed from soil profiles by passing 30 cm of water per meter depth of soil

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profile. However, removal of exchangeable sodium necessitates application of chemical amendments to remove the sodium from the soil's cation exchange sites. Sahin *et al.* (2002) proved that reclamation of saline sodic and sodic soils generally starts by increasing calcium on the exchange complex at the expense of sodium. Calcium ions required for the exchange reaction could be obtained either from the added calcium amendments or from the native calcium carbonate which could be mobilized through the addition of acids or acid formers (Kamphorst and Aolt, 1976; Singh *et al.*, 1981; Bresler *et al.*, 1982; Loveday, 1984 and Abou Yuossef 2001), Loveday (1984) and Yahia *et al.*, (1975) demonstrated the effectiveness of surface-applied sulfuric acid for reclaiming sodic soils and reported that applications of 5 to 15 Mg/ha proved superior to surface-applied gypsum for calcareous sodic soils. Prather *et al.* (1978) summarized the advantages of sulfuric acid, gypsum, and $CaCl_2$ singly or in combination for sodic soil reclamation. Their results indicate that a combination of amendments may provide effective in reclamation at low costs. On the other hand various organic amendments such as mulch, manures, and compost have been investigated for their effectiveness on remediation of saline-sodic soils (Diez and Krauss 1997; Wahid *et al.*, 1998). In general, organic amendments have a very little effect on improving soil salinity and sodicity when they are applied alone (Madejon *et al.*, 2001). However their effectiveness in improving many soil properties is well documented in literature (Cheny and Swift, 1984; Hanay *et al.*, 1992; Gao and Chang, 1996; Prihar *et al.*, 1996; Entry *et al.*, 1997; Giusquiani *et al.*, 1995; Ibrahim and Shindo, 1999; Mamo *et al.*, 2000; Naeini and Cook, 2000). Al-Khateeb *et al.*, (2001) concluded that planting halophyte plants in saline soils would help in accumulating sodium in leaves and reclamation of saline soils. The current work was undertaken to predict the optimal combination of some soil amendments for saline sodic reclamation using a tetra factorial computer model.

MATERIALS AND METHODS

A tetra factorial computer model by Moussa and Youssef (1992) was applied to assess the effect of using gypsum "G", limestone "L", sulfuric acid "S" and organic compost "C", on chemical properties of the soil as shown in Tables 1 and 2. The mathematical approach and elevation model could be found in Chung (2002). Application of gypsum based on the gypsum requirements (GR) equation (USDA, 1954) taking in consideration a required final value of exchangeable sodium percent (ESP_f) to be 10%, the actual exchangeable sodium percent (ESP_i) is equal 38.01% (Table 1). The gypsum was of 98.81% purity and its addition rate was 13.5 $Mgfed^{-1}$ (which costs 2029.53 LE). The investigated materials in the experiment (G, L, S, and C) were designated as X1, X2, X3, and X4 respectively. However the levels of amendment ranging from zero to a maximum. The maximum dose of each amendment is chosen to so as to cost (i.e. in terms of cost rather than gypsum requirement) 2029.53 LE / feddan, consequently values for the maximum dose for G, L, S and C in terms of material quantity are 13.5, 5.80, 0.25 and 8.12 $Mgfed^{-1}$, respectively.

There were 19 treatments, which cover all the possible combination of the amendments (Table 3). Following the above mentioned Tetra-factorial model, the four amendments G, L, S and C were allocated the four heads of the tetrahedron on each top site they were equal to maximum 100% or 8 points graduated to be 0% on the opposite base. Treatments 1 to 4 and 6 to 11 lie on the surface of the tetrahedron while treatments 12 to 19 lie inside it, whereas treatment 5 lies exactly on the tetrahedron center which consists of the four amendments (25% each) or 2 units each (the sum of any treatment is 100% or 8 units, with equal the fixed cost of 2029.53 LE/fed.. Treatments were done in 3 replicate each in plastic cylinder columns of 75 cm height and 16 cm inside diameter. The bottom of each column was sealed with perforated mesh nylon screen and glass wool. Acid washed inert sand (pre-washed with HCl and water) was placed on the tube bottom to make a 5 cm layer of the column to regulate the flow of water and to prevent plugging the lower part of column by the immigrating fine materials. Soil was packed in the tubes so as to a soil column 60 cm height and bulk density of 1.65 Mgm^{-1}. This required a quantity of soil of 20 kg of air-dried soil per column. Such arrangement allowed for 10 cm on top of soil column to give sufficient space for addition of water for irrigation and leaching process. Treatments were prepared according to Table 3. Amendments were mixed homogeneously within the top 30 cm to be ready for starting the leaching process.

Water taken from El-Sallam Canal (used irrigate Sahl El-Tina) was used for the leaching and irrigation process (Table 1). The leaching procedure using the intermittent method was done so as to add water portions to the already saturated soil columns; and obtain leachates which are equal to the added portions. The amount of added water was thirty centimeters depth of water. Such water was divided into two equal doses 15 cm each and allowed to pass through the soil column. Termination of leaching was done after passing the two equal doses. The leachates were collected and analyzed and soil sample were taken from each column at three layers 0 - 20, 20 - 40 and 40 - 60 cm depth using cylindroids tube of 2 cm inside diameter. Each sample was air dried, crushed, mixed and passed through a 2 mm sieves and analyzed for salinity, soluble ions, pH and exchangeable cations. The 2 cm hole was filled with a mixture of sand and hot wax. A halophyte plant (*Atriplex halimus*) was planted in each column after termination of leaching and received all necessary practices. At the end of six month growing period plants were harvested and some plant morphological and chemical characters were recorded. Then soil columns were separated into 3 segments 0-20, 20-40 and 40-60 cm. Soil of each segment was air dried, crushed, mixed and passed through a 2 mm sieves and analyzed for salinity, soluble ions, pH and exchangeable cations.

Each of the determined parameters either in leachates or soil was passed through the tetra factorial computer programmed model of Moussa and Youssef (1992) in which the results of all the possible combination were printed either on the surface or inside the tetrahedron; each value refers to specific combination according to its position on or inside the tetrahedron. The total numbers of the output values are 165. The values located on the surface area of the principle tetrahedron amount to 130 corresponding to 4 single, 21 double and 105 triple-factor treatments. The other 35 located inside the principle one and refer to quadruple-factor. It is worthy to mention that any of the 165 intersections have the same cost of the amendments, which considered highly important when comparing the effect and inter effect of the materials from the economical

Tablel 1. Physical and chemical properties of the studied soil and chemical properties of water used for irrigation (El-Salam canal water)

Property	Soil	Water
Particle size distribution [%]		
▪ Clay	38.54	
▪ Silt	10.14	
▪ Fine sand	35.80	
▪ Coarse sand	15.52	
▪ Texture class [According to USDA triangle]	Sandy Clay	
Soil moisture characteristics [%]		
▪ Saturation percent	33.76	
▪ Field capacity	16.89	
▪ Wilting point	8.44	
density ($Mg.m^{-1}$)		
▪ Bulk density	1.65	
▪ Particle density	2.56	
Organic matter [$g\ kg^{-1}$]	5.30	
$CaSO_4$ [$g\ kg^{-1}$]	15.00	
$CaCO_3$ [$g\ kg^{-1}$]	41.40	
Soluble ions, EC and pH		
▪ EC (dSm^{-1}) [Soil extract 1:2.5]	28.80	1.72
▪ Soil reaction (pH) [Soil suspension 1:2.5]	8.40	7.60
▪ Soluble ions ($mmol_c\ L^{-1}$) [Soil extract 1:2.5]		
• Na^+	135.72	10.47
• K^+	6.09	0.25
• Ca^{++}	96.00	3.69
• Mg^{++}	123.20	2.79
• Cl^-	259.54	13.62
• $CO_3^=$	00.00	00.00
• HCO_3^-	2.24	1.06
• $SO_4^=$	99.23	2.52
• SAR	12.96	5.82
Exchangeable cations and CEC ($cmol_c\ kg^{-1}$)		
▪ Na^+	10.54	
▪ K^+	2.83	
▪ Ca^{++}	5.89	
▪ Mg^{++}	8.46	
▪ CEC ($cmolc\ kg^{-1}$)	27.75	
Exchangeable sodium percentage (ESP)	38.00	

Note: Converting EC dSm^{-1} to $mmol_c\ L^{-1}$ soluble salts (or cations) agrees with the equation of Gupta (1990), getting a factor of 12 to 13 for EC > 5; also Tanji (1990) gives an equation predicting $mmolcL^{-1}$ from EC dSm^{-1} for EC > 5.

Table 2. Properties of amendments used for reclamation

Property	Value
1- Sulphuric acid	
▪ Concentration [%]	95
▪ Specific gravity	1.834
2- Gypsum [$CaSO_4.2H_2O$]	
▪ Purity [%]	98.81
▪ pH [1:5 water]	7.80
▪ EC [1:5 water]	2.56
▪ Ca [g kg^{-1}]	229.8
▪ S [g kg^{-1}]	175.0
3- Limestone [$CaCO_3$]	
▪ Purity [%]	97.50
▪ Moisture [%]	0.20
▪ pH	8.10
▪ Ca [g kg^{-1}]	390.0
▪ CaO [g kg^{-1}]	550.0
4- Compost [made from plant]	
▪ Moisture [%]	23.00
▪ pH [1:10]	7.00
▪ EC dS/m [1:10]	2.56
▪ Total N [g kg^{-1}]	21.50
▪ Total P [g kg^{-1}]	10.90
▪ Total K [g kg^{-1}]	3.10
▪ Organic mater [g kg^{-1}]	672.0
▪ C/N Ratio	1:18

Table 3. Treatment codes and ratios of amendments along with their rates in each treatment Feddan^{-1} in the current study

Treat. No.	Amendments codes and ratios				Amendments codes and rates [Mg.Fed-1]			
	X1 [G]	X2 [L]	X3 [S]	X4 [C]	X1 [G]	X2 [L]	X3 [S]	X4 [C]
1	8	0	0	0	13.50	00.00	00.00	00.00
2	0	8	0	0	00.00	5.80	00.00	00.00
3	0	0	8	0	00.00	00.00	0.25	00.00
4	0	0	0	8	00.00	00.00	00.00	8.12
5	2	2	2	2	3.38	1.45	0.06	2.03
6	4	4	0	0	6.75	2.90	00.00	00.00
7	4	0	4	0	6.75	00.00	0.13	00.00
8	4	0	0	4	6.75	00.00	00.00	4.06
9	0	4	4	0	00.00	2.90	0.13	00.00
10	0	4	0	4	00.00	2.90	00.00	4.06
11	0	0	4	4	00.00	00.00	0.13	4.06
12	5	1	1	1	8.44	0.73	0.03	1.02
13	1	5	1	1	1.69	3.63	0.03	1.02
14	1	1	5	1	1.69	0.73	0.16	1.02
15	1	1	1	5	1.69	0.73	0.03	5.06
16	2.5	2.5	2.5	0.5	4.22	1.81	0.08	0.51
17	2.5	2.5	0.5	2.5	4.22	1.81	0.02	2.54
18	2.5	0.5	2.5	2.5	4.22	0.36	0.08	2.54
19	0.5	2.5	2.5	2.5	0.84	1.81	0.08	254

Notes: X1: Gypsum "G", X2: Lime-stone "L", X3: Sulfuric Acid "S" and X4: Compost "C" point of view. Moreover the average value, general mean error, correlation coefficient, fisher, criterion, optimum combination and adequacy test of the model through the treatments 16-19 are of the programmed output. Physical and chemical analyses were done according to Baruah and barthakur (1997), Page (1991) and Chapman and Pratt (1961).

RESULTS AND DISCUSSION

Effect of the Leaching

Most of the reclamation indicators at the end of both, leaching process and harvesting of halophyte plant as affected by all the possible combination of gypsum "G", lime "L", sulfuric acid "S" and compost "C" were significantly decreased comparing with the original soil (Table 4). However, the response took the same trend.

The effect of EC dSm^{-1}, SAR, and ESP soil properties have the same trend. There was a high prohibitive significant correlation between EC and each of SAR and ESP r = 0.99 and 0.98, respectively. Soil electrical conductivity (EC, dSm^{-1}) was chosen to represent this group of soil parameters.

Soil salinity and sodicity

Data of Table 4 and Fig. 1 show that the EC ranged between 7.07 and 16.77 dSm^{-1} with a general mean 10.95 dSm^{-1}. However the located values of the four single treatments were 15.67, 16.77, 16.43 and 14.93 dSm^{-1} for G, L, S and C, respectively. These results suggest that C gave the promotion effect compared with the other amendments, the order where C > G > S > L. These results could explain that C has pronounced role in decreasing soil salinity.

Scanning the different values of Fig. 1A shows 8.6 dSm^{-1} as the minimum value, corresponding to an interpolated four combined treatments consisting of [0: 2: 3: 3] (of the 8 points score) of [G, L, S & C], respectively. This result indicates the significant effect of G, L, S and C at the rate [0.00, 1.45, 0.09 & 3.05] $Mgfed^{-1}$, respectively. Scanning the different values of Fig. 1B shows that the value 5.80 dSm^{-1} is the minimum one, corresponding to an interpolated four combined treatments consisting of [1.0: 2.0: 3.0: 2.0] (of the 8 points score), respectively of [G, L, S and C], respectively. This result reflects the marked effect of the combination of G, L, S and C at the rate [1.69, 1.45, 0.09 & 2.03] $Mgfed^{-1}$. Fig. 1C indicate that the center point of the tetrahedron has an EC value 14.10 dSm^{-1} corresponding to treatment of [2: 2: 2: 2] i.e. equivalent mixture of the four amendments. The original soil was saline sodic and very compact. Addition of organic must have loosened the soil and increased its porosity (Ahmed *et al.*, 1988). Addition of gypsum and/or FYM must have enhanced the chemical reaction and exchanged the sodium ions with Ca2+ on the soil exchange complex. The Na^+ ions in soluble form would leach down due to improved soil physical conditions.

Generally, Fig. 1 shows that the optimum combination for decreasing EC was obtained by the mixture of G, L, S and C at the ratio of [1.0: 2.0: 3.0: 2.0] (of the 8 points score) [G, L, S and C], respectively. This result reflects significant effect of G, L, S and C at the rate [1.69, 1.45, 0.09 and 2.03] $Mgfed^{-1}$, respectively. The pattern of EC was similar to each of the soluble cations and soluble anions where data reveal highly significant correlation between EC and each of the cations and anions. Niazi *et al.*, (2001), confirmed in field study that gypsum (100% GR) added with FYM and gypsum 75% and H_2SO_4 increased the yield for the first year of rice crop.

Regarding the effect on SAR, the optimum combination for decreasing it, was obtained by a mixture of G, L, S and C at the ratio of [1.0: 2.0: 3.0: 2.0] (of the 8 points score), respectively. This result reflects the marked effect of G, L, S and C at the rate [1.69, 1.45, 0.09 & 2.03] $Mgfed^{-1}$, respectively. Regarding ESP the optimum combination for its decrease was obtained by a mixture of G, L, S and C at the ratio of [2.0: 1.0: 3.0: 2.0] (of the 8 points score) of [G, L, S and C], respectively. This reflects the marked effect of G, L, S and C at the rate [3.38, 0.73, 0.09 & 2.03] $Mgfed^{-1}$, respectively. Chaganti, (2008) examined the effect of "gypsum, sulfur, and poultry manure" on EC, SAR and ESP in soils and found significant decreases in soil SAR and ESP in the 0 - 5 cm depth.

Soil reaction (soil pH)

Regarding soil pH (Table 4 and Fig. 2). Results (Fig. 2A) show that a pH value of 7.99 was the minimum one, corresponding to an interpolated four combined treatments consisting of [0: 0: 0: 8] (of the 8 points score) of [G, L, S and C], respectively. This reflects the positive effect of G, L, S and C at the rate [0.00, 0.00, 0.00 & 8.12] $Mgfed^{-1}$, respectively in decreasing soil pH. Fig. 2B shows a pH value of 8.02 as the minimum one, corresponding to an interpolated treatments consisting of [5: 1: 1: 1] (of the 8 points score) of [G, L, S and C], respectively. This is the effect of G, L, S and C at the rate [8.44, 0.73, 0.03 & 1.02] Mgfed^{-1}, respectively.

Fig. 2C indicates that the center point of the tetrahedron has a pH value 8.12 corresponding to treatment [2: 2: 2: 2] of the four amendments.

Fig. 2 shows the optimum combination for decreasing pH was obtained by a mixture of G, L, S and C at the ratio of [0: 0: 0: 8] (of the 8 points score) respectively of [G, L, S and C], respectively. This shows the significant effect of G, L, S and C at the rate [0.00, 0.00, 0.00 & 8.12] Mgfed^{-1}, respectively. Avinelech *et al.*, (1990) concluded that applying organic composts to saline sodic soils would help in chelating calcium and reduced pH leading to an increase in solubility of $CaCO_3$ and preventing Ca^{++} precipitation. Anand (1992) stated that organic amendments decreased soil sodicity and increased pCO2 and exchangeable Ca^{++} and Mg^{++}. Benz *et al.*, (1987) reported that straw mulches effectively used for saline sodic reclamation.

Effect after Growth

Regarding to soil parameters after harvesting of the halophyte plant Table 4 shows considerable positive effects of amendments compared with the effect after leaching; data after plant harvest shows more improvement of soil properties. Leaching and halophyte growing decreased soil salinity by about two thirds. These results are in harmony with those of Al-Khateeb *et al.*, (2001).

Salinity and SAR

Values of EC and SAR have the same trend there was a high correlation between SAR and EC r = 0.99. Hence, the different soil reclamation characters (i.e. pH, ESP and bulk density) can be illustrated by one of them. Soil electrical conductivity (EC, dSm^{-1}) was chosen to represent this group of soil parameters.

Data of Table 4 and Fig. 3 indicate that EC ranged between 13.14 and 3.60 dSm^{-1} with a general mean 7.27 dSm^{-1}. Values for the four single treatments were 12.07, 13.14, 12.75 and 11.18 dSm^{-1} for of G, L, S and C, respectively. Thus C gave the most effect compared with the others, the order being C > G > S > L.

Scanning the different values, Fig 3A shows that 4.80 dSm^{-1} this minimum one, regarding the interpolated combined treatment of [0: 2: 3: 3] (of the 8 points score) of [G, L, S & C], respectively. This is a treatment of G, L, S and C at the rate [0.00, 1.45, 0.09 & 3.05] Mgfed^{-1}, respectively. Fig. 3B shows 2.10 dSm^{-1} as the minimum one, regarding the interpolated treatment of [1.0: 2.0: 3.0: 2.0] (of the 8 points score), respectively of [G, L, S and C], respectively. Thus G, L, S and C at the rate [1.69, 1.45, 0.09 & 2.03] Mgfed^{-1}, was very effective. Fig. 3C indicates that the center point of the tetrahedron has an EC 5.84 dSm^{-1} corresponding to the treatment of [2: 2: 2: 2].The pattern of each of the soluble cations [i.e. Na^+, K^+, Ca^{++} and Mg^{++}] and soluble anions [i.e. Cl^-, $HCO_3^=$ and $SO_4^=$] was similar to that of EC.

Fig. 3 shows the optimum combination for decreasing EC as well as SAR is a mixture of G, L, S and C at the rate of [1.0: 2.0: 3.0: 2.0] (of the 8 points score), respectively. This is treatment of [1.69, 1.45, 0.09 and 2.03] Mg/fed, respectively.

Soil pH and ESP

Regarding to soil pH after harvesting data of Table 4 and Fig. 4 show that soil pH was decreased by the different combinations of G, L, S and C. Fig. 4A shows a pH value 7.70 as regarding an interpolated four combined treatments consisting of [0: 0: 8: 0] (of the 8 points score) of [G, L, S and C], respectively, while Fig. 4B shows a value of 7.84 as the minimum one. Fig. 4C shows that the center point of the tetrahedron has a pH 7.92 for the treatment of [2: 2: 2: 2]. Fig. 4 shows the optimum combination for decreasing pH was obtained by a mixture of G, L, S and C at the ratio of [0: 0: 8: 0] (of the 8 points score) of [G, L, S and C], respectively. This shows a marked effect of applying sulfuric acid at a rate of 0.25 Mgfed^{-1}. The general mean of pH decreased from 8.40 to 7.99 to 7.70 at the end of the leaching process followed by halophyte planting.

Regarding ESP after harvesting, data of Table 4 and Fig. 5 show that ESP was affected by application of amendments. Scanning the different values of Fig. 5A show that ESP 8.80 as the minimum one as interpolated for the treatment of [5: 3: 0: 0] (of the 8 points score) of [G, L, S and C], respectively, while Fig. 5B shows that ESP 9.10 as the minimum one. Fig. 5C indicates that the center point of the tetrahedron has an ESP of 9.70 corresponding to treatment of [2: 2: 2: 2]. Fig. 5

Table 4. Some soil chemical and physical indicators at the end of both, leaching process and harvesting of halophyte plant as affected by different combination gypsum, lime stone, sulfuric acid and organic compost

Treatments				At the end of leaching process				After harvesting					
X1	X2	X3	X4	EC dSm^{-1}	pH	SAR	ESP	EC dSm^{-1}	pH	SAR	ESP	BD	% P
8	0	0	0	15.67	8.07	9.56	20.43	12.07	8.01	8.39	9.44	1.29	51.20
0	8	0	0	16.77	8.02	9.89	22.16	13.14	7.84	8.76	10.85	1.30	51.07
0	0	8	0	16.43	8.01	9.79	21.33	12.75	7.70	8.63	9.97	1.27	51.90
0	0	0	8	14.93	7.99	9.33	19.75	11.18	7.85	8.08	9.92	1.26	52.46
2	2	2	2	14.13	8.12	9.08	19.22	10.40	7.92	7.79	9.67	1.29	51.27
4	4	0	0	13.47	8.14	8.86	18.86	9.69	7.96	7.52	8.89	1.25	52.83
4	0	4	0	12.53	8.26	8.55	17.86	8.93	8.01	7.22	8.87	1.28	51.81
4	0	0	4	11.07	8.29	8.03	17.36	7.29	7.89	6.52	9.80	1.27	52.04
0	4	4	0	11.00	8.30	8.01	17.67	7.15	7.97	6.46	11.44	1.30	50.93
0	4	0	4	10.53	8.33	7.84	16.94	6.94	8.04	6.36	11.08	1.27	52.05
0	0	4	4	9.93	8.12	7.61	16.52	6.12	7.98	5.97	9.99	1.28	51.76
5	1	1	1	7.43	8.02	6.58	13.49	3.64	7.83	4.60	9.12	1.25	52.66
1	5	1	1	8.33	8.10	6.97	15.81	4.76	7.91	5.27	11.21	1.25	52.66
1	1	5	1	7.07	8.07	6.42	13.08	3.37	7.95	4.44	10.04	1.30	50.76
1	1	1	5	7.73	8.07	6.72	14.01	4.14	7.88	4.91	9.81	1.26	52.55
2.5	2.5	2.5	0.5	7.27	8.08	6.51	14.22	3.60	7.98	4.58	8.86	1.26	52.27
2.5	2.5	0.5	2.5	8.83	8.11	7.18	16.02	5.31	7.85	5.56	9.27	1.25	52.88
2.5	0.5	2.5	2.5	7.22	8.12	6.49	12.46	3.33	7.90	4.41	9.42	1.26	52.62
0.5	2.5	2.5	2.5	7.73	8.12	6.72	15.60	4.24	7.97	4.97	9.43	1.27	52.09
Correlation coefficient with EC					-0.11	0.99	0.97						
Correlation coefficient with EC									0.23	0.99	0.12		
Correlation coefficient with BD													-0.98

Notes: X1: Gypsum, X2: Lime-stone, X3: Sulfuric Acid and X4: Compost

Table 5. Optimal combination for the different soil character (of the 8 point score and Mgfed^{-1}) from gypsum, limestone, sulfuric acid and compost

Soil property	Initial value	Optimum combination [After leaching process]			Optimum combination [After harvesting]		
		Ratios [X1:X2:X3:X4]	Mg fed^{-1} [X1:X2:X3:X4]	Value	Ratios X1:X2:X3:X4]	Mg fed^{-1} [X1:X2:X3:X4]	Value
EC [dSm^{-1}]	28.80	[1:2:3:2]	1.69:1.45:0.09:2.03	5.80	[1:2:3:2]	1.69:1.45:0.09:2.03	2.10
pH	8.40	[0:0:0:8]	0.00:0.00:0.00:8.12	7.99	[0:0:8:0]	0.00:0.00:0.25:0.00	7.70
SAR	12.99	[1:1:4:2]	1.69:0.73:0.13:2.03	6.05	[1:2:3:2]	1.69:1.45:0.09:2.03	4.06
ESP	38.01	[2:1:3:2]	3.38:0.73:0.09:2.03	12.4	[5:3:0:0]	8.44:2.18:0.00:0.00	8.80
B.D [Mgm^{-3}]	1.65	———— Not Determined ————			[3:3:1:1]	5.06:2.18:0.03:1.02	1.24
Recommended combination		[1:1:2.5:3.5]	1.70:0.73:0.08:3.60		[2:2:3:1]	3.38:1.45:0.09:1.02	

Notes: B.D: Bulk Density, X1: Gypsum, X2: Limestone, X3: Sulfuric Acid and X4: Compost.

```
NUMBER  OF TREATMENTS  = 19; NUMBER OF REPLICATES = 3
              EXPRIMENTAL DATA AND (MEAN)

  1.15.66  15.62  15.72  (15.67)        2.16.84  16.87  16.59  (16.77)
  3.16.41  16.36  16.53  (16.43)        4.14.95  14.94  14.90  (14.93)
  5.14.08  14.12  14.19  (14.13)        6.13.55  13.44  13.41  (13.47)
  7.12.52  12.41  12.66  (12.53)        8.11.10  11.08  11.03  (11.07)
  9.11.07  11.00  10.93  (11.00)       10.10.51  10.51  10.58  (10.53)
 11.9.91   9.97   9.92    (9.93)       12.7.49   7.52   7.29   ( 7.43 )
 13.8.38   8.59   8.03    (8.33)       14.7.08   7.08   7.04   ( 7.07 )
 15.7.66   7.74   7.79    (7.73)       16.7.27   7.30   7.23   ( 7.27 )
 17.8.81   8.94   8.75    (8.83)       18.7.35   7.23   7.08   ( 7.22 )
 19.7.74   7.69   7.77    (7.73)

GENERAL MEAN  = 10.9514  MEAN ERROR    = 4.820766E-02
CORRELATION COEFFICIENT = 0.9997072
KERETRION FISHER  F( 18 38 ) = 3332.657

REALITY ADEQUATE TEST OF THE MODEL THROUGH THE LAST
FOUR TREATMENTS
-----------------------------------------------------------------
   EXPRIMENTAL TREAT. - TABULAR       DIFFERENCE       KER.STUDENT
 16          7.27 -  7.08 =              0.18              3.18
 17          8.83 -  6.96 =              1.88             32.47
 18          7.22 -  6.30 =              0.92             15.98
 19          7.73 -  5.87 =              1.87             32.27
=================================================================

 THE SIGNIFICANT ADEQUATE SECTOR OF THE SQUARE TEST FOR
        THE CALCULATED VALUE, MULTIPLY BY  10
-----------------------------------------------------------------

  TETRAHYDRON WITH          X-minimum = 0 ;      X-maximum = 1
                               X1
X4                                                            X4
 149 132 119 112 111 114 123 137 157 137 123 124 111 112 119 132 149
   128 115 107 104 107 115 128 146 142 124 111 104 101 104 112 126
      114 105 101 103 109 121 139 132 132 115 104  97  96 100 110
        106 102 102 108 119 135 125 122 127 111 100  95  96 101
           105 105 109 119 135 122 116 117 125 111 102  98  99
              111 115 124 138 122 113 111 116 128 115 107 105
                 123 131 144 125 114 109 111 120 136 124 117
                    142 154 132 117 110 109 115 128 148 137
         X2    168 143 125 114 110 113 123 140 164      X3    Fig. (1A)
                         142 120 106  98  97 104 117 137
                            123 105  93  89  91 101 117
                               111  96  87  58  92 105
                                  105  93  88  90  99
                                    106  98  96 101
                                      114 108 110
                                        128 126
                                          149
                                          X4

TETRAHYDRON WITH          X-minimum = .125      X-maximum = .625
                             X1
          X4                                    X4
                    77  69  65  67  74  67  65  69  77
                      69  64  65  71  67  61  60  65
                        67  67  72  64  64  59  60
                          72  76  65  62  65  62
                 X2     83  70  63  63  71     X3    Fig. (1B)
                             72  61  58  62
                               67  60  60
                                 69  65
                                   77
                                   X4
TETRAHYDRON WITH          X-minimum = .25 ;     X-maximum = .25
                                   X1
                                 X4  X4
                                   148                Fig. (1C)
                                 X2  X3
                                   X4
MINIMUM VALUE        YR = 5.80
OPTIMUM COMBINATION:  (1.0: 2.0: 3.0: 2.0)
```

Fig. 1. Computer output of EC [dSm-1] at the end of leaching process as affected by different combination gypsum, limestone, sulfuric acid and organic compost

```
NUMBER  OF TREATMENTS  = 19; NUMBER OF REPLICATES = 3
              EXPRIMENTAL DATA AND (MEAN)

    1.8.02   8.06   8.12  (8.07)          2.7.97   8.00   8.09  (8.02)
    3.7.97   8.00   8.07  (8.01)          4.7.96   7.96   8.04  (7.99)
    5.8.12   8.13   8.12  (8.12)          6.8.16   8.16   8.11  (8.14)
    7.8.22   8.25   8.32  (8.26)          8.8.24   8.27   8.36  (8.29)
    9.8.26   8.28   8.37  (8.30)         10.8.29   8.30   8.39  (8.33)
   11.8.06   8.15   8.15  (8.12)         12.7.97   8.00   8.09  (8.02)
   13.8.00   8.10   8.19  (8.10)         14.8.04   8.05   8.11  (8.07)
   15.8.02   8.09   8.10  (8.07)         16.8.02   8.07   8.14  (8.08)
   17.8.07   8.10   8.16  (8.11)         18.8.09   8.14   8.12  (8.12)
   19.8.08   8.12   8.17  (8.12)

GENERAL MEAN  = 8.122982  MEAN ERROR = 2.476396E-[illegible]
CORRELATION COEFFICIENT= 0.9175124
KERETRION FISHER  F( 18 38 )= 11.2359

REALITY ADEQUATE TEST OF THE MODEL THROUGH THE LAST
FOUR TREATMENTS
-----------------------------------------------------------------
   EXPRIMENTAL TREAT. - TABULAR       DIFFERENCE       KER.STUDENT
 16          8.08 -  8.20 =             -0.12             -4.00
 17          8.11 -  8.21 =             -0.10             -3.44
 18          8.12 -  8.18 =             -0.07             -2.26
 19          8.12 -  8.23 =             -0.10             -3.52
=================================================================

 THE SIGNIFICANT ADEQUATE SECTOR OF THE SQUARE TEST FOR
        THE CALCULATED VALUE, MULTIPLY BY  100
-----------------------------------------------------------------

  TETRAHYDRON WITH          X-minimum = 0 ;      X-maximum = 1
                               X1
X4                                                            X4
 799 811 820 826 829 828 824 817 807 817 824 828 829 826 820 811 799
   813 823 829 832 831 828 821 810 816 824 829 831 829 824 816 804
      824 830 833 833 830 823 813 819 822 828 831 830 826 819 808
        830 834 834 831 824 814 822 825 826 829 830 827 820 811
           833 833 830 824 814 823 827 829 826 828 826 821 812
              831 828 822 813 823 828 831 829 824 823 819 812
                 825 820 811 821 828 831 831 827 819 816 810
                    816 807 818 826 831 831 828 822 812 806
         X2    802 814 823 829 830 828 823 814 801      X3    Fig. (2A)
                         816 825 831 833 832 827 818 806
                            825 832 835 834 829 821 810
                               831 834 834 830 823 812
                                  833 833 830 823 812
                                    830 827 821 811
                                      824 818 808
                                        813 804
                                          799
                                          X4

TETRAHYDRON WITH          X-minimum = .125    X-maximum = .625
                                X1
           X4                                   X4
               807 811 811 808 802 808 811 811 807
                 814 814 812 806 807 811 812 809
                   816 814 808 811 810 812 810
                     815 810 813 813 810 809
              X2     810 814 815 813 807     X3    Fig. (2B)
                       815 817 815 809
                         816 815 810
                           814 809
                             807
                             X4
TETRAHYDRON WITH          X-minimum = .25 ;      X-maximum = .25
                                X1
                              X4  X4
                                812                 Fig. (2C)
                              X2  X3
                                X4
MINIMUM VALUE        YR = 7.99
OPTIMUM COMBINATION:  (0: 0: 0: 8)
```

Fig. 2. Computer output of pH at the end of leaching process as affected by different combination gypsum, limestone, sulfuric acid and organic compost

```
NUMBER  OF TREATMENTS  = 19; NUMBER OF REPLICATES = 3
              EXPRIMENTAL DATA AND (MEAN)

   1.12.11  12.11  11.99 (12.07)        2.13.18  13.15  13.10 (13.14)
   3.12.77  12.77  12.72 (12.75)        4.11.17  11.25  11.13 (11.18)
   5.10.49  10.34  10.38 (10.40)        6.9.73   9.73   9.61   ( 9.69)
   7.8.93   8.94   8.93   ( 8.93)       8.7.35   7.34   7.18   ( 7.29)
   9.7.16   7.15   7.14   ( 7.15)      10.6.95   6.95   6.93   ( 6.94)
  11.6.15   6.14   6.06   ( 6.12)      12.3.63   3.65   3.63   ( 3.64)
  13.4.76   4.75   4.76   ( 4.76)      14.3.37   3.39   3.37   ( 3.38 )
  15.4.17   4.17   4.08   ( 4.14)      16.3.64   3.66   3.52   ( 3.61)
  17.5.38   5.39   5.15   ( 5.31)      18.3.36   3.41   3.22   ( 3.33 )
  19.4.30   4.15   4.25   ( 4.23)

GENERAL MEAN  = 7.266492 MEAN ERROR = 2.987955E-01
CORRELATION COEFFICIENT= 0.9998784
KERETRION FISHER  F( 18 38 )= 8685.298

REALITY  ADEQUATE TEST  OF  THE  MODEL  THROUGH  THE  LAST
FOUR TREATMENTS
-----------------------------------------------------------
  EXPRIMENTAL TREAT. - TABULAR      DIFFERENCE     KER.STUDENT
 16          3.61 -  3.34 =            0.27            7.45
 17          5.31 -  3.26 =            2.04           56.96
 18          3.33 -  2.57 =            0.76           21.14
 19          4.23 -  2.19 =            2.05           57.12
===========================================================

THE SIGNIFICANT ADEQUATE SECTOR OF THE SQUARE TEST FOR
        THE CALCULATED VALUE, MULTIPLY BY   10
===========================================================

 TETRAHYDRON WITH           X-minimum = 0 ;      X-maximum = 1
                             X1
X4                                                          X4
     112  94  82  75  73  77  86 101 121 101  86  77  73  75  82  94 112
         91  78  69  67  69  77  90 109 106  87  74  66  63  66  75  88
             78  68  64  65  72  84 102  95  96  79  66  60  58  62  72
                 70  65  65  70  81  97  88  86  91  74  63  58  58  63
                     69  68  72  82  97  84  79  80  89  74  64  60  61
                         75  78  86 100  84  75  74  79  92  78  70  67
                             87  94 107  88  76  71  73  83 100  87  80
                                106 117  95  79  71  70  77  91 111 100
                    X2   131 106  87  76  72  75  85 103 128      X3    Fig. (3A)
                                    106  84  68  60  59  65  79 100
                                         87  68  56  51  53  63  80
                                             75  59  50  48  54  67
                                                 69  56  51  52  61
                                                     70  61  58  63
                                                         78  71  72
                                                             91  88
                                                               112
                             X4
 TETRAHYDRON WITH       X-minimum = .125   X-maximum = .625
                             X1
          X4                                    X4
                41  32  28  29  36  29  28  32  41
                    33  28  28  34  29  24  23  29
                        31  30  35  27  26  22  23
                            36  39  28  24  28  25
                  X2    48  33  26  26  34      X3    Fig. (3B)
                                36  25  21  25
                                    31  24  23
                                        33  29
                                            41
                             X4
TETRAHYDRON WITH            X-minimum = .25 ;      X-maximum = .25
                             X1
                           X4  X4
                            584                  Fig. (3C)
                           X2  X3
                             X4
MINIMUM VALUE      YR = 2.10
OPTIMUM COMBINATION:  (1: 2: 3: 2)
```

Fig. 3. Computer output of EC [dSm^{-1}] after harvesting of halophyte plant as affected by different combination gypsum, limestone, sulfuric acid and organic compost

```
NUMBER  OF TREATMENTS  = 19; NUMBER OF REPLICATES = 3
              EXPRIMENTAL DATA AND (MEAN)

   1. 7.99   8.00   8.03  (8.01)        2. 7.80   7.88   7.85  (7.84)
   3. 7.71   7.61   7.77  (7.70)        4. 7.80   7.85   7.90  (7.85)
   5. 7.92   7.90   7.95  (7.92)        6. 7.98   7.96   7.92  (7.95)
   7. 8.00   8.05   7.98  (8.01)        8. 7.97   7.93   7.77  (7.89)
   9. 7.92   8.00   7.98  (7.97)       10. 8.06   8.07   8.00  (8.04)
  11. 7.98   7.96   8.00  (7.98)       12. 7.76   7.87   7.87  (7.83)
  13. 7.84   7.98   7.92  (7.91)       14. 7.91   7.96   7.97  (7.95)
  15. 7.76   7.93   7.95  (7.88)       16. 7.99   7.96   8.00  (7.98)
  17. 7.85   7.78   7.93  (7.85)       18. 7.88   7.92   7.91  (7.90)
  19. 7.97   7.98   7.95  (7.97)

GENERAL MEAN  = 7.91807  MEAN ERROR    = 2.567601E-02
CORRELATION COEFFICIENT = 0.8726434
KERETRION FISHER  F( 18 38 ) = 6.740749

REALITY  ADEQUATE TEST  OF  THE  MODEL  THROUGH  THE  LAST
FOUR TREATMENTS
-----------------------------------------------------------
  EXPRIMENTAL TREAT. - TABULAR      DIFFERENCE     KER.STUDENT
 16          7.98 -  7.97 =           -0.01            0.37
 17          7.85 -  7.93 =           -0.07           -2.34
 18          7.90 -  7.95 =           -0.05           -1.53
 19          7.97 -  8.02 =           -0.05           -1.68
===========================================================

THE SIGNIFICANT ADEQUATE SECTOR OF THE SQUARE TEST FOR
THE CALCULATED VALUE, MULTIPLY BY   100
===========================================================

 TETRAHYDRON WITH           X-minimum = 0 ;      X-maximum = 1
                             X1
X4                                                          X4
 785 785 786 787 789 791 794 797 801 797 794 791 789 787 786 785 785
     794 793 793 793 794 796 798 800 804 801 798 796 794 793 792 792
         800 798 797 797 797 798 799 803 805 802 800 799 797 797 797
             803 801 799 798 797 797 802 804 804 802 800 799 799 799
                 804 801 799 797 795 800 803 803 801 800 799 798 798
                     803 799 796 793 799 802 802 800 796 795 795 795
                         799 795 791 796 800 801 800 796 789 789 789
                             793 788 794 798 799 798 795 789 780 781
                X2    784 791 795 797 797 794 788 780 770    X3    Fig. (4A)
                                 793 799 802 802 801 796 790 781
                                     799 804 806 805 802 797 789
                                         803 806 807 805 801 795
                                             804 806 806 803 798
                                                 803 804 803 799
                                                     800 799 797
                                                         794 792
                                                             785
                             X4
TETRAHYDRON WITH          X-minimum = .125      X-maximum = .625
                             X1
          X4                                     X4
             788 786 785 784 783 784 785 786 788
                 793 790 788 786 789 790 792 794
                     795 791 788 792 793 794 797
                         794 790 794 796 795 797
                X2    791 796 798 798 795     X3    Fig. (4B)
                             794 798 798 797
                                 795 797 797
                                     793 794
                                         788
                             X4
 TETRAHYDRON WITH         X-minimum = .25 ;      X-maximum = .25
                             X1
                           X4  X4
                            792                 Fig. ( 4C)
                           X2  X3
                             X4
MINIMUM VALUE         YR = 7.7
OPTIMUM COMBINATION:  (0: 0; 8: 0)
```

Fig. 4. Computer output of pH after harvesting of halophyte plant as affected by different combination gypsum, limestone, sulfuric acid and organic compost

```
                    NUMBER  OF TREATMENTS  = 19; NUMBER OF REPLICATES = 3
                              EXPRIMENTAL DATA AND (MEAN)

          1. 8.45   9.66  10.22   ( 9.44 )                       2. 11.47   9.82  11.27  ( 10.85)
          3. 10.29  10.41   9.20  ( 9.97 )                       4. 11.68   9.24   8.85  ( 9.92 )
          5. 9.67  10.14   9.21   ( 9.67 )                       6. 9.49   9.46   7.72   ( 8.89 )
          7. 9.04   9.46   8.09   ( 8.86 )                       8. 8.80  10.50  10.10  ( 9.80 )
          9. 11.54  10.37  12.41  ( 11.44)                      10. 11.78  10.87  10.58 ( 11.08)
         11. 10.99   8.77  10.22  ( 9.99 )                      12. 9.21   9.02   9.13   ( 9.12 )
         13. 11.72  11.28  10.62  ( 11.21)                      14. 9.49  10.47  10.17  ( 10.04)
         15. 9.50  10.37   9.56   ( 9.81 )                      16. 8.85   8.85   8.89   ( 8.86 )
         17. 9.51   9.79   8.51   ( 9.27 )                      18. 8.36  10.11   9.80   ( 9.42 )
         19. 8.96  10.14   9.19   ( 9.43 )

GENERAL MEAN = 9.846842  MEAN ERROR    = 0.3774801
CORRELATION COEFFICIENT = 0.7621138
KERETRION FISHER  F( 18 38 ) = 2.925146

REALITY ADEQUATE TEST OF THE MODEL THROUGH THE LAST FOUR TREATMENTS
--------------------------------------------------------------------------------------------------
                    EXPRIMENTAL TREATMENT - TABULAR       DIFFERENCE          KER.STUDENT
          16              8.86 -  9.90 =                    -1.04                -2.29
          17              9.27 -  9.99 -                    -0.72                -1.59
          18              9.42 -  9.53 =                    -0.11                -0.24
          19              9.43 - 10.84 =                    -1.41                -3.11
          ========================================================================

THE SIGNIFICANT ADEQUATE SECTOR OF THE SQUARE TEST FOR THE CALCULATED VALUE, MULTIPLY BY   100
==================================================================================================

                         TETRAHYDRON WITH          X-minimum = 0 ;       X-maximum = 1
                                                      X1
                 X4                                                                   X4
                      990 990 990 990 980 970 970 960 940 960 970 970 980 990 990 990 990
                        1030 1020 1010 990 970 950 930 910 910 930 940 960 970 980 990 990
                          1070 1040 1010 980 950 920 890 900 890 920 930 950 970 980 1000
                            1090 1050 1010 970 920 880 890 900 890 910 930 960 980 1000
                              1110 1060 1000 950 890 910 910 910 890 920 950 970 1000
                                1110 1050 980 910 940 950 940 930 900 930 970 1000
                                  1110 1040 960 980 1000 1000 980 960 920 960 1000
                                    1100 1010 1040 1060 1060 1060 1030 1000 950 1000
                          X2      1090 1120 1140 1150 1140 1130 1100 1050 1000     X3     Fig. (5A)
                                      1100 1130 1140 1140 1120 1090 1050 1000
                                        1110 1130 1130 1110 1090 1050 1000
                                          1110 1120 1110 1080 1050 1000
                                            1110 1100 1080 1050 1000
                                              1090 1070 1040 1000
                                                1070 1040 1000
                                                  1030 990
                                                     990
                                                      X4

                        TETRAHYDRON WITH          X-minimum = .125         X-maximum = .625
                                                      X1
                              X4                                       X4
                                  980 970 950 930 910 930 950 970 980
                                    1030 1000 970 940 920 940 970 990
                                      1070 1030 980 970 940 970 990
                                        1100 1040 1030 1000 970 1000
                                X2      1120 1110 1090 1050 1000     X3     Fig. (5B)
                                          1100 1080 1050 1000
                                            1070 1040 990
                                              1030 990
                                                 980
                                                  X4
                        TETRAHYDRON WITH          X-minimum = .25 ;        X-maximum = .25
                                                  X1
                                                X4  X4
                                                  970                      Fig. (5C)
                                                X2  X3
                                                  X4
MAXIMUM VALUE          YR = 8.80
OPTIMUM COMBINATION:  (5: 3: 0: 0)
```

Fig. 5. Computer output of ESP after harvesting of halophyte plant as affected by different combination gypsum, limestone, sulfuric acid and organic compost

```
NUMBER  OF TREATMENTS  = 19; NUMBER OF REPLICATES = 3
              EXPRIMENTAL DATA AND (MEAN)

  1. 1.29  1.28  1.31 (1.29)          2. 1.29  1.26  1.34 (1.30)
  3. 1.25  1.27  1.30 (1.27)          4. 1.28  1.24  1.25 (1.26)
  5. 1.28  1.29  1.30 (1.29)          6. 1.29  1.24  1.22 (1.25)
  7. 1.27  1.25  1.31 (1.28)          8. 1.25  1.32  1.24 (1.27)
  9. 1.30  1.31  1.30 (1.30)         10. 1.22  1.28  1.31 (1.27)
 11. 1.28  1.30  1.25 (1.28)         12. 1.25  1.26  1.25 (1.25)
 13. 1.29  1.24  1.24 (1.26)         14. 1.25  1.32  1.35 (1.31)
 15. 1.21  1.28  1.27 (1.25)         16. 1.33  1.22  1.25 (1.27)
 17. 1.21  1.25  1.28 (1.25)         18. 1.28  1.25  1.24 (1.26)
 19. 1.30  1.27  1.25 (1.27)

GENERAL MEAN  = 16.99754 MEAN ERROR = 0.4964015
CORRELATION COEFFICIENT= 0.954936
KERETRION FISHER  F( 18 38 )= 21.85232

REALITY ADEQUATE TEST OF THE MODEL THROUGH THE LAST
FOUR TREATMENTS
--------------------------------------------------------------
    EXPRIMENTAL TREAT. - TABULAR    DIFFERENCE     KERSTUDENT
 16         1.27 -  1.27 =            -0.00          -0.04
 17         1.25 -  1.25 =             0.00           0.02
 18         1.26 -  1.27 =            -0.01          -0.72
 19         1.27 -  1.28 =            -0.00          -0.20
==============================================================

THE SIGNIFICANT ADEQUATE SECTOR OF THE SQUARE TEST FOR
THE CALCULATED VALUE, MULTIPLY BY   100
==============================================================

  TETRAHYDRON WITH         X-minimum = 0 ;      X-maximum = 1
                            X1
 X4                                                        X4
   126 126 126 127 127 127 128 129 129 129 128 127 127 127 126 126 126
     126 126 126 126 126 127 127 127 129 128 128 127 127 127 127 126
       126 126 126 126 126 126 126 127 128 128 128 127 127 127 127
         127 126 126 126 125 125 126 127 128 128 128 127 127 127
           127 126 126 125 125 126 127 127 128 128 128 128 128
             128 127 126 125 126 127 127 127 127 128 128 128
               128 127 126 127 128 128 128 128 127 128 128
                 129 128 128 129 129 129 129 128 127 128
         X2        130 130 130 131 130 130 129 128 127    X3    Fig. (6A)
                     129 129 130 130 130 129 129 128
                       128 129 129 129 129 128 128
                         128 128 128 128 128 128
                           127 128 128 128 128
                             127 127 127 127
                               126 127 127
                                 126 126
                                   126
                                   X4
 TETRAHYDRON WITH          X-minimum = .125      X-maximum = .625
                            X1
         X4                                  X4
            125 125 125 125 125 125 125 125 125
              125 125 125 125 127 127 127 127
                125 125 124 126 128 128 128
                  125 125 126 128 129 130
            X2      126 127 129 130 131      X3    Fig. (6B)
                      125 127 128 130
                        125 127 128
                          125 127
                            125
                            X4
 TETRAHYDRON WITH          X-minimum = .25 ;     X-maximum = .25
                            X1
                          X4  X4
                           129                Fig. (6C)
                          X2  X3
                            X4
MINIMUM VALUE        YR = 1.24
OPTIMUM COMBINATION:  (3: 3: 1: 1)
```

Fig. 6. Computer output of bulk density after harvesting of halophyte plant as affected by different combination gypsum, limestone, sulfuric acid and organic compost

```
NUMBER  OF TREATMENTS  = 19; NUMBER OF REPLICATES = 3
              EXPRIMENTAL DATA AND (MEAN)

  1. 51.43  51.53  50.65 (51.20)      2. 51.43  52.43  49.36 (51.07)
  3. 52.66  51.94  51.11 (51.90)      4. 51.56  53.15  52.66 (52.46)
  5. 51.60  51.26  50.95 (51.27)      6. 51.44  53.07  53.97 (52.83)
  7. 51.96  53.00  50.46 (51.81)      8. 52.75  50.01  53.35 (52.04)
  9. 50.96  50.71  51.11 (50.93)     10. 53.86  51.60  50.69 (52.05)
 11. 51.73  50.91  52.65 (51.76)     12. 52.97  52.36  52.66 (52.66)
 13. 51.42  53.23  53.32 (52.66)     14. 52.97  50.24  49.07 (50.76)
 15. 54.18  51.56  51.90 (52.55)     16. 49.86  54.04  52.90 (52.27)
 17. 54.34  52.65  51.65 (52.88)     18. 51.59  52.88  53.38 (52.62)
 19. 51.07  52.25  52.94 (52.09)

GENERAL MEAN  = 51.98913  MEAN ERROR     = 0.5874369
CORRELATION COEFFICIENT = 0.540446
KERETRION FISHER  F( 18 38 ) = 0.8710291

REALITY ADEQUATE TEST OF THE MODEL THROUGH THE LAST
FOUR TREATMENTS
--------------------------------------------------------------
    EXPRIMENTAL TREAT. - TABULAR    DIFFERENCE     KERSTUDENT
 16         52.27 -  52.23 =           0.04           0.05
 17         52.88 -  52.94 =          -0.06          -0.09
 18         52.62 -  52.04 =           0.58           0.82
 19         52.09 -  51.84 =           0.25           0.35
==============================================================

THE SIGNIFICANT ADEQUATE SECTOR OF THE SQUARE TEST FOR
THE CALCULATED VALUE, MULTIPLY BY   10
==============================================================

  TETRAHYDRON WITH         X-minimum = 0 ;      X-maximum = 1
                            X1
 X4                                                        X4
   525 524 523 522 520 519 517 515 512 515 517 519 520 522 523 524 525
     524 524 524 524 523 522 521 519 514 516 518 519 520 521 522 522
       523 524 525 525 525 525 524 520 516 517 518 519 520 520 520
         522 524 525 526 527 527 523 520 517 518 518 519 519 519
           521 523 525 527 528 525 522 520 518 518 518 518 518
             519 522 524 527 524 522 520 519 519 519 518 517
               516 520 524 521 519 518 518 518 519 518 517
                 514 518 516 515 514 515 515 517 519 518
         X2        511 509 509 509 509 511 513 516 519    X3    Fig. (7A)
                     514 512 511 511 512 513 515 518
                       516 515 514 514 514 515 517
                         519 517 516 516 516 517
                           521 519 518 517 518
                             522 520 519 519
                               523 521 520
                                 524 522
                                   525
                                   X4
 TETRAHYDRON WITH          X-minimum = .125      X-maximum = .625
                            X1
         X4                                  X4
            525 526 527 527 527 527 527 526 525
              526 528 529 530 522 522 521 520
                527 529 531 524 518 517 515
                  527 530 523 518 513 511
            X2      527 521 516 511 508      X3    Fig. (7B)
                      527 521 516 511
                        527 521 515
                          526 520
                            525
                            X4
 TETRAHYDRON WITH          X-minimum = .25 ;     X-maximum = .25
                            X1
                          X4  X4
                           513                Fig. (7C)
                          X2  X3
                            X4
MAXIMUM VALUE        YR = 52.88
OPTIMUM COMBINATION:  (2.5: 2.5: 0.5: 2.5)
```

Fig. 7. Computer output of soil porosity [%] after harvesting of halophyte plant as affected by different combination gypsum, limestone, sulfuric acid and organic compost

shows the optimum combination for decreasing ESP was obtained by a rate the treatment of [5: 3: 0: 0] (of the 8 points score) [G, L, S and C], respectively. This reflects the marked affect of the [8.44, 2.18, 0.00 & 0.00] $Mgfed^{-1}$, respectively. The general mean of ESP decreased from 38.01 to 12.40 to 8.80 from at the end of leaching process and after harvest, respectively.

Bulk density and porosity

Regarding bulk density "BD" and soil porosity "P" after harvesting data of Table 4 and Figs 6 and 7 shows a marked effect due to application of amendments. The optimum combination for decreasing BD and increasing P occurred with the mixture of G, L, S and C at the ratio of [3: 3: 1: 1], as well as [2.5, 2.5, 0.5, 2.5] (of the 8 points score), respectively.

CONCLUSION

It could be concluded that treating the saline soil with combination of gypsum, sulfuric acid, lime-stone, and organic compost followed by growing the halophyte plant *A. halimus* decreased EC, pH, SAR, ESP. Scanning the results illustrated in Table 5 show that the halophyte plant increased the effect of amendments. However no one combination was most effective for all soil properties. To improve a specific character, it is easy to apply a mixture of gypsum, lime-stone, sulfuric acid and compost. The recommended combination to improve Sahl El-Tina saline sodic at the end of leaching process could be 1.0, 1.0, 2.5, and 3.5 (of the 8 points score) G, L, S and C, respectively i.e. the rate of 1.7, 0.73, 0.08, 3.6 Mg.fed-1 respectively. The recommended combination after harvesting of halophyte plant could be 2.0, 2.0, 3.0, 1.0 (of the 8 points score) i.e. 3.38, 1.45, 0.09 & 1.02 $Mgfed^{-1}$, respectively.

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الاستخدام الأمثل لتوليفات محسنات التربة لاستصلاح وإعادة تأهيل الأراضي المتأثرة بالأملاح

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أقيمت تجربة لتحديد التوليفة المثلي من الجبس والحجر الجيري وحامض الكبريتيك والكمبوست لاستصلاح الأراضي المتأثرة بالأملاح. وأجريت عملية الاستصلاح علي مرحلتين حيث تم إمرار ٣٠ سم من الماء خلال عمود التربة وبعد الانتهاء تم زراعة نبات هالوفيت (*Atriplex halimus*) في كل عمود تربة مع إجراء عملية ري فقط دون نفاذ ماء من العمود. بعد الانتهاء من التجربة أدخلت النتائج إلي موديل الحاسب الآلي رباعي العوامل لتحديد التوليفة المثلي التي أدت إلي تحسين الصفات الكيميائية (**EC, pH, SAR, ESP**) والطبيعية (**Bulk density and porosity**). أوضحت النتائج ما يلي:

كل التوليفات من الجبس الزراعي والحجر الجيري وحامض الكبريتيك والكمبوست أدت إلي انخفاض **EC, pH, SAR, ESP** كما يمكن ملاحظة أن نبات القطف (*A. halimus*) أدي إلي زيادة فعالية محسنات التربة المضافة.

التوليفة المثلي التي أدت إلي خفض درجة التوصيل الكهربي من ٢٨,٨ إلي ٥,٨ ديسيسيمنز / م من الجبس، الحجر الجيري، حامض الكبريتيك والكمبوست بعد انتهاء عملية الغسيل هي ١,٦٩، ١,٤٥، ٠,٠٩، ٢,٠٣ طن / فدان علي الترتيب وهي نفس التوليفة التي أظهرت انخفاض ملحوظ بعد حصاد نبات القطف حيث خفضت درجة التوصيل الكهربي من ٥,٨ إلي ٢,١ ديسيسيمنز / م. بينما التوليفة المثلي التي أدت إلي خفض حموضة التربة من ٨,٤ إلي ٧,٩٩ بعد انتهاء عملية الغسيل هي صفر، صفر، صفر، ٨,١٢ طن / فدان علي الترتيب بينما التوليفة التي أظهرت انخفاض ملحوظ في حموضة التربة بعد حصاد نبات القطف هي صفر، صفر، ٠,٢٥، صفر طن / فدان حيث خفضت درجة تفاعل التربة من ٨,١ إلي ٧,٧.

التوليفة المثلي التي أدت إلي خفض SAR من ١٢,٩٠ إلي ٦,٠٥ من الجبس، الحجر الجيري، حامض الكبريتيك والكمبوست بعد انتهاء عمليـــة الغســـيل هـــي ١,٦٩، ٠,٧٣، ٠,١٣، ٢,٠٣ طن / فدان علي الترتيب بينما التوليفة التي أظهرت انخفاض ملحـــوظ فـــي SAR بعد حصاد نبات القطف هي ١,٦٩، ١,٤٥، ٠,٠٩، ٢,٠٣ طن / فدان حيث خفضت SRA إلي ٤,٠٦. بينما التوليفة المثلي التي أدت إلي خفض حموضة التربة من ٨,٤ إلي ٧,٩٩ بعد انتهاء عملية الغسيل هي صفر، صفر، صفر، ٨,١٢ طن / فدان علي الترتيـــب بينما التوليفة التي أظهرت انخفاض ملحوظ في حموضة التربة بعد حصاد نبات القطف هي صفر، صفر، ٠,٢٥، صفر طن / فدان حيث خفضت درجة تفاعل التربة من ٨,١ إلي ٧,٧. بينما التوليفة المثلي التي أدت إلي خفض ESP بعد انتهاء عمليـــة الغســـيل هـــي ٣,٣٨، ٠,٧٣، ٠,٠٩، ٢,٠٣ طن / فدان علي الترتيب حيث خفضـــت ESP مـــن ٣٨,٠١ إلـــي ١٢,٤ بينما التوليفة التي أظهرت انخفاض ملحوظ في ESP بعد حصاد نبات القطف هـــي ٨,٤٤، ٢,١٨، صفر، صفر طن / فدان حيث خفضت ESP إلي ٨,٨٠.