The Movement of Salts in Saline-Sodic Soils Leached by Enriched Water with Combinations of Phosphogypsum and Humic Acids

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Abstract. A laboratory experiment was conducted on saline-sodic soil taken from the 0-30 cm surface layer of clay loam from the farm of a college of agriculture/Anbar university. Sixteen combinations of humic acids (HA1, HA2, HA3, HA4) and phosphogypsum (G1, G2, G3, and G4) at a concentration of 0.5, 1.0, 1.5, and 2.0 gm l⁻¹ for both were used. In addition to two treatments for comparison, commercial clean salt (CS) and Euphrates water. Eighteen polyethylene columns were used, with a length of 60 cm and an inner diameter of 7.1 cm. After the columns were filled with the soil, the columns were washed with enriched water with combinations of humic acids and phosphogypsum. The combinations were mixed with Euphrates water. Washing of column continued until three porous volumes had passed. The results showed that the value of accumulation salts (gm l⁻¹) and the concentrations of sodium, calcium, and magnesium (mmol l⁻¹) increased with the increase in pore volume passing through. The movement of salts and sodium concentrations increased with the increase of phosphogypsum with the increase in the level of humic acid in combination, as the highest value of salts and washed sodium reached 4921.98 gm l⁻¹ and 38794.53 mmol l⁻¹ respectively, in HA4G4 combination, compared to HA1G1, which reached 2436.64 gm l⁻¹ and 20596.27 mmol l⁻¹ respectively. While the calcium and magnesium concentrations increased with the increase of phosphate gypsum and decreased with the increase in the level of humic acid in combination. The combination AH1G4 gave the highest concentrations of 10158.04 and 3577.27 (mmol l⁻¹), compared to HA4G4, which reached 6867.60 gm l⁻¹ and 2473.01 mmol l⁻¹, respectively. The water washing treatments and the salinity treatment (CS) gave the lowest amount of salts and concentrations of sodium, calcium, and magnesium compared to all combinations. The diffusion equation is the best for describing the kinetics of the release of the sodium adsorption rate in the soil over time, as it gave the highest rate of determination coefficient (R²) (which was 0.985 and the lowest standard error) (SEE), which reached 55.439. With an increase in the level of addition of humic acids.

1. Introduction

Salinity and soda are among the main problems facing agriculture. As it affects the chemical, which leads to the effect of soil structure and thus the permeability of the soil to water decreases, as well as its aeration through the high percentage of exchanged sodium percentage on the surfaces of the exchange of clay particles. The area of soil affected by salinity varies, generally, the proportion of salt-affected land in the world is about 7%, and in Iraq, it exceeds 50% of the arable land area [1] Traditional salinity treatment methods such as surface washing of salts, skimming the surface of the soil, and washing with water only do not work, due to the expansion of the land affected by salinity as well as the high treatment cost as well as the time and effort and the use of large quantities of water as well as efficient septic facilities. In recent times, many salinity treatment compounds have appeared, including chemical and organic, and with multiple brand names, and competition for them has become great among the manufacturers due to the positive effect they add in reducing the effect of salts on the soil, improving the chemical properties of the soil and reducing the exchangeable sodium percentage [2]; [3] Recent
studies have resorted to the use of some chemical and organic materials and compounds to study their effect in reducing salts from the salt of the soil by a chemical process such as ion exchange (displacement and substitution), and among these compounds are Phosphogypsum and humic acids have been used by adding them directly to the soil and gave good results [4]. This is done by reducing the percentage of sodium adsorbed to saline soils when mixing washing water with humic acids [5]. Phosphogypsum is a good source of the calcium ion present in its composition (CaSO4.2H2O) [6]. When adding a mixture to the soil, the calcium displaces and replaces the monovalent sodium present on the exchange complex, which leads to a decrease in the rate of sodium exchange, although it leads to an increase in the electrical conductivity of the electrolyte solution and reduces the pH value through the presence of sulfates in its chemical composition. It is considered a good chemical reformer [7]; [8]. Humic acid are important compounds responsible for many chemical processes that occur in the soil, as they have a role in reducing the pH value of the soil. Also, they contain active groups such as hydroxyl and carboxyl, which have a role in facilitating the washing process of salts through the formation of complexes with mono-valiant and divalent positive salt ions [9]; [10]. As humic acids are complexes with monovalent that are easy to move the sodium ion. While are less mobile with calcium and magnesium ions [11]; [12]. This research aims to study the effect of different combinations of phosphate gypsum and humic acids on the movement and distribution of salts in the soil, in comparison with a commercial clean salt and water treatment.

2. Materials and Methods
A laboratory study was conducted on saline-sodic soil taken from the surface layer 0-30 cm from the farm of the college of agriculture, university of Anbar. Table 1 shows some chemical and physical properties of the soil, and Table 2 shows some chemical properties of phosphate gypsum and commercial clean salt treatment. In this study, 18 columns of solid polyethylene with a length of 0.6 M and an inner diameter of 0.71M were sed. Under each column, a perforated plastic cover was installed and a glass wool filter was placed above the cover with a layer of fine washed gravel 5 cm high. The columns were filled with air-dried soil and sifted with a sieve with a diameter of 0.002 M. The soil height in the column became 30 cm and its mass reached 1600 gm inside the columns to maintain an apparent density similar to the apparent density of field soil, which amounted to 1340 Mg M-3. All columns were placed in a plastic pool containing distilled water and the soil was moistened with capillary action to maintain the homogeneity of the moisture content throughout the column. The columns were fixed on a wooden table with a height of 0.8 M then the table was punched from the top and the bottom with 18 holes equal to the number of columns and the diameter of one hole was 0.70 M, the same as the diameter of the pipe to facilitate the carrying of the tubes. Four levels of phosphogypsum (G1, G2, G3, and G4) were added to four levels of (powder of humic acid) (HA1, HA2, HA3, and HA4) which are 0.5, 1.0, 1.5, and 2.0 gm l-1 for both amendments, mixed in river water and in the form of combinations to become 16 combinations, in addition to two treatments for comparison, which are a commercial clean salt 1.28 gm l-1 (10 L H-1) [4] and river water (W) to make all 18 treatments. The soil of the columns was washed with the water of the aforementioned blends, as the method of continuous washing was used by pouring a fixed water column at a height of 0.15 above the surface of the soil. Fixed the water column over the soil surface and evenly (15 cm deep) for all columns. The washing filtrates were collected from each column separately and according to the volume of the washed filtrate daily and for each column. The washing process continued until the electrical conductivity of the washing filtrates was reached in the range of 4-10 dS m-1. With these values of electrical conductivity for washing filters up to 4-10 dS m-1. With these values of electrical conductivity, the volume of leaching filtrate passing through the soil column (pore volume) for all columns was three times the size of the soil pores inside the column. The electrical conductivity and the concentration of cationic dissolved ions (Ca2+, Mg2+, Na+) were estimated in the filtered water, according to the following:
1. The amount of total dissolved salts (TDS) (gm l-1) in the filtered water using the following equation:
\[
\text{gm l}^{-1} = \text{EC} \times 0.640
\]  
(1)

2. Sodium adsorption ratio was calculated in the leachate, using the following equation:
\[
\text{SAR} = \frac{\text{Na}}{\sqrt{\text{Ca} + \text{Mg}}}
\]  
(2)

2.1. Kinetic equations used in the study:
To study the movement, salts release, and the sodium adsorption ratio in the filtrate with time, mathematical equations with experimental bases and others based on the foundations of kinetic chemistry were used, and referred to by[13;14] and these equations are:
1. Zero-order eq. \( C_t = C_0 - Kt \)  
(3)
2. 1st order equation eq. \( \ln C_t = \ln C_0 - Kt \)  
(4)
3. 2nd order eq. \( \frac{1}{C_t} = \frac{1}{C_0} + Kt \)  
(5)
4. Diffusion eq. \( C_t = C_0 - Kt^2 / 2 \)  
(6)
5. The Elovich equation. \( C_t = C_0 - K \int t \)  
(7)

It represents:
\( C_0 \) = the value of accumulation of sodium adsorption ratio in the leachate at time zero.
\( C_t \) = the value of accumulation of sodium adsorption ratio in the leachate at the specified time.
\( K \) = rate of sodium adsorption ratio release velocity.
The following indicators were adopted: Determination Factor (R2), the Standard Error of Estimate, and the Tabular T-test value (the variance between values) to determine the most efficient equation to describe the release of salt.

### Table (1) Some chemical and physical properties of soil

| EC (dSm
\[^{-1}\]) | pH | Na (mmol l
\[^{-1}\]) | Ca (mmol l
\[^{-1}\]) | Mg (mmol l
\[^{-1}\]) | K (mmol l
\[^{-1}\]) | O.M (gm kg
\[^{-1}\]) | CaCO3 (gm kg
\[^{-1}\]) |
|-------------|----|----------------|---------------|----------------|----------------|----------------|----------------|
| 143.5       | 7.78 | 882.36       | 213.86        | 44.25          | 2.20           | 2.33           | 230.14         |

| SAR | ESP (%) | CEC (Cmol kg
\[^{-1}\] soil) | Bulk density (Mg M
\[^{-3}\]) | Texture clay loam | sand | silt | Clay |
|-----|---------|----------------|----------------|----------------|------|------|------|
| 41.44 | 28.24 | 1340          | 418.00         | 283.00         | 299.00 |      |      |

### Table (2) Some chemical properties of phosphogypsum and clean salt

| EC (1:1) | pH (1:1) | Na (mmol l
\[^{-1}\]) | K (mmol l
\[^{-1}\]) | Clean Salt |
|---------|----------|----------------|----------------|------------|
| 3.89    | 5.6      | 65.13          | 111.04         | 2.11        |

### 3. Results and Discussion

3.1. The total amount of salts (gm l-1) released from soil washing columns with the pore volume.
Figure 1 shows the relationship between the values of accumulation of salts (gm l-1) released from soil wash columns under the influence of combinations of humic acids, phosphogypsum, water, and a clean salt with the pore volume. It is noticed from the figure that the value of the accumulation amount of the
salts increased by increasing the pore size and for all combinations in addition to washing with water and with a clean salt. It is also noticed that the value of accumulations value amount salts increased with the increase of phosphogypsum in addition to the increase in the level of addition of humic acids, as the highest amount of the value of accumulation salts reached 4921.98 (gm l⁻¹) in the pore volume 3 when washing with HA4G4 combination compared to HA1G1 washing mixture, which reached 2436.86 (gm l⁻¹) while washing with water (W) and with a clean salt (CS) gave the lowest amount of liberated salts compared to the rest of the wash combinations when they reached 1883.93 and 2132.16 (gm l⁻¹) respectively. The reason for the increase in the value of accumulation of salts released with the increase in the concentration of phosphogypsum is attributed to calcium and sulfate ions resulting from dissolving phosphogypsum, which leads to an increase in the concentration of ions in the solution and then moves them down with the filtrate released from the washing columns, which leads to an increase in the electrolytic conductivity [4]. As for the reason for the increase in the liberated salts with the increase in the concentration of humic acids, it is due to the role of humic acids in the chelation of dissolved ions in the soil solution and the formation of organic complexes because it contains active groups such as carboxyl (COOH⁻) and hydroxyl (OH⁻) that control the electro chemical behavior of humic acids that It is considered one of the reactions such as adsorption and cation exchange reactions through chelation and complexity of ions and reducing their effect on the soil [15];[16]. The phenol groups also work to break down the salts and facilitate their movement and wash them down with the washing water, which affects the concentration of ions in the soil solution, which in turn affects the value of the accumulation of salts [9];[10]. These results are consistent with the findings of [4];[5] who indicated that the amount of salts released from soil columns increases with the addition of humic acids mixed with the soil.

Figure 1. Effect of a combination of humic acids & phosphogypsum, water and clean salt in salt accumulative release.
3.2. Calcium accumulation released (mmol l\(^{-1}\)) from leached soil columns with pore volume.

Figure 2 shows the relationship between the accumulated calcium concentrations (mmol l\(^{-1}\)) released from soil wash columns under the influence of combinations of humic acids, phosphogypsum, water, and clean salt with the pore volume. It was noticed that the calcium concentrations increased with the increase of phosphogypsum and decreased with the increase in the level of humic acid addition, 6867.60 (mmol l\(^{-1}\)). Whereas, washing with water (W) and with a clean salt (CS) gave the lowest concentrations of liberated calcium compared to the rest of the washing combinations, reaching 3896.57 and 4723.71 (mmol l\(^{-1}\)), respectively. The reason for the increase in the concentrations of calcium released with the increase in the concentration of phosphogypsum with the decrease in the level of addition of humic acids are because phosphogypsum is rich in calcium resulting from its dissolution, which leads to an increase in the concentration of calcium ion in the solution and then moves it down with the filtrate released from the washing columns [6]. These results are consistent [4]. The reason for the gradual decrease in the concentration of the liberated calcium when increasing the level of humic acids addition is because they contain active groups such as the carboxyl and hydroxyl groups that work on chelating, complexity, adsorption, and formation of organic complexes that are less mobile in the soil with calcium, which reduced the washing process outside the soil columns [9]. These results are consistent with [4]; [5] who indicated that the concentration of aggregate calcium released from washing soil columns decreases with increasing the level of humic acid addition.

![Figure 2](image-url)

Figure 2. Effect of a combination of humic acids & phosphogypsum, water and clean salt in Calcium accumulative release.
Magnesium accumulation released (mmol l⁻¹) from leached soil columns with pore volume. Figure 3 shows the relationship between the values of magnesium accumulation (mmol l⁻¹) released from washing soil columns under the influence of combinations of humic acids, phosphogypsum, water, and clean salt treatment with pore volume. It is noticed from the figure that the concentrations of magnesium released increased with the increase of the pore size and for all combinations in addition to washing with water and with commercial clean salt treatment, and it is also noticed that the concentrations of magnesium increased with the increase of phosphate gypsum and decreased with increasing the level of humic acid addition. The highest value of magnesium accumulation magnesium was 3577.27 (mmol l⁻¹) in the pore volume 3 when washed with AH1G4 combination as compared to HA4G4 wash mixture which gave 2473.01 (mmol l⁻¹). Whereas washing with water (W) and with a clean salt (CS) gave the lowest concentrations of magnesium released compared to the rest of the washing blends, as they reached 1451.51 and 1667.38 (mmol l⁻¹), respectively. The reason for the increase in the magnesium released concentrations with the increase in the concentration of phosphogypsum and the low level of humic acids is because phosphogypsum is rich in calcium and magnesium resulting from its dissolution, which leads to an increase in the concentration of the magnesium ion in the solution and then moves it down with the filtrate released from the washing columns [6]. These results are consistent [4]. The reason for the gradual decrease in the concentration of magnesium released when increasing the level of addition of humic acids is because they contain active groups such as the carboxyl and hydroxyl groups that work on chelating, complexing, adsorption, and forming organic complexes that are less mobile in the soil with the magnesium ion, which reduced the washing process outside the soil columns [15]. These results are consistent with [7, 8] who indicated that the values of magnesium accumulation released from washing soil columns decrease with increasing the level of humic acid addition.

Figure 3. Effect of a combination of humic acids & phosphogypsum, water and clean salt in Magnesium accumulative release.
3.3. Sodium accumulation released (mmol l\(^{-1}\)) from leached soil columns with the pore volume.

Figure 4 shows the relationship between the values of sodium accumulation concentrations (mmol l\(^{-1}\)) released from soil wash columns under the influence of combinations of humic acids, phosphogypsum, water, and a commercial clean salt treatment with the pore volume. It can be seen from the figure that the total sodium released concentrations increased with increasing the pore volume for all combinations in addition to washing with water and with a commercial clean salt treatment. It is also noticed that the sodium concentrations increased with the increase of phosphogypsum in addition to the increase in the level of humic acid addition, as the highest values of sodium accumulation concentrations of sodium reached 38794.53 (mmol l\(^{-1}\)) in the pore volume 3 when washing with AH4G4 combination compared to the washing combination HA1G4 which gave 20596.27 (mmol l\(^{-1}\)). Whereas washing with water (W) and with a clean salt (CS) gave the lowest concentrations of released sodium compared to the rest of the washing mixtures, as they reached 15073.06 and 18234.53 (mmol l\(^{-1}\)), respectively. The reason for the increase in sodium concentrations when increasing the level of phosphogypsum in the mixture is due to the increase in the concentration of divalent calcium ions in the soil solution resulting from dissolving phosphogypsum, which displaces the monovalent sodium ions on the surfaces of the ion exchange complexes and the displacement of the sodium downward with the washing water \([10];[11]\). These results are consistent with \([7]\). The reason for the gradual increase in the concentration of sodium released with the increase in the level of humic acids added in the mixture is because it contains active groups such as the carboxyl and hydroxyl groups that act on the formation, complexity, adsorption, and formation of organometallic complexes that are easy to dissolve and faster movement with sodium in the soil, which increases the washing process \([15]\). These results are consistent with several researchers \([7]\); \([8]\).

![Figure 4. Effect of a combination of humic acids & phosphogypsum, water and clean salt in Sodium accumulative release.](image-url)
3.4. Kinetics of the liberated sodium adsorption ratio over time (day)

The diffusion equation showed the best determination coefficient for the relationship between several variables as the ratio (the ratio of sodium adsorption, the value of salts, the concentrations of calcium, magnesium, and sodium) with time (day), although the equations for order zero and the elovich equation gave a high determination factor (R2), the diffusion equation gave a higher Determination coefficient (R2) and the lowest standard error (SEe), and it was highly significant at 0.01 using the tabular T-test. The mathematical model of the propagation equation $C_t = C_0 - Kt^{1/2}$ is the best in determining the relationship between SAR with time (day). Table 3 shows the indicators of the different kinetic equations to describe the kinetics of the sodium adsorption ratio (SAR) released from the soil wash columns under the influence of combinations of humic acids, phosphogypsum, washing with water and with a commercial salinity treatment, and from it is noticed that the diffusion equation gave the highest determination coefficient (R2) of 0.985 with a standard error. 55.439 as a general average for all combinations, these results agree with [7];[8];[20];[21] who found that the diffusion equation is the best in describing the kinetics of liberating the percentage of sodium adsorption and the values of salts and cations (calcium, magnesium, and sodium) when adding phosphate gypsum and humic acids to the soil. Fig. 5 and Table 4 show the relationship between the percentage of the total liberated sodium adsorption with the time root of day (t1/2) under the influence of combinations of humic acids and phosphogypsum with washing water, washing with water and with a commercial salinity treatment, and from it is noticed that the rate of release velocity (K) increased with increasing concentration Humic acids, as well as with the increase in the concentration of phosphogypsum for all combinations, as the HA4G4 combination gave the highest rate of release velocity and it was 563.06 compared to the rate of release velocity of the HA1G1 combination and it was 266.29, while washing with water (W) and with a clean salt (CS) gave the lowest rate of release rate of 242.15 And 257.82, respectively, the results of the kinetics of the rate of rate of release of the rate of sodium adsorption were similar with the results of the kinetics of the rate of rate of release of the amount of salts as well as the concentrations of calcium, magnesium and sodium. The reason for the increase in the rate of sodium adsorption when increasing the concentrations of phosphogypsum is due to the increase in the concentration of divalent calcium ions in the soil solution resulting from dissolving phosphogypsum, which replaces the monovalent sodium ions on the surfaces of the ion exchange complexes and the displacement of the sodium downward with the washing water [10];[11]. These results are consistent with [7];[8]. The reason for the increase in the percentage of adsorption of liberated sodium gradually with the increase in the level of addition of humic acids is due to its containment of the active groups such as the carboxyl and hydroxyl groups that work on the chelating, complexity, and adsorption of ions and the values of salts as well as the concentrations of calcium, magnesium, and sodium. The reason for the increase in the sodium adsorption ratio when increasing the concentrations of phosphogypsum is due to the increase in the concentration of divalent calcium ions in the soil solution resulting from dissolving phosphogypsum, which replaces the monovalent sodium ions on the surfaces of the ion exchange complexes and the displacement of the sodium downward with the washing water [10];[11]. These results are consistent with [7];[8]. The reason for the increases in the sodium adsorption ratio released with the increase in the level of addition of humic acids is due to its containment of the active groups such as the carboxyl and hydroxyl groups that work as chelating, complexity, and adsorption of ions to the formation of easy to dissolve organometallic complexes which are and faster movement with sodium in the soil, that increases the washing process [15] The formation of mineral organic complexes with less calcium movement. These results are consistent with [7];[8].
Table 3. Indicators of the different kinetic equations to describe the effect of washing a saline sodic soil in SAR of soil wash columns.

| Equation | indicators | Zero - Order | 1st. - order | 2nd. - order | Diffus. | Elovitch |
|----------|------------|--------------|--------------|--------------|---------|----------|
| W        | R2         | 0.932        | 0.620        | 0.190        | 0.982   | 0.942    |
|          | Se         | 78.574       | 0.719        | 0.024        | 40.472  | 72.859   |
|          | T          | 19.016       | 6.523        | -2.474       | 37.881  | 20.611   |
| G3       | R2         | 0.939        | 0.636        | 0.201        | 0.984   | 0.937    |
|          | Se         | 79.260       | 0.697        | 0.020        | 40.723  | 80.407   |
|          | T          | 20.161       | 6.750        | -2.561       | 40.084  | 19.819   |
| G4       | R2         | 0.937        | 0.638        | 0.203        | 0.982   | 0.938    |
|          | Se         | 83.676       | 0.685        | 0.018        | 43.760  | 82.894   |
|          | T          | 19.674       | 6.783        | -2.577       | 38.527  | 19.872   |
|          | R2         | 0.945        | 0.651        | 0.205        | 0.985   | 0.943    |
|          | Se         | 80.650       | 0.665        | 0.017        | 41.727  | 88.704   |
|          | T          | 21.266       | 6.970        | -2.595       | 41.959  | 19.282   |
|          | R2         | 0.948        | 0.670        | 0.228        | 0.985   | 0.952    |
|          | Se         | 82.684       | 0.618        | 0.012        | 43.087  | 93.727   |
| G4       | R2         | 0.950        | 0.679        | 0.235        | 0.986   | 0.931    |
|          | Se         | 84.481       | 0.563        | 0.010        | 43.780  | 99.701   |
|          | T          | 22.417       | 7.430        | -2.826       | 44.069  | 18.801   |
| G1       | R2         | 0.945        | 0.670        | 0.243        | 0.985   | 0.953    |
|          | Se         | 83.869       | 0.614        | 0.011        | 42.708  | 91.303   |
|          | T          | 21.240       | 7.265        | -2.889       | 42.592  | 19.407   |
|          | R2         | 0.951        | 0.681        | 0.237        | 0.986   | 0.930    |
|          | Se         | 85.531       | 0.597        | 0.010        | 44.746  | 103.027  |
|          | T          | 22.675       | 7.463        | -2.847       | 44.132  | 18.609   |
|          | R2         | 0.956        | 0.698        | 0.247        | 0.985   | 0.921    |
|          | Se         | 89.236       | 0.581        | 0.009        | 51.510  | 119.466  |
|          | T          | 23.877       | 7.765        | -2.922       | 42.237  | 17.509   |
|          | R2         | 0.959        | 0.698        | 0.242        | 0.986   | 0.921    |
|          | Se         | 87.977       | 0.579        | 0.009        | 50.186  | 122.461  |
|          | T          | 24.773       | 7.769        | -2.882       | 44.045  | 17.440   |
|          | R2         | 0.968        | 0.697        | 0.217        | 0.987   | 0.913    |
| G3       | Se         | 90.765       | 0.598        | 0.009        | 56.585  | 149.060  |
|          | T          | 28.054       | 7.738        | -2.684       | 45.453  | 16.597   |
|          | R2         | 0.970        | 0.700        | 0.211        | 0.987   | 0.909    |
| G4       | Se         | 90.941       | 0.595        | 0.009        | 60.404  | 159.510  |
|          | T          | 29.365       | 7.793        | -2.638       | 44.582  | 16.209   |
|          | R2         | 0.970        | 0.726        | 0.270        | 0.989   | 0.914    |
|          | Se         | 94.013       | 0.518        | 0.005        | 57.536  | 160.166  |
|          | T          | 29.321       | 8.308        | -3.104       | 46.360  | 16.708   |
|          | R2         | 0.980        | 0.749        | 0.284        | 0.986   | 0.899    |
|          | Se         | 86.640       | 0.500        | 0.004        | 71.249  | 193.282  |
|          | T          | 35.703       | 8.812        | -3.218       | 43.558  | 15.280   |
|          | R2         | 0.969        | 0.705        | 0.213        | 0.984   | 0.906    |
| G3       | Se         | 105.793      | 0.589        | 0.008        | 73.769  | 183.610  |
|          | T          | 28.547       | 7.887        | -2.654       | 41.274  | 15.911   |
|          | R2         | 0.970        | 0.722        | 0.240        | 0.985   | 0.905    |
| G4       | Se         | 104.302      | 0.553        | 0.006        | 74.561  | 190.149  |
|          | T          | 29.801       | 8.228        | -2.868       | 41.986  | 15.781   |
|          | R2         | 0.974        | 0.744        | 0.287        | 0.986   | 0.906    |
|          | Se         | 104.408      | 0.497        | 0.004        | 74.223  | 198.195  |
|          | T          | 31.240       | 8.693        | -3.240       | 44.234  | 15.876   |
|          | R2         | 0.980        | 0.761        | 0.303        | 0.984   | 0.895    |
|          | Se         | 97.689       | 0.478        | 0.003        | 86.879  | 227.717  |
|          | T          | 36.418       | 9.119        | -3.363       | 41.033  | 14.928   |
| Mean     | R2         | 0.957        | 0.691        | 0.236        | 0.985   | 0.920    |
|          | Se         | 89.471       | 0.591        | 0.010        | 55.439  | 134.235  |
|          | T          | 25.846       | 7.698        | -2.840       | 42.602  | 17.645   |

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Figure 5. The relationship between sodium adsorption ratio under the influence of combinations of humic acids & phosphogypsum, water and clean salt with a root of time (day) according to the diffusion equation.

Table 4. Diffusion equations and rate constants of the sodium adsorption ratio under the influence of combinations of humic acids & phosphogypsum, water, clean salt with a root of time (day)

|       | CS       | W        | HA4G1 | HA3G1 | HA2G1 | HA1G1 | HA4G2 | HA3G2 | HA2G2 | HA1G2 | HA4G3 | HA3G3 | HA2G3 | HA1G3 | HA4G4 | HA3G4 | HA2G4 | HA1G4 |
|-------|----------|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Y     | 257.82x  | 242.15x  | 406.23x | 480.91x | 425.34x | 494.46x | 439.48x | 518.56x | 490.18x | 563.06x | 406.23x | 494.46x | 439.48x | 518.56x | 490.18x | 563.06x | 406.23x | 494.46x | 439.48x | 518.56x | 490.18x | 563.06x |
| W     | 257.82x  | 242.15x  | 406.23x | 480.91x | 425.34x | 494.46x | 439.48x | 518.56x | 490.18x | 563.06x | 406.23x | 494.46x | 439.48x | 518.56x | 490.18x | 563.06x | 406.23x | 494.46x | 439.48x | 518.56x | 490.18x | 563.06x |
| HA1G1 | y=266.29x | y=287.31x | y=406.23x | y=480.91x | y=425.34x | y=494.46x | y=439.48x | y=518.56x | y=490.18x | y=563.06x | y=266.29x | y=287.31x | y=406.23x | y=480.91x | y=425.34x | y=494.46x | y=439.48x | y=518.56x | y=490.18x | y=563.06x |
| HA1G2 | y=276.54x | y=311.9x  | y=425.34x | y=494.46x | y=382.87x | y=461.46x | y=425.34x | y=494.46x | y=382.87x | y=461.46x | y=276.54x | y=311.9x  | y=425.34x | y=494.46x | y=382.87x | y=461.46x | y=425.34x | y=494.46x | y=382.87x | y=461.46x |
| HA1G3 | y=288.95x | y=341.64x | y=439.48x | y=518.56x | y=575.93x | y=659.64x | y=439.48x | y=518.56x | y=575.93x | y=659.64x | y=288.95x | y=341.64x | y=439.48x | y=518.56x | y=575.93x | y=659.64x | y=439.48x | y=518.56x | y=575.93x | y=659.64x |
| HA1G4 | y=304.73x | y=349.13x | y=490.18x | y=563.06x | y=677.18x | y=780.84x | y=490.18x | y=563.06x | y=677.18x | y=780.84x | y=304.73x | y=349.13x | y=490.18x | y=563.06x | y=677.18x | y=780.84x | y=490.18x | y=563.06x | y=677.18x | y=780.84x |

X = root time  y = SAR
4. Conclusions
Washing with water enriched with phosphogypsum and humic acids proved that it is highly efficient in washing salts and sodium in soil columns compared to commercial clean salt and Euphrates water. Increasing the levels of and humic acids in the combination led to an increase in the sodium adsorption ratio in the washing filtrates from saline-sodic soil columns. The washed sodium concentration increased leaching that soil columns with an increase in the level of addition of phosphogypsum and humic acids in the mixture, while significant concentrations of calcium and magnesium washed from the soil columns decreased with the increase in the level of humic acids in the combination. The release constant of the sodium adsorption ratio and the sodium concentration increased with the increased level of humic acid addition. The release of calcium and magnesium decreased with the increase in the level of humic acid addition. The diffusion equation proved to be highly efficient in describing the kinetics of the sodium adsorption ratio. Therefore, the highest level of humic acids and phosphogypsum in combination are a substantial organic-chemical clean salt.

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