Relationship Between Soil Physical and Chemical Properties and Hydrophysical Soil Properties under Reuse of Agricultural Drainage Water

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Abstract: Egypt as a semi-arid country is forced to look for new and alternative water sources. Regarding to the limited fresh water resources, agriculture drainage water especially at the end of irrigation canals could represent a reasonable solution. The current study was carried out to assess the relationships between soil physical, chemical properties and soil water constant, water movement under reuse of agricultural drainage water. To control and monitor the soil variables, soil samples (0-30 cm) were collected from El-Khashaah, Kafr El-Sheikh Governorate, Egypt, to analyzing soil and irrigation water chemical properties (pH, EC, cation exchange capacity, exchangeable cations (Ca$^{2+}$, Mg$^{2+}$, Na$^+$ and K$^+$). Data were statistically analyzed to obtain the relations between water and soil parameters, Pearson correlation coefficient were computed. Obtained results showed that a decrease in the organic matter content and an increase of parameters such as pH, electrical conductivity and some exchangeable cations were expected. A negative correlation was found with soil hydraulic conductivity, highly significant with EC (p<0.01). Same trend was obtained in relation between soluble cations and sodium adsorption ratio values, except Ca$^{2+}$. The highest coefficients values (r) were recorded with Mg followed by Na$^+$. Results showed that they had significant correlation coefficient, except Ca$^{2+}$, while Mg$^{2+}$ had a highly one with the previous irrigation water properties. But Na$^+$ had low significant correlation coefficient with FC, WP and AW (p<0.01) except with WP (p<0.05) and the higher r values were recorded with AW followed by FC. The results mainly attributed to the effect of Na$^+$ as a dominant monovalent cation in soil solution and the irrigation water. It affects on the clay depression and highly responsible on the soil deterioration under the investigation conditions. Increase Mg$^{2+}$ in the irrigation water at the expense of Ca$^{2+}$ had a negative effect on the both Ca/Mg ratio and its effect on the soil deterioration of soil aggregates and breakdown. Regression equation between sol ESP as affected by soil EC and CEC was estimated and data predicted that highly positive significant relation (p< 0.01) were obtained with soil EC and low significant one with soil CEC.

Key words: Reuse drainage water • Soil physical • Chemical properties and soil water constant • Hydraulic conductivity

INTRODUCTION

The reuse of agriculture drainage water and/or low water quality for beneficial purposes in Egypt is a most suitable solution, that help considerably expanding the irrigated land and hence saving of fresh water for other essential sectors, such as municipal and food manufactured etc., is expected. The future of irrigated agriculture poses the need to develop irrigation strategies using poorer quality water to fulfill the food and fibre production gap, in order to ensure long-term sustainability in irrigated agriculture without soil degradation occur especially hydrophysical ones. A soil system can be considered as a network of soil properties. Soil water retention is a basic soil property that is influenced by some soil physical and chemical properties. It is related to soil moisture constants, fluids flow in soils, irrigation water quality and drainage requirement [1]. Abdel Hady [2] reported that soil water relationships are very important parameters not only for selecting type of plant grown but also managing soil water systems. Who found that soil moisture showed positive relationships.
with fine particles, soil salinity, organic matter content and cation exchangeable capacity (CEC). Cosby et al. [3] and Rawls et al. [4] studied the relationships between field capacity (FC) and wilting point (WP) with some soil properties and found that these water constants could be estimated by means of developed regression models. The silt and clay content play an important role in the adsorption and desorption of water molecules as soil fine particles, which have highly surface area.

The adsorptive forces of clay minerals surface greatly affect water retention due to the permanent negative charges of the fine particles and the polar nature of water molecules [5]. Marcel and Leij [6] stated that soil hydraulic conductivity (HC) has numerous sources of variations related to spatial, temporal and management related process. Soil type is considered to be the dominant source of variability and parameterization is typically based on soil survey database. Also, [7] mentioned that HC of soil matrix depends mainly on the soil structure, which can be described in terms of spatial distribution of pore spaces. He added that soil sodium adsorption ratio (SAR) and exchangeable sodium percent (ESP) were the most important factors that affect indirectly on the water flow through soil column. Also the dominant mono cation (Na+) plays a vital role in soil deterioration and aggregates breakdown. Tayel and Abdel Hady [8] reported that soil EC and pH had a higher direct effect on HC value through negative relationship and described on the base of soil alkalinity. A monovalent cations adsorption ratio (MCAR) may predict the adsorption of monovalent ions by soil colloids on the basis of cation exchange isotherms, but it fails to weight the relative efficacy of Na and K in the numerator and of Ca and Mg in the denominator and treats members of each pair as identical [9]. Therefore, there is a need to derive and define a new ratio of these cations in place of SAR, which will indicate the effects of Na, K, Mg and Ca on soil structural stability. This will be achieved using a formula analogous to the SAR but which selectively incorporates the dispersive effects of Na and K on the one hand with the flocculating effects of Ca and Mg on the other [10,11].

The aim of the work is to assess the relationships between soil physical, chemical properties and soil water constant, water movement under reuse of agricultural drainage water.

RESULTS AND DISCUSSION

The descriptive statistical parameters for studied soil variables which showed spatial correlation between pairs are illustrated in Table (1). The result can be summarized as: Na is the dominant cations on the soil solution and on the clay. Where ESP ranged from 12.78 to 67.27%, which indicated that the studied soils were sodic saline. This finding is supported by soil pH. Also, SAR and MCAR were closed to each other and their values ranged from 3.58 to 9.69 and from 3.87 to 9.69, respectively. Organic matter content is very low and did not go far from mean (1.06 to 2.3%). It must be mentioned that SA is very high

MATERIALS AND METHODS

Twelve soil samples from different landscapes (0-30 cm) were collected from El-Khashaah, Kafr El-Sheikh Governorate, Egypt, to study the effect of reuse of agricultural drainage water on some soil physical, chemical properties from side and soil water constant and water movement from the other one. Physical and chemical routine properties of soil and irrigation water were determined after [12]. Moisture retention at field capacity (FC) and wilting point (WP) after [13].

Sodium adsorption ratio is defined as follows:

$$SAR = \frac{Na}{[(Ca + Mg)/2]^{1/2}}$$

where concentrations of Na, Ca and Mg are expressed as mill moles of charge/L.

A Monovalent Cations Adsorption Ratio (MCAR), defined by:

$$MCAR = \frac{(Na+K)}{[(Ca + Mg)/2]^{1/2}}$$

Soil hydraulic conductivity (HC) in saturated condition was measured in the laboratory under a constant head technique [14] using the following formula:

$$HC = \frac{(QL)}{(At \Delta H)}$$

Where: HC: water quantity flowing through saturated soil sample/unit time, Q: volume of water flowing through saturated soil sample per unite time (L/t), A: cross sectional flow area (L²), L: length of the soil sample and $\Delta H$: differences in hydraulic head across the sample (L) and t: time (hr).

Cation exchange capacity (CEC) in meq/L was determined after [15] and soil surface area (SA) m²/g after [16].

The spatial dependence of each individual variable as well as the relationship among them was evaluated. Data were subjected to analysis of correlation and multiple regressions were estimated after computer’s program provided by using the SAS program [17].
Table 1: Descriptive analysis of the investigated soil samples

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Ca**</th>
<th>Mg**</th>
<th>Na</th>
<th>K</th>
<th>ESP</th>
<th>SA</th>
<th>CEC</th>
<th>SAR</th>
<th>MCAR</th>
<th>pH</th>
<th>EC</th>
<th>OM</th>
<th>FC</th>
<th>WP</th>
<th>AW</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>4.63</td>
<td>5.27</td>
<td>14.76</td>
<td>1.39</td>
<td>45.85</td>
<td>266.95</td>
<td>27.34</td>
<td>6.66</td>
<td>6.06</td>
<td>8.15</td>
<td>2.19</td>
<td>1.61</td>
<td>0.43</td>
<td>0.28</td>
<td>0.15</td>
<td>0.55</td>
</tr>
<tr>
<td>Standard Error</td>
<td>0.50</td>
<td>0.42</td>
<td>1.86</td>
<td>0.16</td>
<td>5.93</td>
<td>3.00</td>
<td>1.86</td>
<td>0.76</td>
<td>0.64</td>
<td>0.10</td>
<td>0.31</td>
<td>0.12</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>0.24</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1.57</td>
<td>1.33</td>
<td>5.87</td>
<td>0.51</td>
<td>18.74</td>
<td>9.48</td>
<td>5.87</td>
<td>2.42</td>
<td>2.01</td>
<td>0.31</td>
<td>0.97</td>
<td>0.37</td>
<td>0.08</td>
<td>0.05</td>
<td>0.03</td>
<td>0.75</td>
</tr>
<tr>
<td>Minimum</td>
<td>3.25</td>
<td>3.25</td>
<td>6.90</td>
<td>0.65</td>
<td>12.78</td>
<td>252.00</td>
<td>21.50</td>
<td>3.58</td>
<td>3.76</td>
<td>7.60</td>
<td>0.40</td>
<td>1.06</td>
<td>0.27</td>
<td>0.17</td>
<td>0.09</td>
<td>0.21</td>
</tr>
<tr>
<td>Maximum</td>
<td>7.10</td>
<td>7.51</td>
<td>25.22</td>
<td>2.27</td>
<td>67.27</td>
<td>282.00</td>
<td>37.49</td>
<td>10.84</td>
<td>9.70</td>
<td>8.50</td>
<td>3.70</td>
<td>2.30</td>
<td>0.48</td>
<td>0.32</td>
<td>0.19</td>
<td>2.50</td>
</tr>
<tr>
<td>Confidence Level (95.0%)</td>
<td>1.13</td>
<td>0.95</td>
<td>4.20</td>
<td>0.36</td>
<td>13.41</td>
<td>6.24</td>
<td>0.76</td>
<td>0.64</td>
<td>0.10</td>
<td>0.31</td>
<td>0.97</td>
<td>0.37</td>
<td>0.08</td>
<td>0.05</td>
<td>0.03</td>
<td>0.75</td>
</tr>
</tbody>
</table>


Table 2: Descriptive analysis of the investigated soil samples

<table>
<thead>
<tr>
<th>Parameters</th>
<th>EC</th>
<th>pH</th>
<th>Ca**</th>
<th>Mg**</th>
<th>Na</th>
<th>K</th>
<th>SAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.94</td>
<td>7.60</td>
<td>3.41</td>
<td>3.76</td>
<td>11.97</td>
<td>0.29</td>
<td>6.24</td>
</tr>
<tr>
<td>Standard Error</td>
<td>0.22</td>
<td>0.05</td>
<td>0.40</td>
<td>0.56</td>
<td>1.59</td>
<td>0.04</td>
<td>0.77</td>
</tr>
<tr>
<td>Median</td>
<td>2.05</td>
<td>7.61</td>
<td>3.37</td>
<td>4.38</td>
<td>12.10</td>
<td>0.25</td>
<td>6.15</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.63</td>
<td>0.13</td>
<td>1.12</td>
<td>1.59</td>
<td>4.50</td>
<td>0.10</td>
<td>2.19</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.49</td>
<td>7.37</td>
<td>2.00</td>
<td>0.15</td>
<td>2.33</td>
<td>0.20</td>
<td>2.08</td>
</tr>
<tr>
<td>Maximum</td>
<td>2.50</td>
<td>7.80</td>
<td>5.06</td>
<td>5.00</td>
<td>17.10</td>
<td>0.52</td>
<td>8.99</td>
</tr>
<tr>
<td>Confidence Level (95.0%)</td>
<td>0.53</td>
<td>0.11</td>
<td>0.94</td>
<td>1.33</td>
<td>3.76</td>
<td>0.09</td>
<td>1.83</td>
</tr>
</tbody>
</table>

SAR: sodium adsorption ratio, EC: electrical conductivity

Table 3: Simple correlation between soil hydrophysical and chemical properties

<table>
<thead>
<tr>
<th>Parameters</th>
<th>ESP</th>
<th>SA</th>
<th>CEC</th>
<th>SAR</th>
<th>MCAR</th>
<th>pH</th>
<th>EC</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC</td>
<td>0.876</td>
<td>0.629</td>
<td>0.494</td>
<td>0.607</td>
<td>0.507</td>
<td>0.893</td>
<td>0.898</td>
</tr>
<tr>
<td>WP</td>
<td>0.843</td>
<td>0.571</td>
<td>0.363</td>
<td>0.491</td>
<td>0.382</td>
<td>0.837</td>
<td>0.820</td>
</tr>
<tr>
<td>AW</td>
<td>0.851</td>
<td>0.673</td>
<td>0.679</td>
<td>0.756</td>
<td>0.680</td>
<td>0.905</td>
<td>0.950</td>
</tr>
<tr>
<td>HC</td>
<td>-0.841</td>
<td>-0.599</td>
<td>-0.389</td>
<td>-0.553</td>
<td>-0.458</td>
<td>-0.806</td>
<td>-0.827</td>
</tr>
</tbody>
</table>


which related mainly to the clay content from side and to the desperation effect of the dominant cation (Na**). It can be seen that most of the variables express an extremely high variability. The highest of all is for ESP followed by SA with standard deviation 18.74 and 9.48, respectively. Obviously that depends on the surface and subsurface samples and clay contents and aggregates index (stability).

Table 1 illustrated descriptive analysis of the studied soil hydrophysical and chemical properties. The results can be summarized as: soil samples are mostly clay in texture, low in organic matter and moderately in soil pH. The mean soil moisture constant values were 0.43, 0.28 and 0.15 cm/cm³ for field capacity (FC), wilting point (WP) and available water (AW), respectively. Table 1 also indicated that hydraulic conductivity (HC) for the soils was from 0.21 to 2.50 cm/h. The permeability classes of the soils based on the HC data indicated that the soils were mainly very slow to slow (Table 1). This is because concentration of the Na’ in the soil solution is high and the opposite was true in case of the Ca**. Also Mg** took same trend where increased in soil solution than Ca** and affected directly on the stability of the soil aggregates and hence on the water movement under saturated condition (HC). All these may reduce the permeability of the soil and hence affected on the potential structural deformation index [18] who indicated that the lowest potential structural deformation index in the topsoil and hence may resist deformation by water more than the subsurface.

Descriptive analysis of the irrigation water analysis (through 12 monthly reading along the year) was recorded in the Table 2. Values of the standard deviation were reasonable to descript accurate determinations of the studied properties. The maximum value of the studied irrigation water properties were 3.5 dS/m (EC), 7.8 (pH), 5.06 (Ca**), 5.0 (Mg**), 17.1 (Na’), 0.52 (K’) and 8.99 (SAR) meq/L. Table 3 showed that the correlation coefficients between some soil chemical properties from side and HC and soil water constant (FC, WP and AW).
Table 4: Simple correlation between soil water constant and irrigation water characteristics

<table>
<thead>
<tr>
<th>Soil water constant</th>
<th>EC</th>
<th>pH</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>SAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC</td>
<td>0.806</td>
<td>0.411</td>
<td>0.117</td>
<td>0.717</td>
<td>0.591</td>
<td>0.515</td>
</tr>
<tr>
<td>WP</td>
<td>0.789</td>
<td>0.369</td>
<td>0.244</td>
<td>0.735</td>
<td>0.555</td>
<td>0.449</td>
</tr>
<tr>
<td>AW</td>
<td>0.760</td>
<td>0.448</td>
<td>-0.119</td>
<td>0.615</td>
<td>0.599</td>
<td>0.582</td>
</tr>
<tr>
<td>HC</td>
<td>-0.929</td>
<td>-0.358</td>
<td>-0.190</td>
<td>-0.881</td>
<td>-0.786</td>
<td>-0.683</td>
</tr>
</tbody>
</table>

EC: electrical conductivity, SAR: sodium adsorption ratio, FC: field capacity, WP: wilting point, AW: available water, HC: hydraulic conductivity

Data indicated that there are inverse relationships between all studied soil properties with HC (p<0.01) except with CEC significant at 5% level. This result mainly due to high values of ESP and salinity (EC), where sodium is a dominant cation and consequently responsible on the soil deterioration through dispersion effect. Also, related to the role of the hydration films around the Na⁺.

With respect to the EC, pH and CEC values, they correlated positively with the studied soil water constant with significance level 1%. The highest significant values of r was attained EC values versus AW (0.950**) and FC (0.898**) and pH versus AW (0.905**) and FC (0.893**). Regarding to the correlation coefficients between ESP and FC, WP and AW, r values were highly significant (p<0.01) and the highest value was 0.876** is recorded with FC. Regarding to the surface area (SA) correlation coefficient with FC, positive significant coefficients (p<0.01) was recorded and reflected also on the SA with AW.

Concerning to the SAR and MCAR and soil water constant, coefficients values of SAR were higher than MCAR and more significant. The highest r values were obtained between SAR and MCAR with AW (0.756**, 0.680**) followed by FC (0.607**, 0.507**), respectively. This also confirmed by the positive relationships between them and Na⁺. These findings could explain on the base of soluble salts in soil solution (EC) and Na⁺ as the dominant cations, respectively. Whereas MCAR had a moderately effect relative to low concentration of mono cations in soil solution.

According to the EC and pH of irrigation water, negative correlation was found with soil hydraulic conductivity (HC), highly significant with EC (p<0.01). Same trend was obtained in relation between soluble cations and SAR value, except Ca⁺⁺. The highest coefficients values (r) were recorded with Mg followed by Na⁺. This finding is interpreted on the base of the effect of both Mg and Na on the soil alkalinity from side and clay dispersion from the other one (Table 3). Also, these studied soils were recognized by weak Ca/Mg ratio and higher ESP (increase Na⁺ on the adsorption complex materials). This result is agreement with those obtained by Ragab et al. [19] and Abu-Sinna et al. [20].

Highly significant correlation was obtained between irrigation water salinity (EC) and soil water constants (FC, WP and AW), while the lowest r values with significant level 5% were recorded with pH of irrigation water. The study also established the relationship between soluble cations in irrigation water (Ca, Mg and Na) and soil water constants, results showed that they had significant correlation coefficient, except Ca⁺⁺, while Mg ++ had a highly one with the previous irrigation water properties (Table 4). But Na⁺ had low significant correlation coefficient with FC, WP and AW (p<0.01) except with WP (p<0.05) and the higher r values were recorded with AW followed by FC. The results mainly attributed to the effect of Na⁺ as a dominant monovalent cation in soil solution and the irrigation water. It affects on the clay depression and highly responsible on the soil deterioration under the investigation conditions [21]. Also, same table illustrated an increase Mg in the irrigation water at the expense of Ca⁺⁺ had a negative effect on the both Ca/Mg ratio and its effect on the soil deterioration of soil aggregates and breakdown. Rengasamy and Sumner [22] reported that potassium, being a monovalent cation, can cause clay swelling and dispersion. But, potassium appears not equivalent to sodium in causing structural problems in soils. Although early basic colloid studies showed an almost exact correspondence between the effect of sodium and potassium (as mono cations) in ‘simple’ aqueous suspensions of lyophobic colloids [23].

Regression equation between sol ESP as affected by Soil salinity (EC) and soil CEC was estimated and data predicted that highly positive significant relation (p< 0.01) were obtained with soil EC and low significant one with soil CEC. Also, the trend in the first relation was more sharp the second one (Fig. 1a, b). Same trend was obtained in case of EC and Na⁺ of irrigation water (Fig. 2a, b). In the same Figure the regression equation of
the 1st relation (EC of irrigation water) is more significant than the other equation (with Na⁺ of irrigation water). The results were with the coincidence of the results obtained by Omar et al. [24] who reported that the concentration of Na⁺ in agriculture drainage water has a strong relation with soil ESP, which meant the irrigation water is the main source of the adsorbed Na⁺ in soil ESP %. Also, they mentioned that Na⁺ is a dominant cation in the irrigation water. Smiles [25] reported that there is, on average, more water-soluble and exchangeable potassium than sodium across a range of soils in the Murray-Darling Basin. He concluded that neglect of potassium and simple appeal to SAR to infer soil structural stability will be misleading. Many sodic soils, particularly sub soils, in Australia have higher exchangeable magnesium than calcium. Rengasamy et al. [26] concluded that the enhanced clay dispersion in high magnesic sodic soils is due to the lower flocculating effect of Mg²⁺ compared to Ca²⁺.

CONCLUSIONS

From the abovementioned discussion it can be concluded that:

- Reuse of low water quality is considered as an important component of the water policies.
- Chemical characteristics under salt-affected soil could be used as a tool for expect soil hydrophysical properties deterioration and
- Improvement of some soil properties could be help to overcome soil deterioration under reuse of agriculture drainage water.

REFERENCES


