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# POTASSIUM INTENSITY AND CAPACITY RELATIONS IN REMEDIATED SALT-AFFECTED SOILS

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**ABSTRACT:** **The objective of the current work is to investigate the intensity and capacity (the so-called I and Q) relations of K during remediation of salt-affected soils collected from El-Sharkia Governorate. Gypsum requirements were added to soils placed in pots as sulfur or phosphogypsum followed by intensive leaching. Sub-samples were taken for analysis to determine parameters including potassium activity ratio at equilibrium ($AR^k_e$) and potential buffering capacity for potassium ($PBC^k$). Subsequently, wheat was grown on the pots to full maturity then grains were harvested and analyzed for K uptake. Data inspection for $AR^k_e$ shows a rather modest significant correlation coefficient between the $AR^k_e$ and the clay content but highly significant with the EC. The highest $AR^k_e$ value reached 0.026 $(M/L)^{1/2}$ but decreased considerably upon remediation. On the other hand, clayey soils have the highest $PBC^k$ value reaching 109.6 cmol $kg^{-1}$ / $(M/L)^{1/2}$ . Furthermore, there is an invariable increase in the $PBC^k$ after the remediative treatments. The biological experiment did not indicate a significant correlation between the $AR^k_e$ and the grain yield of wheat and revealed a modest significant correlation with K uptake. On the other hand, the corresponding correlation coefficients with the $PBC^k$ are highly significant. It is rational to interpret these results on the pretext that since the $AR^k_e$ parameter is an intensive property, it would be liable to sudden changes given the extreme dynamic nature of the soil environmental conditions. Excessive salinity and sodicity**

**perturb $AR^k_e$ as a nutritional indicator, and thus its usefulness is confined to normal soils. In contrast, the $PBC^k$ parameter is a capacity property, and as such, it is sluggish and can withstand drastic changes. Therefore, the $PBC^k$ is fit to assess the nutritional status of K in normal as well as salt-affected soils.**

***Keywords:*** **activity ratio, buffering capacity, remediation, thermodynamics.**

## INTRODUCTION

Natural soil salinization and sodification processes that limit soil productivity resulting in soil degradation and contributing to desertification are commonplace in arid regions. Human activity can speed up such processes but by the same token can also help reduce their effects and even remediate affected soils. Examples of the latter include application of leaching requirements to remove excessive soluble salts, and application of gypsum requirements to remove excessive exchangeable sodium. The gypsum requirements may be added in the form of either mined gypsum or phosphogypsum. It may also be specific chemical agents such as sulfur or sulfuric acid that are capable of activating added or indigenous calcium carbonates (Richards, 1954; James *et al.* 1882; FAO, 1988; Sparks, 1995; and Tejedor *et al.* 2003).

The chemical mechanisms involved in the remediation process of salt-affected soils are well understood. However, proper management procedures to enhance rehabilitation, and consequently maximize their potential to sustain higher crop yields within short periods of time are often overlooked. The case of K availability to growing plants lends itself as an illustrative example. It has been established that soil K maintains a dynamic equilibrium in soils between forms comprising soluble, exchangeable, and structural K. Furthermore, defining soil K availability by characterizing a single parameter could be both elusive and misleading. Previous observations on the K behavior documented by theory and experimentation have shown that K availability is directly proportional to the relative abundance of two sets of minerals. These are the K-bearing minerals and clay minerals content of soils.

The first set provides the supply side whereas the second provides the reaction pool of the nutrient (Tahoun and Hamdi, 1973; and Tahoun and Assal, 1986).

Beckett (1972), Fanning *et al.* (1989), Hassan (1992), Tahoun *et al.* (1995), and Agbenin (2002) reported on variations of a special approach to express K availability in a thermodynamic sense. Two components are of primary importance in this approach. The first is an intensity factor (I) which is a function of the individual activity (a) of K, Ca, and Mg ions in the soil solution to produce a term known as the potassium activity ratio ($AR^k$). The term is similar to the classical sodium adsorption ratio (SAR), except that activity rather than concentration is used and the Ca plus Mg sum is not divided by 2 as is the case of the SAR equation. The second term is a capacity (Q) term that is related to changes in exchangeable $K^+$ as a function of K depletion or replenishment as the case may be in soils hosting the reaction.

Fanning *et al.* (1989) illustrated the elaboration of determining theI and Q values and using these values to construct a graph from which important K expressions could be derived. The first expression is the potassium activity ratio at equilibrium ($AR^k_e$). It pertains to an equilibrium condition corresponding to $\Delta K = 0$, at which no net exchange of K occurs between the solid and solution phase. This $AR^k_e$ is widely used as a measure of the immediate availability or intensity of labile K in soils. The second expression is the potential buffering capacity for potassium ($PBC^k$). It has been so called to represent the change magnitude of adsorbed K, $\Delta K$, as a function of the activity ratio. It is widely believed that soils with numerically high $PBC^k$ values are those which have greater ability to resist changes in their K concentration. In this context, Hassan (1992), Tahoun *et al.* (1995), El-Tohamy (1995), and Banjha *et al.* (2001) showed that the $PBC^k_e$ of soils is affected by several variables including texture, salinity, and sodicity. As far as the texture variable is concerned, the finding sounds reasonable as it relates to clay content and associated surface reaction processes. The question of salinity and sodicity carries many possibilities, and thus deserves to be investigated further.

The objective of the current work is to investigate possible I and Q changes prior and after remediation of salt-affected soils of different textural classes. Furthermore, the implication of these changes on biomass production as well as K uptake by wheat would also be assessed.

## MATERIALS AND METHODS

### Soil samples

To obtain a collection of salt-affected soils of different textural grades, a preliminary survey was undertaken across localities in El-Sharkia Governorate where about 50 surface samples (0 - 30 cm) were collected. After performing chemical analysis, 12 samples of different textural classes and spatial localities in the governorate were selected for detailed work. It turned out that the selected samples belong to villages in three counties (Markaz in Arabic). The fine and medium-textured soil samples belong to the villages of Abo-Omar, Zyad, El- Rowad, El-Waleed, and El-Ezdhar of El-Hussienya County. A loamy sample belongs to the village of Beshet of El-Zagazig County. Ekyad and El-Salhya villages of Fakous County provided sandy samples.

### Experimental procedures

The soil samples were air dried, crushed, and passed through 2.0 mm sieve before being subjected to determinations of relevant physical and chemical properties. These analyses included determination of gypsum content of soils according to Page *et al.* (1982). To remediate soils, exactly 7 kg in triplicates of each sample were placed in plastic pots 25 cm in diameter and 22 cm in height. The bottom of each pot was previously perforated to have five drainage holes lined with filter paper. Four holes in pots containing sandy soils were plugged with adhesive material during leaching to extend the contact time between the liquid and solid phases. Plugs were removed during the subsequent biological experiment.

Three sets of pots each with three replicates were prepared for each soil. The first was subjected to leaching with water added at levels twice the saturation percentage of respective soil. The second set was treated with calibrated amounts of sulfur mixed with surface soil layer to reduce the exchangeable sodium percentage (ESP) of the whole soil in the pot to 5 then leached with water. The third set was treated with phosphogypsum mixed with the surface layer to reduce the ESP to 5 then leached as in other treatments. Six leaching installments were used separated by 12, 10 and 5 days for the fine, medium, and coursed-textured soils, respectively. Time was taken to collect the entire leachate prior to analysis. Utilized water came from the Bahr Mowis, which is a Nile primary canal tributary that runs through the city of El-Zagazig (El-Tohamy, 2004).

On terminating the leaching process, soil sub-samples were taken for chemical analysis. The rest of soil in each pot was used to cultivate wheat cultivar Sakha 8 (*Triticum aestivum* L.) in the greenhouse with pots distributed in a random block design. Twenty seeds were planted in each pot, thinned to ten homogenous seedlings after 10 days from emergence. An activation dose of fertilizer containing N, P, and K was added, and irrigation water was added whenever needed. Plants were allowed to grow till maturity where grains were collected, dried at 70° C, and weighed. Sub-samples of about 0.2 g of grains were digested using $HClO_4$ and $H_2SO_4$ mixture to determine the K concentration by the flame photometer.

### I and Q potassium parameters

The determinations of these parameters were conducted by the modified method of Beckett (1972) as described by Hassan (1992) and Tahoun *et al.* (1995). Exactly 5 g on the oven-dry basis of each soil sample were equilibrated with 50 ml of 0.002 M $CaCl_2$ containing 0.00, 0.05, 0.1, 0.2, 0.4 and 0.8 mM of KCl. The suspension was shaken at intervals for 2 hours and allowed to equilibrate overnight at laboratory temperature of about 25°C, and then the supernatant solution was filtered. Aliquots of the filtrate were used to determine K by a flame photometer and Ca and Mg by the versenate method (Page *et al.* 1982). Changes in the exchangeable K content of the individual soil samples were determined by the corresponding changes of their equilibrium K concentration.

The activity ratio for K was calculated using the formula $AR^K = {}^aK / {}^a(Ca + Mg)^{1/2}$, where (a) is the activity of the respective ion given by the formula $a_i = c_i \gamma_i$ , where $c_i$ is the molar concentration of ion i and $\gamma_i$ is the corresponding activity coefficient. The Debye-Hückel equation and the ionic strength were used to calculate the ionic activity as follows (Sparks, 1995):

$$\log \gamma_i = \frac{-AZ_i^2 (I)^{1/2}}{1 + (I)^{1/2}}$$

where A is constant equal to 0.51 at 25° Celsius, Z is ion valence, I is ionic strength of the solution given in terms of the summation of ion concentration times the valence of the respective ion calculated as follows:

$$I = 1/2 \sum_{i=1}^{n} c_i Z_i^2$$

Subsequently, a graph is constructed with individual values of the calculated activity ratio, $AR^k$ used as an abscissa (I), and the corresponding change in the exchangeable K content of the soil, $\Delta K$, used as an ordinate (Q). The potassium activity ratio at equilibrium ($AR^k_e$) pertains to the condition corresponding to $\Delta K = 0$, at which no net exchange of K occurs between the solid and solution phase. The slope of the curve designates the potential buffering capacity for potassium ($PBC^k$). The illustrative details of these steps are given in the review paper of Fanning *et al.* (1989).

## RESULTS AND DISCUSSION

### Soil samples description

The complete description of samples properties is given in details by El-Tohamy (2004). However, it may suffice here to mention that the clay content of samples ranges between 46.3 and 5.2%. The organic matter content is highest in the clayey soils reaching 2.30%, but the sandy soils are extremely poor with a content reaching 0.20%. Not much of a variation in the calcium carbonate content of all soils as 3% could be taken as a general average with little scattering. Some soils contain conspicuous needle-shaped crystals identified later as gypsum.

### Soil Responses to Remediation

Table 1 shows changes in the EC of the saturated paste and ESP values of the investigated soils and in response to remediation processes. On the onset, it should be stated that soils are sequenced in the table in a decreasing clay order. To illustrate, soils of Abo-Omar come first and second on top of the list as they contain 46.3 and 45.8% clay, respectively. In contrast, soils from El-Salhya come at the bottom of the list as

**Table 1. Electrical conductivity and exchangeable sodium percentage in initial and remediated soils***

| Soil location | EC,dS/m | | | | | ESP | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | I | W | S | G | L. S. D. | I | W | S | G | L. S. D. |
| Abo-Omar 1 | 21.00 | 4.49 | 3.16 | 2.75 | 1.50 | 31.34 | 16.21 | 5.28 | 4.84 | 1.65 |
| Abo-Omar 2 | 5.52 | 3.09 | 2.10 | 1.88 | 0.32 | 22.65 | 13.07 | 5.47 | 4.86 | 0.78 |
| El-Ezdehar | 51.10 | 4.70 | 2.97 | 2.19 | 1.83 | 32.95 | 17.93 | 4.85 | 4.32 | 0.36 |
| Zyad | 31.12 | 4.04 | 2.66 | 2.45 | 0.74 | 31.77 | 18.52 | 4.90 | 4.30 | 0.76 |
| El-Waleed 1 | 53.20 | 4.95 | 2.69 | 2.10 | 0.25 | 34.42 | 16.52 | 4.72 | 4.08 | 0.70 |
| El-Rowad | 32.00 | 4.18 | 2.87 | 2.24 | 1.55 | 35.22 | 17.01 | 6.62 | 4.74 | 0.53 |
| El-Waleed 2 | 21.50 | 4.01 | 3.00 | 2.40 | 0.72 | 35.68 | 16.83 | 9.53 | 6.61 | 0.91 |
| Beshet | 5.61 | 2.25 | 1.60 | 1.31 | 0.29 | 34.29 | 14.86 | 9.27 | 6.12 | 0.54 |
| Ekyad | 5.41 | 2.70 | 1.30 | 1.10 | 0.40 | 40.00 | 19.43 | 6.99 | 4.26 | 1.59 |
| El-Salhya 1 | 22.10 | 5.28 | 2.99 | 2.19 | 0.16 | 42.38 | 18.32 | 6.41 | 4.12 | 0.45 |
| El-Salhya 2 | 31.50 | 6.09 | 3.30 | 2.85 | 0.76 | 37.09 | 15.43 | 5.23 | 3.88 | 0.59 |
| El-Salhya 3 | 52.10 | 6.71 | 3.75 | 3.00 | 1.88 | 41.18 | 17.49 | 4.69 | 3.81 | 0.71 |
| L. S. D. | 1.40 | 0.20 | 0.23 | 0.18 | ----- | 1.03 | 0.61 | 0.47 | 0.38 | ---- |

Treatment designations are as follows: I = initial, W = leached with water, S = treated with sulfur then leached and G = treated with phosphogypsum then leached. L. S. D. values are calculated at the 0.05 level; ns=not significant.

they contain only 5.6, 5.4 and 5.2% clay, respectively (El-Tohamy, 2004).

The EC and the ESP values of the untreated soils hereby named initial soils are far greater than the threshold level of 4 $dSm^{-1}$ for saline soils and 15 for the sodic soils. Therefore, all soils are saline-sodic (Richards, 1954; James *et al.*, 1982; FAO, 1988; and Sparks, 1995). It is of interest to note that soils of the same locality often differ considerably in their salinity and sodicity, e.g., the three soils from El-Salhya village. This difference implies characteristic development for each soil, and emphasizes that salinity and sodicity are mostly site-specific properties.

Leaching alone, although statistically significant effect at the 0.05 level, was not enough to rid many soils completely of their excessive salinity. It is rather striking to note that this unloading inability was more pronounced in the three sandy soils of El-Salhya. The paradox is that sandy soils are well-known for their high permeability. As such, the residence time of the percolating water in the pots was too short to allow sufficient contact between water and solid phases even after sealing four out of the five drainage holes. In this context, the distinction made by Zhu *et al.* (2002) between measured leachate volumes and actual leachate fluxes in soils is extremely valuable.

Based on sound scientific principles outlined by Bresler *et al.* (1982), James *et al.* (1982), and Abo-Hashim (2002), successive leaching of saline-sodic soils with water of high quality would eventually induce colloidal dispersion and downward migration of clay particles. This is absolutely true in theory, but needs two qualifying adjustments in real nature. First, sodium-infested soils do not disperse unless their electrolyte content reaches low levels. Second, some soils with excessive salinity may contain gypsum as a minor constituent. These adjustments apply to the present work. Leachates after the second installment in several soils gave indications of clay migration in the form of turbidity, but reverted to transparency beginning with the fourth installment. The conspicuous needle-shaped crystallites in some soils proved to be gypsum by appropriates chemical analysis as given in Page *et al.* (1982). The content ranged from 0.17 to 0.48%.

Bresler *et al.* (1982) quoted earlier literature on the dissolution action of water flowing through beds of gypsum fragments in soils. It was reported that an appreciable amount of gypsum was dissolved by water. In the current work, it seems as if such released gypsum was adequate to provide active Ca ions to rid soils of about 50 % of their ESP as given in Table 1. The soils are still yet sodic in nature, but their aggregates are mostly intact preserved by suppressed dispersion and coherent hydraulic conductivity (Abo-Hashim, 2002).

Sulfur followed by leaching alleviated markedly the salinity and sodicity of affected soils, far greater than leaching with water alone as given in Table 1. In all likelihood, sulfur was readily oxidized to $H_2SO_4$, which promptly reacted with native calcium carbonate (around 3 % in most soils as reported by El-Tohamy, 2004) to produce activated gypsum. Standard analytical references indicate that the solubility of gypsum is far greater than that of calcite as indicated by their pK values at 4.62 and 8.42, respectively. This explains the favorable impact of sulfur in remediating sodic soils.

The data of Table 1 confirm that added gypsum in the form of phosphogypsum is the best remediative agent to reclaim saline-sodic soils. Values of both the EC and ESP are invariably lowest in this treatment compared with others. In most cases, the differences are statistically significant. The basis of gypsum superiority is two-fold. First, there are thermodynamic factors related to provision of Ca ions required to displace exchangeable Na. Second, there are kinetic factors related to sustaining the Ca ions supply throughout a diffusion-controlled process (Sparks, 1995). A final note concerning Table 1 is worthwhile. It was previously given that leaching sandy soils with water did not completely remediate them on the pretext of insufficient residence time. With sulfur and phosphogypsum, the remediation was perfectly complete regardless of the residence time. The outstanding feature here is the elevated Ca activity in the soil solution. According to Agden *et al.* (2004), Ca fortified soil solutions are more efficient in ejecting exchangeable Na and disposing of electrolytes out of the salt-affected soil system.

## Intensity and Quantity Relations

### Potassium activity ratio

Table 2 shows the $AR^k_e$ values of the investigated soils prior and after the application of the reclamation treatments. The data show that the high $AR^k_e$ values belong to the initial soils. Among these soils, the highest $AR^k_e$ value at 0.026 $(M/L)^{1/2}$ belongs to the clayey soil of El-Ezdehar whereas the three sandy soils of El-Salhya have low values around 0.008 $(M/L)^{1/2}$. It is likely that these quoted values are merely of fortuitous coincidence, as data inspection would show that some clayey soils have fairly low $AR^k_e$ values and some lighter-textured soils have greater values. This is confirmed by the rather modest significant correlation coefficient between the $AR^k_e$ and the soil clay content with a value of 0.35.

The data of Table 2 also show an association between the $AR^k_e$ and the EC values of soils. This finding is supported by two pieces of evidences. The first is statistical as calculations reveal a highly significant correlation between the $AR^k_e$ and the EC values of the soil with a correlation coefficient of 0.64. The second is provided by the work of Tahoun *et al.* (1995) where the average $AR^k_e$ value in saline soils was about twice that of the normal soils.

The authors of the present paper would like to contemplate that several interactive variables may be operating simultaneously to define the magnitude of $AR^k_e$ values in soils. The following is an illustrative example derived from statistical data. As outlined previously, the correlation coefficients between $AR^k_e$ and EC and the clay content are 0.64 and modest 0.35, respectively. However, if the $AR^k_e$ values were considered in terms of a compound parameter comprised of the multiplication product of the EC times the clay content of soils, then there is a highly significant correlation coefficient at 0.84. It is also rather peculiar that differences between treatments are only significant, with few exceptions, in medium-textured soils. Further specific work is invited to provide rational interpretations to these peculiarities. However, it may be postulated that there is some sort of constructive interference between soil texture and salinity as far as the $AR^k_e$ is concerned. A plausible theoretical basis for this phenomenon stands on the fact that sandy soils with their negligible clay contents disturb possible

Table 2. Potassium activity ratio and potential buffering capacity for potassium in initial and remediated soils*

| Soil location | $AR^k_e$ | | | | | $PBC^k$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | I | W | S | G | L. S.D. | I | W | S | G | L. S.D. |
| Abo-Omar 1 | 0.014 | 0.009 | 0.006 | 0.004 | ns | 107.2 | 124.5 | 158.2 | 217.7 | 2.5 |
| Abo-Omar 2 | 0.007 | 0.005 | 0.004 | 0.003 | 0.002 | 112.0 | 126.6 | 129.3 | 149.3 | 3.8 |
| El-Ezdehar | 0.026 | 0.017 | 0.008 | 0.006 | ns | 90.0 | 107.9 | 173.7 | 207.2 | 3.2 |
| Zyad | 0.018 | 0.015 | 0.006 | 0.005 | 0.006 | 101.9 | 104.3 | 129.8 | 147.2 | 2.2 |
| El-Waleed 1 | 0.018 | 0.013 | 0.007 | 0.005 | 0.003 | 124.6 | 134.8 | 207.5 | 231.2 | 2.3 |
| El-Rowad | 0.014 | 0.008 | 0.004 | 0.004 | 0.003 | 84.6 | 139.3 | 163.1 | 168.4 | 1.9 |
| El-Waleed 2 | 0.011 | 0.008 | 0.006 | 0.004 | 0.003 | 77.9 | 87.4 | 88.6 | 96.3 | 2.3 |
| Beshet | 0.008 | 0.006 | 0.006 | 0.005 | ns | 124.3 | 134.5 | 140.4 | 143.4 | 2.3 |
| Ekyad | 0.007 | 0.005 | 0.003 | 0.002 | ns | 15.6 | 18.5 | 20.5 | 22.8 | 1.2 |
| El-Salhya 1 | 0.007 | 0.006 | 0.004 | 0.003 | ns | 18.9 | 20.2 | 22.6 | 29.2 | 2.2 |
| El-Salhya 2 | 0.010 | 0.007 | 0.006 | 0.006 | 0.002 | 25.9 | 26.4 | 26.6 | 31.1 | 1.7 |
| El-Salhya 3 | 0.008 | 0.006 | 0.005 | 0.004 | ns | 43.7 | 44.8 | 48.6 | 49.1 | 1.4 |
| L. S. D. | 0.004 | 0.004 | ns | ns | ---- | 1.7 | 2.5 | 1.5 | 2.0 | ---- |

Same treatment designations as in Table 1 correlation relations within a collection of soils. In the circumstances, the dominant soil reactions in the light-textured soils would pertain to the solution rather than the exchange types of reactions (Sparks, 1995).

Table 2 shows significant reductions in the $AR^k_e$ values in the medium-textured reclaimed soils. In most cases, soils treated with phosphogypsum gave the lowest $AR^k_e$ values. These results could be explained on the basis of two criteria. First, K being more mobile than both Ca and Mg ions in the soil solution and thus was more vulnerable to leaching. Second, samples were not given time to release K from their K-bearing minerals, and thus replenishment to compensate leached K was not kinetically feasible. In this context, Sparks and Liebhardt (1981), Fanning *et al.* (1989), and Agbenin (2002) inferred that the magnitude of $AR^k_e$ gives an indication of sites involved in the exchange reaction. Values > 0.01 $(M/L)^{1/2}$ indicate that K is adsorbed at planer position whereas values < 0.001 indicate edge positions. These sites represent different selectivity levels for K on the clay mineral surface as previously elaborated by Sawhney (1972) and Tahoun (1974). It is good to recall, however, that Beckett (1972) asserted that $AR^k_e$ is irrelevant to adsorption sites, and that it is only a valid measure of K intensity under reference conditions.

## Potassium buffering capacity

The $PBC^k$ values of the studied soils prior and after the application of remediative treatments are given in Table 2. Two distinctive features are clear in the table. First, the magnitude of the parameter gets smaller as the textural class of the soil moves toward the coarse side. To illustrate, the average $PBC^k$ value of the two clayey soils of Abo-Omar prior to reclamation is 109.6 cmol $kg^{-1}$ / $(M/L)^{1/2}$ whereas the average corresponding value of the three sandy soils of El-Salhya is 29.5 $PBC^k$. The statistical calculation confirmed this observation by a highly significant correlation coefficient of 0.80 between the $PBC^k$ values and the clay content. This result was somewhat expected in terms of the well-known fact that clays are important seat of chemical reactions in soils involving ion exchange phenomena. In the context of K pool, this conclusion is supported by the work of many authors such as Beckett (1972), Sparks and Liebhardt (1981), and Fanning *et al.* (1989).

The second distinctive feature of Table 2 is the invariable significant increase in the $PBC^k$ magnitude for all soils after the remediative treatments. The increase was so great that the $PBC^k$ of remediated soil accounted for several orders of magnitude compared with the initial soil. Examples could be given by the soils of Abo-Omar 1 and El-Ezdehar whose initial $PBC^k$ values are 107.2 and 90.00 cmol $kg^{-1}$/ $(M/L)^{1/2}$, respectively, elevated to 217.7 and 207.2 cmol $kg^{-1}$/ $(M/L)^{1/2}$ after being remediated by phosphogypsum. A first impression to interpret this result is to invoke the associated reduction in the EC values as a key to the complicated situation. But the key does not work for two reasons. First, statistical calculation did not reveal any correlation between the $PBC^k$ and EC values.

Second, the specific effect of individual remediating agents carries a soil texture differential. To illustrate, the averages of the remediated two clayey soils of Abo-Omar by leaching with water, sulfur, and phosphogypsum are 125.6, 143.8, and 183.5 cmol $kg^{-1}$/ $(M/L)^{1/2}$, respectively. The corresponding averages of the three sandy soils of El-Salhya are 30.5, 32.6, and 36.5 cmol $kg^{-1}$ / $(M/L)^{1/2}$. These results are taken to indicate that phosphogypsum did not only rid the clayey soils of their hazardous sodicity, but it also enhanced its K resilience. Such action was not registered in the sandy soils for the very simple fact of clay scarcity. A supporting line of this argument is the encountered significant negative correlation coefficient at -0.34 between the ESP and $PBC^k$ values.

## Biological Implications

Table 3 shows the grain yield and K uptake by wheat grown on the initial and remediated soils. It is good to recall that wheat strain Sakha 8 is known for its salinity tolerance, and that this work was not designed to substantiate this fact. With this consideration in mind, three observations could be made regarding the grain yield reported in Table 3. First, the plant nearly or completely failed to give grains in three soils: the clayey soil of El-Ezdehar, the clay loamy soil of El-Waleed 1, and the sandy soil of El-Salhyia 3. The common feature of these three soils is their excessive salinity where the EC value is greater than 50 $dSm^{-1}$.

Table 3. Dry matter accumulation and potassium uptake by wheat grown on initial and remediated soils*

| Soil location | grain yield, g /pot | | | | | K uptake, mg/kg soil | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | I | W | S | G | L. S. D. | I | W | S | G | L. S. D. |
| Abo-Omar 1 | 23.43 | 30.77 | 38.54 | 41.35 | 2.54 | 34.15 | 72.37 | 109.69 | 125.24 | 19.08 |
| Abo-Omar 2 | 29.08 | 32.21 | 37.79 | 39.56 | 1.46 | 58.80 | 82.83 | 107.13 | 113.57 | 19.72 |
| El-Ezdehar | 0.22 | 29.63 | 37.57 | 40.16 | 0.64 | 00.08 | 62.29 | 96.10 | 106.19 | 26.09 |
| Zyad | 21.04 | 31.15 | 36.44 | 38.27 | 1.27 | 24.14 | 72.12 | 98.40 | 107.71 | 14.66 |
| El-Waleed 1 | 0.00 | 25.35 | 30.71 | 33.14 | 0.77 | 0.00 | 46.41 | 71.10 | 80.58 | 15.59 |
| El-Rowad | 16.36 | 24.80 | 30.07 | 31.61 | 0.83 | 13.82 | 47.52 | 68.91 | 75.48 | 7.32 |
| El-Waleed 2 | 18.15 | 23.42 | 29.63 | 30.51 | 0.14 | 19.73 | 47.22 | 63.56 | 68.03 | 6.17 |
| Beshet | 22.62 | 26.18 | 29.74 | 30.19 | 0.56 | 39.03 | 50.50 | 63.34 | 65.14 | ns |
| Ekyad | 9.36 | 10.88 | 13.04 | 13.97 | 0.57 | 15.03 | 19.75 | 25.16 | 28.18 | ns |
| El-Salhya 1 | 5.75 | 7.43 | 10.91 | 11.25 | 0.89 | 2.98 | 8.45 | 17.66 | 18.57 | 5.73 |
| El-Salhya 2 | 5.25 | 7.86 | 9.95 | 10.74 | 0.16 | 2.10 | 9.13 | 16.36 | 18.44 | 4.45 |
| El-Salhya 3 | 0.00 | 7.57 | 9.63 | 10.26 | 0.76 | 0.00 | 7.72 | 15.26 | 17.10 | 5.41 |
| L. S. D. | 0.59 | 0.54 | 0.70 | 0.48 | ---- | 4.93 | 10.56 | 11.22 | 14.30 | ---- |

Same treatment designations as in Table 1

Second, wheat grown on soils of high sodicity faired better if salinity was rather low, indicating that wheat is tolerant to sodicity. Third, there was a soil texture differential associated with the negative impact of salinity and sodicity on grain yield. Under comparable levels, wheat performed better on the fine and medium-textured soils compared to light-textured soils. It is most likely that this differential is related to the high potential of clay soils to sustain plant growth, inclusive provision of nutritional requirements.

Remediated fine-textured soils overcame their transitional defects, and therefore, gave significantly high grain yield as shown in Table 3. The magnitude of the yield was somewhat proportional to the relative efficiency of the remediative agent, with phosphogypsum on the top. Once more, there is a texture differential effect. The fine-textured soils were far more productive compared to the light textured. Such behavior brings into focus what many scientists call soil resilience, meaning the ability of a given soil to revert back to normal once the negative impact of an unfavorable factor is removed (Doran and Parkin, 1996).

Table 3 indicates also that K uptake by wheat was somewhat proportional to the dry matter production of the plant with multivariant trends. In general, K uptake increased in wheat grown on remediated soils compared with the initial, and phosphogypsum treated soils gave the highest uptake. The proven superiority of phosphogypsum could be attributed to its well-documented efficiency in ridding soils of their sodicity. It could also be attributed to its added value in terms of nutritional content of phosphorus and micronutrients as reported by Mahmoud (1996). The second trend in K uptake is the fairly distinct texture differential, most obvious in the phosphogypsum treated soils where three groups could be distinguished. The clayey soils form the firs group whose K uptake is greater than 100 mg/kg soil. The second group includes the medium-textured soils whose K uptake is greater than 60 mg/kg. Coarse-textured soils constitute the third group with K uptake is less than 30 mg/kg.

The statistical calculation did not indicate a significant correlation between the $AR^{k}_{e}$ values and the grain yield of wheat. Regarding K uptake, there was a significant correlation with a modest value of -0.34. Amazingly, the corresponding correlation coefficients with the $PBC^k$ values are highly significant at 0.81 and 0.80, respectively.

It is rational to interpret these results on the pretext that since the $AR^k_e$ parameter is an intensive property, it would be liable to jerky changes given the extreme dynamic nature of the soil environmental conditions. Excessive salinity and sodicity perturb the $AR^k_e$ as a nutritional indicator, and thus its usefulness is confined to normal soils. In contrast, the $PBC^k$ parameter is a capacity property, and as such, it is sluggish and can withstand somewhat drastic changes. Therefore, the $PBC^k$ is fit to serve in assessing the nutritional status of K in normal as well as salt-affected soils.

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# علاقات السعة والكثافة للبوتاسيوم أثناء إصلاح الأراضى المتأثرة بالأملاح

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جمعت ٥٠ عينة تربة سطحية من الأراضى المتأثرة بالأملاح فى محافظة الشرقية وتم اختيار ١٢ عينة مختلفة القوام أجريت عليها بعض التحليلات الطبيعية والكيميائية لدراسة علاقات السعة والكثافة للبوتاسيوم أثناء الإصلاح. وأضيفت الاحتياجات الجبسيه إلى العينات بالأصص على صورة الكبريت أو الجبس الفوسفورى وأعقبها الغسيل بضعف السعة التشبعية فى الغسلة الواحدة مع إستمرار الغسيل المتقطع ٦ مرات. ثم أخذ جزء من العينات لتقدير نسبة نشاط البوتاسيوم عند الإتزان والسعة التنظيمية الجهدية للبوتاسيوم. وتمت زراعة القمح بالأصص مع الرى حتى النضج التام للحصول على الحبوب ولتقدير البوتاسيوم الممتص. وتوضح البيانات وجود معامل إرتباط منخفض المعنوية بين نسبة نشاط البوتاسيوم عند الإتزان ومحتوى الطين فى الأراضى، بينما وجد ارتباط مرتفع المعنوية مع التوصيل الكهربى، وكانت أعلى قيمة لنسبة نشاط البوتاسيوم ٠,٠٢٦ (مول/لتر)$^{١/٢}$ تناقصت بعد معالجة هذه الأراضى المتأثرة بالأملاح. ومن ناحية أخرى وجد أن الأراضى الطينية تملك أعلى قيمة للسعة التنظيمية الجهدية للبوتاسيوم بلغت ١٠٩,٦ سنتيمول كجم-١ (مول/لتر)$^{١/٢}$ علاوة على الزيادة الملحوظة فى القيم بعد المعالجة. ويتضح من التجربة البيولوجية أن الارتباط معنوى بين نسبة النشاط للبوتاسيوم وإنتاج الحبوب لنبات القمح، بينما كان الإرتباط منخفضاً مع البوتاسيوم الممتص، ومع السعة التنظمية الجهدية للبوتاسيوم كان معامل الإرتباط مرتفعاً. ويتضح من ذلك أن نسبة النشاط للبوتاسيوم (خاصية الكثافة) عرضة للتغيرات المفاجئة التى هى من سمات الطبيعة الديناميكية للظروف البيئية للأرض، ولقد تبين من هذه الدراسة أن الملوحة والقلوية هى مصدر قلق لنسبة نشاط البوتاسيوم الذى يعتبر مؤشراً غذائياً هاماً. وعلى العكس فالسعة التنظمية الجهدية للبوتاسيوم تستطيع مقاومة التغيرات الشديدة الناجمة عن إرتفاع الملوحة والقلوية فى التربة. ومن هذا المنطلق فإن السعة التنظمية الجهدية تقيم تيسر البوتاسيوم فى الأراضى العادية وكذلك الأراضى المتأثرة بالأملاح.