Potassium release as affected by soil indigenous properties in some soils of Upper Egypt.

تأثّر بعض خواص التربة على انطلاق عنصر البوتاسيوم في بعض أراضي مصر العليا

الملخص:

في الأونة الأخيرة، أصبح البوتاسيوم عنصرًا غذائيًا مهمًا لنمو النباتات، خاصة في التربة ذات القوام الخشن. علاوة على ذلك، يتم ضبط البوتاسيوم بسهولة من التربة عندما تحتوي مياه الري أو المحاليل على تركيزات عالية من الكلسيوم والكالسيوم الأخرى ويتأثر ذلك بنوع طين التربة أيضا. منطلقًا من ذلك أجريت دراسة متعددة الارتباطات لإيجاد العلاقات بين محتويات الطين في التربة وصور البوتاسيوم في الأراضي تحت الدراسة وللتحقيق من مسارات تفاعل الأسمدة البوتاسية المضافة بمعدلات مختلفة في أراضي مختلفة القوام. تم جمع عينات تربة من أربعة مواقع مختلفة هي وادي النقرة وجرف حسين والجعافرة وأضداد.

اجريت تجربة امتصاص بإستخدام سلسلة من تركيزات البوتاسيوم المختلفة (20-180 مللي جرام لتر-1) على الأراضي تحت الدراسة.

1 معهد البحوث والدراسات الأفريقية ودول حوض النيل جامعة أسوان، مصر.

(تأثّر بعض خواص التربة على انطلاق عنصر البوتاسيوم .......) عبد الرحمن ربيع
تم موافقة العلاقات المتحصل عليها مع ثلاثة معادلات رياضية هي لانجمير وبيميلين فريرنلش وتيكين. أظهرت النتائج أن هناك ارتباط قوي بين البوتاسيوم ذات والاستخلاص بخلاط الامونيوم مع محتوى الأراضي تحت الدراسة. وأظهرت النتائج أن نموذج فريرنلش الرياضي هو أفضل نموذج حاكاي امتصاص وإطلاق البوتاسيوم في الأراضي تحت الدراسة. لقد زادت تركيزات البوتاسيوم الذائب مع زيادة تركيزات البوتاسيوم المضافة بالمللي (جرام كجم -1).

يبدو أن نوع التربة وبالأخص محتوى التربة من الطين قام بدور مهم جدا في زيادة احتفاظ التربة بالبوتاسيوم حيث سجلت أقل زيادة في محتوى البوتاسيوم الذائب بالترب ذات المحتوي الأعلى من الطين في الجافرة (طينية، 45.77% طين) بينما حدثت أعلى زيادات في جرف حسن (رملية سلتي، 17.91% طين) وواسط النمرة (رملية طينية سلتي، 35.69% طين). قل البوتاسيوم الذائب بنسبة كبيرة مع زيادة وقت التماس مع التربة. البوتاسيوم المستخلص بخلاط الامونيوم زاد بزيادة تركيزات البوتاسيوم المضافة ولكن على عكس البوتاسيوم الذائب قد زاد بزيادة وقت التماس مع التربة.

الكلمة الدالة: إطلاق البوتاسيوم، نوع الطين، معادلات الامتزاز، حالة البوتاسيوم التربة، مصر.

(تأثير بعض خواص التربة على انطلاق عنصر البوتاسيوم .......) عبّد الرحمن ربيع
ABSTRACT

Recently, K has become a critical nutrient for plant growth, especially in soils of coarse textures. Moreover, K is readily leached out from soils when irrigation waters or soil solutions contain high concentrations of calcium and other cations and affected by soil clay type. Thus, a multi-correlation study was conducted to find the relations between clay contents in the investigated soils and the available forms of K in soil and investigating the reaction pathways of K-fertilizer applied at different rates to soils with different textures. Soil samples collected from 4 different sites i.e., Wadi El-Nokra, Garf Hussein, El-Gaafrah, and Adndan. A sorption experiment was conducted using a series of K concentrations (20-180 mg L⁻¹) on the investigated soils. The obtained relations were fitted to three adsorption isotherms, i.e., Langmuir, Bemmelen-Freundlich, and Temkin. Results show that both water soluble-K and the NH₄OAC-K significantly correlated with the clay contents in the study soils (P=0.020 and 0.034, respectively). Results revealed that Van Bemmelen-Freundlich isotherm model seemed to be the best model fitting K sorption data in all the investigated soils. Concentrations of water-soluble K increased significantly, with increasing the rate of applied K (mg kg⁻¹). It seems that soil type played an essential role in increasing the retention of K in soil, i.e., the lowest increases in the water-soluble K occurred in soils with the highest clay contents in El-Gaafrah soil (Clay, 77.45% clay), whereas the highest increases occurred in Garf Hussein (Sandy Loam, 17.91% clay) and Wadi El-Nokra (Sandy Clay Loam, 35.69% clay). water-
soluble K decreased significantly with increasing contact time. NH₄OAc–K increased in soil with increasing the rate of applied K. On contrary, these concentrations increased with increasing the contact time with soil.

**Key words:** K release, clay type, K sorption, isotherm models, soil k status Egypt.
INTRODUCTION

Potassium is a vital nutrient that crops require in considerable amounts. Unfortunately, farmers in impoverished nations do not utilize it as much as they should. This negligence has resulted in agricultural plants' over-mining of potassium in soils, resulting in a negative K balance. This decrease needs increased potassium fertilizer usage in agriculture. (Shirale et al., 2019). Over 20,000 mg kg$^{-1}$ of total potassium is typically found in Egyptian soils. Plants cannot use most of these since they are structural components of soil minerals.

Plants can only utilize potassium absorbed in soil solution and exchange potassium on the soil particle's exterior. (Wakeel and Ishfaq., 2022). The interaction's pace and orientation between solution and exchangeable forms of K dictate whether applied K is leached into lower horizons, absorbed by plants, transformed into inaccessible, or liberated into accessible forms.

The rate of K removal by plants and the rate at which k can be desorbed from the adsorbed phase define the concentration of k in the soil solution. In comparison, the initial adsorption of equilibrium solution k levels acts as a measure of K availability. As a result, equilibrium K appears to be a more accurate indicator of soil fertility (Bilias and Barbayiannis., 2019). To estimate the rate of additional K fertilizers in soils and create detailed K fertilizer recommendations, THERE IS a need for knowledge of the variance in K adsorption among soils and the equilibrium
between the intensity and quantity phases of soil K (Kassa et al., 2019). As a result, K fertilization is crucial in meeting the K requirements of the plant cropping system.

The studies of K-release Kinetics have used a variety of models and approaches. The miscible displacement and batch procedures are standard and have been used successfully. They also provide similar outcomes when time intervals are employed at equal intervals. The batch approach, which includes placing the adsorbent and adsorptive in a centrifuge tube, has been widely used because of its simplicity. After that, the solution is agitated and centrifuged to separate a clear supernatant for testing.

Although potassium is an essential macronutrient for higher plants, the intricacy of K release and fixation in soils is one of the key reasons why the processes that limit K availability to plants are still unknown, particularly in soils containing K-fixing clay minerals (Bilias and Barbayiannis., 2019). Furthermore, soil testing laboratories have yet to adopt soil testing procedures for determining available K that account for K dynamics and the contribution of non-exchangeable K to plant availability.

As a result, this research aims to investigate the reaction pathways of potassium applied to various textures gathered from multiple locations using sorption conducted under laboratory circumstances utilizing the batch approach. 

**MATERIALS and METHODS**

Aswan area (24° 5.333’N and 32° 53.983’E) is located in the south of Egypt, on the East and Western bank of the Nile River. The study area is confined to four sites. Wadi El-
Nokra, Garf Hussein, El-Gaafrah, and Adndan. Aswan occupies a total area of 34.608 km² with an estimated population of around 351.332 inhabitants and an Elevation of 194m above sea level.

Soil samples at depths 0-30 and 30-60 cm were collected from four different sites to represent soils of different textural classes, then air-dried, ground, and sieved with a 2 mm sieve. Some of its properties were analyzed according to (Page et al., 1982). The total N was determined using macro-Kjeldahl (Gerhardt model VAP 30 S). Total P was determined calorimetrically using vandomolbadate yellow using U.V./Vis spectrophotometer (JENWAY model 6705 UV/Vis), and K⁺, Na⁺ content was detected by a flame photometer (JENWAY model PFP7). Finally, the contents of Ca²⁺, Mg²⁺, Fe, Mn, Zn, and Cu were measured by an ICP-AAS spectrophotometer (Agilent Technologies model 8800) (Jackson., 1959; Cottenie et al., 1982), and data obtained Tabulated in Table 1.
Table 1, Some physical-chemical characteristics of Soil at different sites of Aswan Governorate, Egypt.

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Soil particles size distribution, %</th>
<th>Texture Class</th>
<th>Soil chemical properties</th>
<th>Bd g cm⁻³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clay</td>
<td>Silt</td>
<td>F.S</td>
<td>C.S</td>
</tr>
<tr>
<td>Wadi El-Nokra</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-30</td>
<td>35.69</td>
<td>10.71</td>
<td>47.34</td>
<td>6.26</td>
</tr>
<tr>
<td>30-60</td>
<td>28.22</td>
<td>14.76</td>
<td>52.93</td>
<td>4.09</td>
</tr>
<tr>
<td>Garf Hussein</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-30</td>
<td>17.91</td>
<td>8.84</td>
<td>38.90</td>
<td>34.35</td>
</tr>
<tr>
<td>30-60</td>
<td>12.88</td>
<td>12.78</td>
<td>46.74</td>
<td>27.60</td>
</tr>
<tr>
<td>El-Gaafrah</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-30</td>
<td>77.45</td>
<td>15.97</td>
<td>1.69</td>
<td>4.89</td>
</tr>
<tr>
<td>30-60</td>
<td>76.84</td>
<td>15.72</td>
<td>2.13</td>
<td>5.31</td>
</tr>
<tr>
<td>Adndan</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-30</td>
<td>39.44</td>
<td>20.82</td>
<td>38.32</td>
<td>1.42</td>
</tr>
<tr>
<td>30-60</td>
<td>27.15</td>
<td>33.99</td>
<td>37.97</td>
<td>0.89</td>
</tr>
</tbody>
</table>

Experimental procedure
Adsorption experiment
A series of K concentrations (20 to 200 mg l⁻¹) were prepared from potassium monophosphate (KH₂PO₄ ≥ 99%) dissolved in de-ionized Water. Soil portions equivalent of 2.5 g, were equilibrated with 20 mL of the prepared K solutions for 24h. Soil suspensions were then centrifuged and filtrated using Whatman filter paper No. 42, and the obtained supernatants were kept for K determination.

Adsorption isotherm models
A- Langmuir adsorption equation (Jalali., 2006)

\[
C/(x/m) = 1/kb + C/b
\]

Where: C is the equilibrium solution K concentration (mg l⁻¹),

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x/m is the mass of K adsorbed per unit mass of Soil (mg kg$^{-1}$),
k is a constant related to the bonding energy of K to the Soil, Moreover, b is the maximum K adsorption capacity of the Soil.

**B- Van Bemmelen- Freundlich adsorption equation** (Sposito., 1980)

$$\frac{x}{m} = a C^b$$

By rearranging $\log (x/m) = \log a + b \log C$

Where:
- x/m is the mass of K adsorbed per unit mass of Soil (mg kg$^{-1}$),
- C is the equilibrium solution K concentration (mg l$^{-1}$),
- a and b are constants. The values of a and b are obtained from the intercept and slope, respectively.

**C- Temkin adsorption equation** (Bangroo et al., 2012)

$$\frac{x}{m} = a + b \ln C$$

Where:
- x/m is the mass of K adsorbed per unit mass of Soil (mg kg$^{-1}$),
- C is equilibrium solution K concentration (mg l$^{-1}$),
- a and b are constants. The values of a and b are obtained from the intercept (a) and the slope (b), respectively.

A batch technique model was followed to find out the reaction pathways of K-fertilizer in Soil upon its application for up to 30 hours and the mechanisms of its retention in Soil. Soil portions of 2.5 g were added to plastic cups together with a 25 ml solution of 0.01 M CaCl$_2$ at 25 °C.
according to (Abdul et al., 2007) containing different K concentration levels, *i.e.*, 20, 40, 60, 80, 100, 120, 140, 160, 180 and 200 mg l⁻¹. The lids of the cups were sealed to avoid water evaporation, and the cups were incubated under laboratory conditions for 30 hours. The experimental design was a complete randomized one with eighteen replicates for each treatment. Three samples were taken from each treatment at the following incubation periods 5, 10, 15, 20, 25, and 30 hours of contact, and both the Water and the NH₄OAc extractable K were measured. The amount of K adsorbed was determined as given below:

\[ \Delta K = \frac{(C_{K_i} - C_{K_f})}{(V/W)} \]

Where: \( \Delta K \) is the change of K in soil solution. \( C_{K_i} \) and \( C_{K_f} \) are the initial (K concentration added) and final equilibrium concentrations of K in the solution. V and W are the solution volume and soil mass, respectively.

**Statistical analysis**

The obtained data were statistically analyzed (correlation coefficients) according to the methods mentioned by (Gomez and Gomez., 1984) using Statistical Package for Social Sciences program (SPSS) version 18.0 (Stern., 2010).

**RESULTS and DISCUSSION**

**a) Results**

*Potassium forms in the investigated soils*

The potassium forms of the investigated soils (Water soluble and NH₄OAc extractable) at different areas of Aswan Governorate, Egypt, *i.e.*, Wadi El-Nokra, Garf Hussein, El-Gaafrah, and Adndan, are presented in Table 2. It is evident
from that table that soils of Wadi El-Nokra were of the highest contents of all the studied potassium forms, i.e., soluble K, NH₄-OAc-extractable K contents. Water soluble K and NH₄-OAc-extractable K tended to decrease with depth.

Soils of Garf Hussein represented in Table 2 show lower water-soluble K, NH₄-OAc- extractable K contents. However, although K content was in the surface layer almost higher than that of subsurface soil, the deepest layer contained an almost high content of K in the corresponding layer of surface one. However, it is crucial to indicate that water-soluble contents of the different layers of Garf Hussein soils were not far below the corresponding ones of Wadi El-Nokra soils, even though Wadi El-Nokra soil's contents of K were almost twice the corresponding ones of Garf Hussein. Perhaps the indigenous soil properties of Garf Hussein soils facilitated solubility of the higher portion of potassium.

Relatively, higher values of all K forms were found in soils of El-Gaafrah and Adndan, probably due to the higher contents of the K-bearing minerals.

The soils of both El-Gaafrah and Adndan showed similar trends for soluble K but with relatively more magnitudes than other soils under study, as presented in Table 2. The relatively higher values of both Water soluble and NH₄OAc-extractable K might be attributed to the nature of both soils besides the rich of these soils in their contents of total potassium.
Table 2, Potassium forms in soils at different sites of Aswan Governorate, Egypt.

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Water soluble K mg kg⁻¹</th>
<th>NH₄-OAc</th>
<th>Water soluble K mg kg⁻¹</th>
<th>NH₄-OAc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wadi El-Nokra</td>
<td>288</td>
<td>675</td>
<td>153</td>
<td>585</td>
</tr>
<tr>
<td>0-30</td>
<td>200</td>
<td>553</td>
<td>90</td>
<td>476</td>
</tr>
<tr>
<td>El-Gaafrah</td>
<td>478</td>
<td>752</td>
<td>340</td>
<td>722</td>
</tr>
<tr>
<td>0-30</td>
<td>266</td>
<td>607</td>
<td>196</td>
<td>704</td>
</tr>
<tr>
<td>Garf Hussein</td>
<td>200</td>
<td>553</td>
<td>90</td>
<td>476</td>
</tr>
<tr>
<td>30-60</td>
<td>340</td>
<td>722</td>
<td>196</td>
<td>704</td>
</tr>
</tbody>
</table>

Relationships among some indigenous properties and the different forms of potassium in soils

Potassium contents in the Soil are affected, to a great extent, by its indigenous properties such as particle size distribution (texture), soil reaction (pH), organic matter (O.M.), and calcium carbonate (CaCO₃) content that play an essential role in the equilibrium between the potassium forms, hence its availability for plant uptake. Any change in the status of one form tends to be balanced by an appropriate shift in the other forms (Lalitha and Dhakshinamoorthy., 2014).

Table 3 reveals a significant relationship between the water-soluble and NH₄OAc K in all Soil under study. water soluble-K and the NH₄OAC-K were significantly affected by the clay contents in the study soils, and values were (r= -0.865 at El-Gaafrah and -0.852 at Adndan, respectively). Furthermore, the organic matter content significantly affected the water soluble-K and the NH₄OAC-K, and the values were (r=0.697 at El-Gaafrah and 0.654 at Adndan, respectively). Calcium carbonate did affect available K, particularly in

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Wadi El-Nokra and Garf Hussein, since the values were ($r = -0.630$ and $-0.523$, respectively).

**Table 3**, Correlation coefficients between $K$ form in Soil and selected physical and chemical properties of the investigated soils.

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>E.C.</th>
<th>Soluble $K$</th>
<th>$NH_4$OAc-$K$</th>
<th>Organic content</th>
<th>$CaCO_3$ content</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wadi El-Nokra</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EC</td>
<td>-0.907</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soluble $K$</td>
<td>-0.875</td>
<td>0.154</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$NH_4$OAc-$K$</td>
<td>0.736</td>
<td>0.453</td>
<td>0.803</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic content</td>
<td>-0.814</td>
<td>0.176</td>
<td>0.647</td>
<td>0.498</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$CaCO_3$ content</td>
<td>-0.891</td>
<td>0.657</td>
<td>-0.630</td>
<td>-0.644</td>
<td>-0.750</td>
<td></td>
</tr>
<tr>
<td>Clay content</td>
<td>-0.023</td>
<td>0.123</td>
<td>0.762</td>
<td>0.660</td>
<td>0.543</td>
<td>-0.046</td>
</tr>
<tr>
<td><strong>Garf Hussein</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>EC</td>
<td>-0.254</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soluble $K$</td>
<td>-0.868</td>
<td>0.162</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$NH_4$OAc-$K$</td>
<td>0.501</td>
<td>0.334</td>
<td>0.768</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic content</td>
<td>-0.564</td>
<td>0.156</td>
<td>0.576</td>
<td>0.441</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$CaCO_3$ content</td>
<td>-0.374</td>
<td>-0.122</td>
<td>-0.523</td>
<td>-0.589</td>
<td>-0.711</td>
<td></td>
</tr>
<tr>
<td>Clay content</td>
<td>-0.053</td>
<td>0.137</td>
<td>0.658</td>
<td>0.155</td>
<td>0.575</td>
<td>-0.053</td>
</tr>
<tr>
<td><strong>El-Gaafrat</strong></td>
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<tr>
<td>EC</td>
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<tr>
<td>Soluble $K$</td>
<td>-0.454</td>
<td>0.151</td>
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</tr>
<tr>
<td>$NH_4$OAc-$K$</td>
<td>-0.309</td>
<td>0.405</td>
<td>0.954</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic content</td>
<td>-0.667</td>
<td>0.158</td>
<td>0.654</td>
<td>0.513</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$CaCO_3$ content</td>
<td>-0.063</td>
<td>-0.104</td>
<td>-0.413</td>
<td>-0.051</td>
<td>-732</td>
<td></td>
</tr>
<tr>
<td>Clay content</td>
<td>-0.674</td>
<td>0.133</td>
<td>0.865</td>
<td>0.165</td>
<td>0.541</td>
<td>-0.035</td>
</tr>
<tr>
<td><strong>Adndan</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EC</td>
<td>-0.286</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soluble $K$</td>
<td>-0.428</td>
<td>0.184</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$NH_4$OAc-$K$</td>
<td>-0.428</td>
<td>-0.533</td>
<td>0.887</td>
<td></td>
<td></td>
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<tr>
<td>Organic content</td>
<td>-0.577</td>
<td>0.158</td>
<td>0.697</td>
<td>0.513</td>
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<td></td>
</tr>
<tr>
<td>$CaCO_3$ content</td>
<td>-0.074</td>
<td>-0.134</td>
<td>-0.393</td>
<td>-0.046</td>
<td>-0.754</td>
<td></td>
</tr>
<tr>
<td>Clay content</td>
<td>-0.584</td>
<td>0.142</td>
<td>0.852</td>
<td>0.153</td>
<td>0.505</td>
<td>-0.044</td>
</tr>
</tbody>
</table>

*: significant at 5%

*Modeling $K$ sorption data in the studied soils*
Table 4 shows the concentrations of water-soluble K in the studied soils as affected by the application rate of K. Sorption data of K on the investigated soils were calculated versus equilibrium concentrations of K, and the obtained relations fitted to three adsorption isotherms, *i.e.*, Langmuir, *Bemmelen-Freundlich*, and Temkin isotherms. The calculated parameters of the different isotherm models showed in Table 5.

**Table 4**, Water-soluble K is affected by the rate of K-application to the studied soils.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Concentrations of K- applied (mg l⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Wadi El-Nokra</td>
<td>297.6</td>
</tr>
<tr>
<td>Garf Husseini</td>
<td>159.9</td>
</tr>
<tr>
<td>El-Gaafrah</td>
<td>485.3</td>
</tr>
<tr>
<td>Adndan</td>
<td>344.6</td>
</tr>
</tbody>
</table>

Table 5 reveals that *Van Bemmelen-Freundlich* isotherm model seemed to be the best model fitting K sorption data in all the investigated soils. The negative value of the Langmuir isotherm constants (b) indicates that this model is unsuitable for describing K sorption in the investigated soils. Likewise, the Temkin model's coefficient of determination ($r^2$) values was low to accept this model for describing K sorption in Soil.
Table 5, The calculated parameters and coefficients of determination for the used adsorption isotherms.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Langmuir isotherm</th>
<th>Freundlich isotherm</th>
<th>Temkin isotherm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>b</td>
<td>r²</td>
</tr>
<tr>
<td>Wadi El-Nokra</td>
<td>-414.70</td>
<td>0.0</td>
<td>0.9425.49</td>
</tr>
<tr>
<td>Garf Hussein</td>
<td>-1452.08</td>
<td>0.0</td>
<td>0.9530.267</td>
</tr>
<tr>
<td>El-Gaafrah</td>
<td>-1764.74</td>
<td>0.0</td>
<td>0.92923.93</td>
</tr>
<tr>
<td>Adndan</td>
<td>-375.80</td>
<td>0.0</td>
<td>0.91444.46</td>
</tr>
</tbody>
</table>

Results shown in Table 6 reveal that the concentrations of Water -K in Wadi El-Nokra increased significantly in Soil with increasing the rate of applied K (mg l⁻¹). However, such concentrations decreased with increasing contact time. Likewise, the NH₄OAc-K increased in Soil with the rate of applied K. Moreover, these concentrations increased significantly in Soil with increasing contact time with soil particles.

Table 7 showed that increasing the applied K concentration in Garf Hussein soil increased water-soluble concentrations of K in Soil. Such increases seemed to buffer in Soil, especially under the lower applied doses of K, i.e., the water-soluble K changed slightly with the application of 60 vs. 40 mg K l⁻¹, 100 vs. 80 mg K l⁻¹. On the other hand, the concentrations of water-soluble K decreased with increasing contact time with Soil. Concerning NH₄OAc–K, the results
indicate that increasing the rate of applied K led to concurrent increases in the concentrations of NH₄OAc–K. Contact time seemed to have a significant effect on increasing NH₄OAc–K.

Table 8 shows that water-soluble K increased significantly in Soil of El-Gaafrah with increasing the rate of applied K. These concentrations decreased significantly in Soil with increasing the contact time of soil. On the other hand, NH₄OAc–K increased in Soil with increasing the rate of applied K. Such a result reveals the significance of K fertilization for increasing the available form of K in Soil. It is worth mentioning that NH₄OAc–K concentration increased significantly in Soil with increasing contact time with Soil.

Table 9 shows the same general trend for water-soluble K and NH₄OAc-K as in the other 3 soils, both increased in Soil of Adndan with increasing the rate of applied K. However, such increases seemed to take the form of interval increases rather than steady increases. Within each interval slight increases occurred. It is worth mentioning that the increases in the water-soluble K owing to the application of 60 mg K l⁻¹ seemed to be slight compared with those attained with the application of 40 mg K l⁻¹. On the other hand, water-soluble K declined in Soil with increasing contact time with Soil, whereas NH₄OAc-K increased with increasing the contact time with soil.
Table 6, Water-soluble K and NH₄OAc–K in the Soil of Wadi El-Nokra as affected by the applied K.

<table>
<thead>
<tr>
<th>Applied K (mg kg⁻¹)</th>
<th>Time (h)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water soluble K (mg kg⁻¹ soil)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>251.19</td>
<td>238.07</td>
</tr>
<tr>
<td>40</td>
<td>262.5</td>
<td>249.38</td>
</tr>
<tr>
<td>60</td>
<td>273.42</td>
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<tr>
<td>80</td>
<td>285.12</td>
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<tr>
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<td>313.2</td>
<td>301.25</td>
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<tr>
<td>140</td>
<td>327.24</td>
<td>316.07</td>
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<tr>
<td>160</td>
<td>358.83</td>
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<td>358.58</td>
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<tr>
<td>200</td>
<td>416.55</td>
<td>366.38</td>
</tr>
<tr>
<td>Mean</td>
<td>316.05</td>
<td>297.545</td>
</tr>
<tr>
<td>NH₄OAc –K (mg kg⁻¹ soil)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>701.93</td>
<td>702.83</td>
</tr>
<tr>
<td>40</td>
<td>810.03</td>
<td>818.73</td>
</tr>
<tr>
<td>60</td>
<td>839.93</td>
<td>850.53</td>
</tr>
<tr>
<td>80</td>
<td>872.43</td>
<td>895.23</td>
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<tr>
<td>100</td>
<td>904.83</td>
<td>897.61</td>
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<tr>
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<td>1067.1</td>
<td>1077.53</td>
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<td>1197</td>
<td>1212.73</td>
</tr>
<tr>
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<td>1288.3</td>
<td>1315.63</td>
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<tr>
<td>180</td>
<td>1360.8</td>
<td>1376.43</td>
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<tr>
<td>200</td>
<td>1408.1</td>
<td>1461.13</td>
</tr>
<tr>
<td>Mean</td>
<td>1045.1</td>
<td>1060.838</td>
</tr>
</tbody>
</table>
Table 7, Water-soluble K and NH₄OAc–K (mg kg⁻¹) in the Soil of Garf Hussein were affected by the applied concentrations of K.

<table>
<thead>
<tr>
<th>Applied K (mg kg⁻¹)</th>
<th>Time (h)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Water soluble K (mg kg⁻¹ soil)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>146.65</td>
<td>133.92</td>
</tr>
<tr>
<td>40</td>
<td>165.37</td>
<td>153.42</td>
</tr>
<tr>
<td>60</td>
<td>184.09</td>
<td>171.75</td>
</tr>
<tr>
<td>80</td>
<td>201.25</td>
<td>183.45</td>
</tr>
<tr>
<td>100</td>
<td>214.51</td>
<td>198.27</td>
</tr>
<tr>
<td>120</td>
<td>215.29</td>
<td>202.95</td>
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<tr>
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<td>230.89</td>
<td>218.55</td>
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<tr>
<td>160</td>
<td>253.51</td>
<td>236.49</td>
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<tr>
<td>180</td>
<td>266.38</td>
<td>252.48</td>
</tr>
<tr>
<td>200</td>
<td>281.59</td>
<td>260.67</td>
</tr>
<tr>
<td>Mean</td>
<td>215.95</td>
<td>201.195</td>
</tr>
</tbody>
</table>

| NH₄OAc –K (mg kg⁻¹ soil) |           |          |          |          |          |          |
| 20                   | 656.83    | 662.73   | 668.24   | 673.75   | 673.24   | 698.88   | 672.2783 |
| 40                   | 719.65    | 742.73   | 753.75   | 778.62   | 792.47   | 806.32   | 765.59   |
| 60                   | 857.86    | 886.06   | 893.75   | 924.78   | 929.14   | 945.55   | 906.19   |
| 80                   | 893.24    | 930.16   | 978.62   | 1026.83  | 1016.57  | 1072.98  | 986.4    |
| 100                  | 1002.2    | 1005.04  | 1059.7   | 1117.34  | 1127.34  | 1171.7   | 1080.547 |
| 120                  | 1111.5    | 1119.39  | 1133     | 1146.57  | 1163.75  | 1177.34  | 1141.913 |
| 140                  | 1179.1    | 1194.78  | 1207.3   | 1245.8   | 1278.37  | 1292.98  | 1233.068 |
| 160                  | 1247.1    | 1306.57  | 1318.6   | 1362.73  | 1467.34  | 1461.7   | 1360.675 |
| 180                  | 1334.3    | 1336.83  | 1386.3   | 1409.65  | 1453.75  | 1474.52  | 1399.223 |
| 200                  | 1407.3    | 1417.34  | 1435.3   | 1458.11  | 1482.47  | 1549.91  | 1458.41  |
| Mean                 | 1040.9    | 1060.163 | 1083.5   | 1114.42  | 1138.444 | 1165.188 |            |
Table 8, Water-soluble K and NH₄OAc-K (mg kg⁻¹) in the Soil of El-Gaafrah.

<table>
<thead>
<tr>
<th>Applied K (mg l⁻¹)</th>
<th>Time (h)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Water soluble K (mg kg⁻¹ soil)</td>
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<td></td>
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<tr>
<td>20</td>
<td>430.02</td>
<td>418.85</td>
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<tr>
<td>40</td>
<td>436.19</td>
<td>417.32</td>
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<td>60</td>
<td>446.33</td>
<td>427.43</td>
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<tr>
<td>80</td>
<td>486.11</td>
<td>436.4</td>
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<tr>
<td>100</td>
<td>466.61</td>
<td>446.54</td>
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<td>477.92</td>
<td>459.41</td>
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<tr>
<td>140</td>
<td>499.37</td>
<td>462.14</td>
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<td>489.62</td>
<td>466.04</td>
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<td>553.19</td>
<td>526.49</td>
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<tr>
<td>200</td>
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<td>515.96</td>
</tr>
<tr>
<td>Mean</td>
<td>482.14</td>
<td>457.658</td>
</tr>
</tbody>
</table>

NH₄OAc-K (mg kg⁻¹ soil)

<table>
<thead>
<tr>
<th>Applied K (mg l⁻¹)</th>
<th>Time (h)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>772.73</td>
<td>775.93</td>
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<td>40</td>
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<td>80</td>
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<td>834.43</td>
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<td>881.53</td>
<td>943.43</td>
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<td>958.93</td>
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<td>1158.2</td>
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<tr>
<td>200</td>
<td>1275</td>
<td>1291.43</td>
</tr>
<tr>
<td>Mean</td>
<td>943.83</td>
<td>957.57</td>
</tr>
</tbody>
</table>
Table 9. Water-soluble K and NH₄OAc-K (mg kg⁻¹) in the Soil of Adndan.

<table>
<thead>
<tr>
<th>Applied K (mg L⁻¹)</th>
<th>Times (h)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Water soluble K (mg kg⁻¹ soil)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>318.53</td>
<td>306.19</td>
</tr>
<tr>
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<td>329.45</td>
<td>317.11</td>
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<td>348.95</td>
<td>335.83</td>
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<td>354.8</td>
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<td>401.35</td>
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<tr>
<td>200</td>
<td>423.83</td>
<td>406.03</td>
</tr>
<tr>
<td>Mean</td>
<td>373.01</td>
<td>369.85</td>
</tr>
<tr>
<td>NH₄OAc –K (mg kg⁻¹ soil)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>766.83</td>
<td>767.73</td>
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<tr>
<td>40</td>
<td>817.63</td>
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<td>80</td>
<td>911.53</td>
<td>919.63</td>
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<td>964.63</td>
<td>969.63</td>
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<td>1376.83</td>
</tr>
<tr>
<td>Mean</td>
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<td>1080.22</td>
</tr>
</tbody>
</table>
b) Discussion

The results showed that water-soluble K increased in all the investigated soils with increasing the rate of applied K; however, these concentrations decreased in soils with increasing the soil contact time. clay minerals behave as soil reservoirs for soil K (Barré et al., 2007; Barré et al., 2008). Such reductions in K solubility, termed K sorption, significantly affect the effectiveness of the applied K-fertilizers (Rao et al., 2000; Murashkina et al., 2007). However, its rate still depends on K⁺ saturation in Soil (Simonsson et al., 2007; Zhang et al., 2009). The results obtained in this study show that type of Soil played an essential role in increasing K sorption in soils, i.e., the lowest increases in the water-soluble K occurred in soils with the highest clay contents in El-Gaafrah soil (Clay, 77.45% clay), whereas the highest increases occurred in Garf Hussein (Sandy Loam, 17.91% clay) and Wadi El-Nokra (Sandy Clay Loam, 35.69% clay). Investigating the kinetics of K sorption in the Soil is valuable to provide more insight views on the reaction pathways and their mechanisms in Soil (Sparks and Carski., 1985).

The Freundlich isotherm model best fitted k-sorption data in all the investigated soils. Similar results were reported by (Pal et al., 1999), who found that K adsorption data best fitted the Freundlich isotherm model and took the form of multi-layers on clay minerals.

On the other hand, NH₄OAc-K increased in Soil with the rate of applied K. Moreover, these concentrations increased significantly in the investigated soils with increasing contact
time with soil particles. K-desorption probably occurred from the non-exchangeable K-fractions in Soil. Although rapid sorption of K might exist in soils after K applications (Kolahchi and Jalali., 2007); however, the dissociation of CaCO₃ in soils took place according to the following equation:

\[
\text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{Ca}^{2+} + 2\text{HCO}_3^-
\]

(Gledhill and Morse., 2006)

Thus, the calcium of the slow-release CaCO₃ source replaced K⁺ on soil complexes. Accordingly, the ability of soil minerals to release Ca²⁺ in Soil determines the concentration of the released K (Jalali and Rowell., 2003; Kolahchi and Jalali., 2006). Thus, gradual increases occurred in K concentrations with increasing contact time. It reported that the Ca²⁺ in the calcareous Soil replaced interlayer K⁺ and the non-exchangeable K⁺ release in calcareous soils. Thus, the released K can affect soil fertility (Jalali., 2006).
REFERENCES


