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

تأثير بعض خواص التربة علي انطلاق عنصر البوتاسيوم في بعض أراضي مصر العليا

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الملخص:

في الآونة الأخيرة ، أصبح البوتاسيوم عنصراً غذائياً مهماً لنمو النبات ، خاصة في التربة ذات القوام الخشن. علاوة على ذلك ، يتم غسيل البوتاسيوم بسهولة من التربة عندما تحتوي مياه الري أو المحاليل على تركيزات عالية من الكالسيوم والكاتيونات الأخرى ويتأثر ذلك بنوع طين التربة ايضا. منطلقا من ذلك أجريت دراسة متعددة الارتباطات لإيجاد العلاقات بين محتويات الطين في التربة وصور البوتاسيوم في الاراضي تحت الدراسة وللتحقق من مسارات تفاعل الاسمدة البوتاسية المضافة بمعدلات مختلفة في اراضي مختلفة القوام. تم جمع عينات تربة من اربعة مواقع مختلفة هي وادي النقرة وجرف حسين والجعافرة وادندان.

اجريت تجربة امتصاص بإستخدام سلسلة من تركيزات البوتاسيوم المختلفة (20–180 مللي جرام لتر–1) علي الاراضي تحت الدراسة.

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تم موائمة العلاقات المتحصل عليها مـع ثلاثـة معـادلات رياضـية هـي لانجمير وبيميلين فريندليش وتيمكين. أظهـرت النتـائج أن هنـاك إرتبـاط قوي بين البوتاسيوم الذائب والمستخلص بخــلات الأمونيــوم مـع محتـوي الأراضــي تحـت الدراسـة. وأظهــرت النتــائج أن نمــوذج فريندليش الرياضي هو أفضل نموذج يحــاكي امتصــاص واطــلاق البوتاسـيوم فـي الأراضي تحت الدراسـة. لقـد زادت تركيـزات البوتاسيوم الـذائب مـع زيادة تركيزات البوتاسيوم المضافة بالمللي (جرام كجم –1).

يبدو أن نوع التربة وبالأخص محتوي التربة من الطين قام بدور مهم جدا في زيادة إحتفاظ التربة بالبوتاسيوم حيث سجلت أقل زيادة في محتوي البوتاسيوم الذائب بالتربة ذات المحتوي الأعلي من الطين في الجعافرة (طينية, 77.45% طين), بينما حدثت أعلي زيادات في جرف حسين (رملية سلتية, 17.91% طين) ووادي النقرة (رملية طينية سلتية, 35.69% طين). قل البوتاسيوم الذائب بنسبة كبيرة مع زيادة وقت التماس مع التربة. البوتاسيوم المستخلص بخلات الأمونيوم زاد بزيادة تركيزات البوتاسيوم المضافة ولكن علي عكس البوتاسيوم الذائب قد زاد بزيادة وقت التماس مع التربة.

الكلمة الدالة: إطلاق البوتاسيوم ، نوع الطين, معادلات الإمتزاز, حالة بوتاسيوم التربة, مصر.

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 NH_4OAC-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. NH_4OAc–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 km^2 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 Ca^{+2}, Mg^{+2}, 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.

Soil depth (cm)	Soil particles size distribution, %				Texture Class	Soil chemical properties				Bd g cm 3
	Clay	Silt	F.S	C.S		pH 1:2.5	E.C. 1:2.5	CaCO₃ %	O.M. %	
Wadi El-Nokra										
0-30	35.69	10.71	47.34	6.26	Sandy Clay Loam	7.21	1.04	3.00	1.84	1.24
30-60	28.22	14.76	52.93	4.09		6.78	1.12	3.53	1.19	1.56
Garf Hussein										
0-30	17.91	8.84	38.90	34.35	Sandy Loam	7.43	0.52	1.88	1.42	1.22
30-60	12.88	12.78	46.74	27.60		7.28	0.47	3.01	1.32	1.50
El-Gaafrah										
0-30	77.45	15.97	1.69	4.89	Clay	7.17	0.70	1.76	2.79	1.39
30-60	76.84	15.72	2.13	5.31		7.25	0.65	1.06	1.22	1.66
Adndan										
0-30	39.44	20.82	38.32	1.42	Clay	7.28	0.53	2.05	2.15	1.38
30-60	27.15	33.99	37.97	0.89	Loam	7.13	0.49	1.33	1.12	1.69

Experimental procedure
Adsorption experiment

A series of K concentrations (20 to 200 $mg\ l^{-1}$) were prepared from potassium monophosphate ($KH_2PO_4 \geq 99\%$) 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 ($mg\ l^{-1}$),

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)

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

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)

$$x/m = a + b\ ln\ C$$

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 $\underline{M}$ 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 NH_4OAc extractable K were measured. The amount of K adsorbed was determined as given below:

$$\Delta K = (CK_i - Ck_f)/ (V/W)$$

Where: ΔK is the change of K in soil solution. CK_i and Ck_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 NH_4OAc 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, NH_4-OAc-extractable K contents. Water soluble K and NH_4-OAc-extractable K tended to decrease with depth.

Soils of Garf Hussein represented in Table 2 show lower water-soluble K, NH_4-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 NH_4OAc-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.

Soil depth (cm)	Water soluble $mg\ kg^{-1}$	NH4-OAc	Water soluble	NH4-OAc
	Wadi El-Nokra		**Garf Hussein**	
0-30	288	675	153	585
30-60	200	553	90	476
	El-Gaafrah		**Adndan**	
0-30	478	752	340	722
30-60	266	607	196	704

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 ($CaCO_3$) 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

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.

	pH	E.C.	Soluble K	NH$_4$OA$_C$-K	Organic content	CaCO$_3$ content
Wadi El-Nokra						
EC	-0.907					
Soluble K	-0.875	0.154				
NH$_4$OAc- K	0.736	0.453	0.803			
Organic content	-0.814	0.176	0.647	0.498		
CaCO$_3$ content	-0.891	0.657	-0.630	-0.644	-0.750	
Clay content	-0.023	0.123	0.762	0.660	0.543	-0.046
Garf Hussein						
EC	-0.254					
Soluble K	-0.868	0.162				
NH$_4$OAc- K	0.501	0.334	0.768			
Organic content	-0.564	0.156	0.576	0.441		
CaCO$_3$ content	-0.374	-0.122	-0.523	-0.589	-0.711	
Clay content	-0.053	0.137	0.658	0.155	0.575	-0.053
El-Gaafrah						
EC	-0.236					
Soluble K	-0.454	0.151				
NH$_4$OAc- K	-0.309	0.405	0.954			
Organic content	-0.667	0.158	0.654	0.513		
CaCO$_3$ content	-0.063	-0.104	-0.413	-0.051	-732	
Clay content	-0.674	0.133	0.865	0.165	0.541	-0.035
Adndan						
EC	-0.286					
Soluble K	-0.428	0.184				
NH$_4$OAc- K	-0.428	-0.533	0.887			
Organic content	-0.577	0.158	0.697	0.513		
CaCO$_3$ content	-0.074	-0.134	-0.393	-0.046	-0.754	
Clay content	-0.584	0.142	0.852	0.153	0.505	-0.044

*: 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.

Sites	Concentrations of K- applied ($mg\ l^{-1}$)								
	20	40	60	80	100	120	140	160	180
Wadi El-Nokra	297.6	309.7	314	317.1	324.5	324.9	328.8	329.2	40.5
Garf Hussein	159.9	162.23	162.62	168.08	171.9	174.7	174.3	175.5	166.7
El-Gaafrah	485.3	491.5	506.9	512.8	515.7	516.1	518.4	518.8	486.3
Adndan	344.6	350.8	370.3	373.02	374.6	378.9	379.7	379.6	380.8

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.

Sites	Langmuir isotherm			Freundlich isotherm			Temkin isotherm		
	A	b	r^2	B	X	r^2	a	B	r^2
Wadi El-Nokra	-414.70	-0.02	0.942	5.49	4.69	0.855	-1075.11	602.79	0.592
Garf Hussein	-1452.08	-0.02	0.953	0.267	1.78	0.980	-2053.50	884.56	0.731
El-Gaafrah	-1764.74	-0.03	0.929	23.93	1.44	0.890	-1606.20	1159.70	0.751
Adndan	-375.80	-0.02	0.914	4.46	4.03	0.864	-440.60	464.28	0.516

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 NH_4OAc-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 NH_4OAc–K, the results

indicate that increasing the rate of applied K led to concurrent increases in the concentrations of NH_4OAc–K. Contact time seemed to have a significant effect on increasing NH_4OAc–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 NH_4OAc-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 NH_4OAc-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.

Applied K (mg kg⁻¹)	Time (h)						Mean
	5	10	15	20	25	30	
Water soluble K (mg kg⁻¹ soil)							
20	251.19	238.07	227.29	214.95	204.17	193.39	221.51
40	262.5	249.38	235.2	224.7	211.97	200.8	230.7583
60	273.42	256.01	241.33	223.53	210.41	196.9	233.6
80	285.12	272	260.05	246.54	231.47	218.35	252.255
100	298.77	281.36	266.68	248.49	235.76	222.64	258.95
120	313.2	301.25	287.74	271.89	255.65	244.09	278.97
140	327.24	316.07	300.61	286.71	273.2	261.25	294.18
160	358.83	336.35	319.72	300.36	287.24	273.34	312.64
180	373.65	358.58	343.51	331.56	318.44	300.25	337.665
200	416.55	366.38	349.36	331.17	307.52	295.18	344.36
Mean	316.05	297.545	283.15	267.99	253.583	240.619	
NH₄OAc –K (mg kg⁻¹ soil)							
20	701.93	702.83	704.13	721.43	731.93	761.73	720.6633
40	810.03	818.73	820.03	827.83	852.23	906.73	839.2633
60	839.93	850.53	868.85	886.03	888.73	895.53	871.6
80	872.43	895.23	932.53	957.93	971.53	993.73	937.23
100	904.83	897.61	946.23	1007.63	1021.03	1095.23	978.76
120	1067.1	1077.53	1123	1162.33	1189.73	1202.53	1137.047
140	1197	1212.73	1244.1	1261.63	1300.33	1306.93	1253.797
160	1288.3	1315.63	1336.9	1404.73	1451.63	1541.83	1389.847
180	1360.8	1376.43	1467.4	1522.03	1568.83	1536.63	1472.03
200	1408.1	1461.13	1479.2	1489.23	1520.03	1550.63	1484.73
Mean	1045.1	1060.838	1092.3	1124.08	1149.6	1179.15	

Table 7, Water-soluble K and NH$_4$OAc–K (*mg kg^{-1}*) in the Soil of Garf Hussein were affected by the applied concentrations of K.

Applied K (*mg kg^{-1}*)	Time (h)						Mean
	5	10	15	20	25	30	
Water soluble K (*mg kg^{-1}* soil)							
20	146.65	133.92	123.14	111.97	101.19	88.46	117.555
40	165.37	153.42	141.08	127.96	116.4	103.28	134.585
60	184.09	171.75	159.22	146.68	134.15	121.61	152.9167
80	201.25	183.45	174.62	157.99	141.36	126.29	164.16
100	214.51	198.27	186.71	168.52	151.5	140.72	176.705
120	215.29	202.95	190.61	178.66	166.71	155.15	184.895
140	230.89	218.55	203.87	188.41	176.46	164.12	197.05
160	253.51	236.49	219.47	203.23	191.28	176.6	213.43
180	266.38	252.48	239.75	226.24	212.34	198.44	232.605
200	281.59	260.67	245.99	232.09	218.97	207.02	241.055
Mean	215.95	201.195	188.45	174.175	161.036	148.169	
NH$_4$OAc –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 NH$_4$OAc-K (*mg kg^{-1}*) in the Soil of El-Gaafrah.

Applied K (*mg l^{-1}*)	Time (h)						Mean
	5	10	15	20	25	30	
Water soluble K (*mg kg^{-1} soil*)							
20	430.02	418.85	407.68	397.29	386.12	375.34	402.55
40	436.19	417.32	406.98	396.51	385.73	375.73	403.0763
60	446.33	427.43	412.75	398.07	386.12	374.95	407.6083
80	486.11	436.4	420.94	405.87	392.36	380.41	420.3483
100	466.61	446.54	426.01	407.43	390.8	378.46	419.3083
120	477.92	459.41	443.56	426.54	409.91	397.57	435.8183
140	499.37	462.14	443.17	429.27	414.2	401.86	441.6683
160	489.62	466.04	453.7	441.36	427.85	414.34	448.8183
180	553.19	526.49	496.99	476.07	447.74	435.79	489.3783
200	536.03	515.96	499.33	481.14	464.51	451.78	491.4583
Mean	482.14	457.658	441.11	425.955	410.534	398.623	
NH$_4$OAc –K (*mg kg^{-1} soil*)							
20	772.73	775.93	784.53	790.23	798.93	810.13	788.7467
40	832.43	834.33	837.13	839.93	844.63	901.73	848.3633
60	832.43	834.13	836.63	843.53	845.23	876.83	844.7967
80	836.73	841.23	847.63	865.83	915.13	932.63	873.1967
100	836.93	834.43	848.63	907.03	990.73	1027.63	907.5633
120	881.53	943.43	992.53	1044.43	1086.83	1111.73	1010.08
140	958.93	975.83	1013	1041.33	1105.73	1271.13	1060.997
160	1053.3	1073.73	1103.9	1120.13	1136.23	1265.53	1125.48
180	1158.2	1171.23	1293.4	1366.23	1379.23	1574.23	1323.763
200	1275	1291.43	1334	1386.83	1426.03	1459.83	1362.197
Mean	943.83	957.57	989.15	1020.55	1052.87	1123.14	

Table 9, Water-soluble K and NH$_4$OAc-K (*mg kg^{-1}*) in the Soil of Adndan.

| Applied K (*mg L^{-1}*)	Times (h)						Mean
	5	10	15	20	25	30	
Water soluble K (*mg kg^{-1} soil*)							
20	318.53	306.19	294.63	282.29	269.56	258	288.2
40	329.45	317.11	302.43	287.36	275.02	264.63	296
60	331.01	317.5	300.87	288.53	276.19	263.46	296.26
80	348.95	335.83	321.15	307.64	293.74	282.57	314.98
100	354.8	342.46	327.78	312.71	300.37	289.59	321.285
120	391.46	377.17	366	349.76	336.25	323.52	357.36
140	400.82	386.14	369.51	357.17	345.61	332.88	365.355
160	415.64	400.18	383.16	361.07	340.54	328.98	371.595
180	415.64	401.35	389.79	371.21	355.75	339.9	378.94
200	423.83	406.03	389.01	377.06	364.33	351.21	385.245
Mean	373.01	369.85	357.07	329.48	315.736	303.474	
NH$_4$OAc –K (*mg kg^{-1} soil*)							
20	766.83	767.73	772.43	792.73	807.03	820.83	787.93
40	817.63	823.53	826.23	833.63	868.13	885.03	842.3633
60	827.13	837.63	845.03	852.33	871.03	896.63	854.9633
80	911.53	919.63	948.23	973.73	1007.83	1030.03	965.1633
100	964.63	969.63	986.43	1023.43	1057.33	1073.53	1012.497
120	1221.2	1240.53	1270.5	1309.53	1316.23	1346.13	1284.03
140	1292	1312.83	1320.3	1335.83	1383.13	1415.73	1343.313
160	1262.5	1244.23	1349.7	1438.03	1487.93	1525.93	1384.73
180	1270.6	1309.63	1346	1403.23	1416.23	1442.23	1364.663
200	1358.1	1376.83	1392.7	1403.23	1447.63	1496.83	1412.563
Mean	1069.2	1080.22	1105.8	1136.57	1166.25	1193.29	

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, NH_4OAc-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 $CaCO_3$ in soils took place according to the following equation:

$$CaCO_3 + CO_2 + H_2O \leftrightarrow Ca^{2+} + 2HCO_3^{-}$$
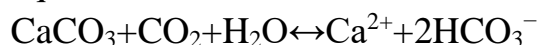
(Gledhill and Morse., 2006)

Thus, the calcium of the slow-release $CaCO_3$ source replaced K^+ on soil complexes. Accordingly, the ability of soil minerals to release Ca^{2+} 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 Ca^{2+} 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

Bangroo, S. A., Wani, M. A., and Ali, T. (2012). Potassium dynamics in representative soils of low, mid and high altitude zones of North Kashmir. International Journal of Agriculture, Environment and Biotechnology, 5(4), 441-444.

Barré, P.; Velde, B.; Catel, N. and Abbadie, L. (2007). Soil-plant potassium transfer: impact of plant activity on clay minerals as seen from X-ray diffraction. Plant and Soil 292, 137-146.

Barré, P.; Velde, B.; Fontaine, C.; Catel, N. and Abbadie, L. (2008). Which 2:1 clay minerals are involved in the soil potassium reservoir? Insights from potassium addition or removal experiments on three temperate grassland soil clay assemblages. Geoderma 146, 216-223.

Bilias, Fotis, and Nikolaos Barbayiannis. (2019). "Potassium-Fixing Clay Minerals as Parameters That Define K Availability of K-Deficient Soils Assessed with a Modified Mitscherlich Equation Model." Journal of Soil Science and Plant Nutrition 19(4):830–40. doi: 10.1007/s42729-019-00082-3.

Cottenie, A., Verloo, M., Kiekens, L., Velghe, G., and Camerlynck, R. (1982). Chemical analysis of plants and soils. Lab. Agroch. State Univ. Gent, Belgium, 63.

Gledhill, D.K. and Morse, J.W., (2006). Calcite dissolution kinetics in Na–Ca–Mg–Cl brines. Geochimica et Cosmochimica Acta 70, 5802-5813.

Gomez, K. A., and Gomez, A. A. (1984). Statistical procedures for agricultural research. John wiley and sons.

Jackson, J. E. (1959). Quality control methods for several related variables. Technometrics, 1(4), 359-377.

Jalali, M. (2006). Kinetics of non-exchangeable potassium release and availability in some calcareous soils of western Iran. Geoderma 135: 63-71.

Jalali, M. (2006). Kinetics of non-exchangeable potassium release and availability in some calcareous soils of western Iran. Geoderma 135: 63-71.

Jalali, M. and Rowell, D.L. (2003). The role of calcite and gypsum in the leaching of potassium in a sandy soil. Experimental Agriculture 39, 379-394.

Kassa, Mesfin, Wassie Haile, and Fassil Kebede. (2019). "Evaluation of Adsorption Isotherm Models for Potassium Adsorption under Different Soil Types in Wolaita of Southern Ethiopia." Communications in Soil Science and Plant Analysis 50(4):388–401. doi: 10.1080/00103624.2018.1563097.

Kolahchi, Z. and Jalali, M. (2007). Effect of water quality on the leaching of potassium from sandy Soil. Journal of Arid Environments 68, 624-639.

Kolahchi, Z. and Jalali, M., (2006). Simulating leaching of potassium in a sandy soil using simple and complex models. Agricultural Water Management 85, 85-94.

Lalitha, M., and Dhakshinamoorthy, M. (2014). Forms of soil potassium-a review. Agricultural reviews, 35(1).

Murashkina, M.A.; Southard, R.J. and Pettygrove, G.S. (2007). Potassium fixation in San Joaquin valley soils derived from Granitic and Nongranitic alluvium abbreviations: C.R., Coast Range; DWA, depth-weighted

average; PANK, plant-available non-exchangeable potassium; SJV, San Joaquin Valley; SN, Sierra Nevada; TPB, tetraphenylboron. Soil Sci. Soc. Am. J. 71, 125-132.

Page, A.L.; Miller, R. H. and Keeney, D.R. (1982). Methods of Soil Analysis Part 2-Chemical and Microbiological Properties. Part II. ASA-SSSA. Agronomy, Madison, USA.

Pal, Y.; Gilkes, R.J. and Wong, M.T.F., (1999). The forms of potassium and potassium adsorption in some virgin soils from.

Rao, C.S.; Rupa, T.R.; Rao, A.S. and Bansal, S.K., (2000). Potassium fixation characteristics of major benchmark soils of India. Journal of the Indian Society of Soil Science 48, 220-228.

Shirale, A. O., Meena, B. P., Gurav, P. P., Srivastava, S., Biswas, A. K., Thakur, J. K., Somasundaram, J., Patra, A. K., and Rao, A. S. (2019). Prospects and challenges in utilization of indigenous rocks and minerals as source of potassium in farming. Journal of Plant Nutrition, 42(19), 2682–2701. https://doi.org/10.1080/01904167.2019.1659353.

Simonsson, M.; Andersson, S.; Andrist-Rangel, Y.; Hillier, S.; Mattsson, L. and Öborn, I. (2007). Potassium release and fixation as a function of fertilizer application rate and soil parent material. Geoderma 140, 188-198.

Sparks, D.L. and Carski, T.H. (1985). Kinetics of potassium exchange in heterogeneous systems. Applied Clay Science 1, 89-101.

Sposito, G. (1980). Derivation of the Freundlich equation for ion exchange reactions in soils. Soil Science Society of America Journal, 44(3), 652-654.

Stern, L. D. (2010). A visual approach to SPSS for Windows. Boston, MA: Allyn andBacon, 115-126.

Wakeel, A., and Ishfaq, M. (2022). Potash Use and Dynamics in Agriculture. Springer.

Zhang, H.; Xu, M.; Zhang, W. and He, X. (2009). Factors affecting potassium fixation in seven soils under 15-year long-term fertilization. Chin. Sci. Bull. 54, 1773-1780.