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Potassium Forms of EL-Dakhla Oasis Soils, New Valley Governorate, Egypt

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ABSTRACT

Thirty surface and subsurface soil samples were collected from 15 sites of El- Dakhla soils, Egypt to study the status of soil potassium forms and their relationship with the physical and chemical properties of these soils. The results indicated that the investigated soil samples showed a wide variation in soil potassium forms. This variation depended upon clay, silt and sand contents as well as soil properties. The soluble K form values ranged from 4.7 to 1332 mg/kg and the exchangeable K form differed from 5.37 to 1368.80 mg/kg. However, the non-exchangeable K form varied from 0.3 to 4.2 g/kg and the total K varied from 2.3 to 19.89 g/kg. The residual K extended from 0.9 to 17.4 g/kg. Generally, about 16.66 % of studied samples were very low in the exchangeable K form. The samples which had a moderate exchangeable K content represented 13.33% of the investigated samples. Also, about 20% of these samples were high in their content of exchangeable K. The very high exchangeable K content represented 40% of the investigated samples. The ECe value had no respectable effects on the soluble K form but, a slight effect was observed in the other K forms. This effect increased in the residual K form. The OM content more than 1% had no remarkable effects on the soluble or exchangeable K forms. However, a clear effect was observed on the residual K form. Generally, all potassium forms had highly significant positive correlations with each other and with organic matter and pH. Also, all forms except the soluble K form showed highly significant negative correlations with calcium carbonates and sand content.

Keywords: soluble K, exchangeable K, non-exchangeable total K, El-Dakhla Oasis.

INTRODUCTION

Potassium (K) is one of the major elemental constituents of the earth crust. It comprises an average of 2.3 % of the earth crust, making it the seventh most abundant element and the fourth most abundant mineral nutrient in the lithosphere (Jalali, 2006). Feldspars and micas as primary minerals and illites and transitional clays as secondary minerals are important K bearing minerals that are present in abundant amounts in some soils. In most soils, the total K reserves are generally large, but only a small portion of them is immediately or slowly available for plant uptake (Fotyma, 2007).The speciation of the nutrients in the soil is related to their chemistry inherited from parent materials as well as the time of impaction. Atomic properties also have a significant role in the cation speciation. The binding mechanisms for nutrients in soils vary with the composition of soils and their physical properties. Thus, the nutrient may form different species according to whether it is bound to various soil compounds, reacting surfaces, and external or internal binding sites with different bonding energy (Kabata-Pendias and Pendias, 1992).

Soil potassium is divided into five forms including soluble, exchangeable, non-exchangeable and residual forms. However, the equilibrium and dynamic between these forms in a soil differ due to the properties of this soil (Bhattacharyya*etal.*,2007 ;Usman and Gameh, 2008; Jalali and Rovell, 2003; Zhang *et al.*, 2010).The soluble and exchangeable forms of K are considered readily available while the other forms are slowly or even unavailable for plants. Water soluble K^+ is taken up by plants and soil microbes mostly from the soil solution. Its quantity in the soil solution depends upon the buffering capacity of the clay minerals (Kirkman *et al.*, 1994; Clawson, 2011).

The exchangeable K exists as an outer-sphere complex that is electrostatically bound to the negative charge sites of clay minerals (Saini and Grewal, 2014). It is affected by the soil mineral type, CEC, anion contents, types and amounts of complementary cations (Sparks, 2000). In Egyptian soils, Abou El-Roos (1972), Ali (1974), Abd-El Hamid (1983) and Hassan (1985) found that the exchangeable K ranged between 31.2 mg/kg in the coarse-textured soils and 1411.8 mg /kg in the fine- textured ones.

The non-exchangeable potassium is held between the layers of clay minerals and its content depends upon the fixing capacity of these minerals, which is controlled by some external variables, such as temperature, moisture status, concentrations of calcium and ammonium cations, and manure utilization as well as some soil properties (Sparks, 2000). This form of K is unavailable to immediate plant uptake but it contributes to the maintenance of exchangeable K levels and the labile K pool (Zhou and Wang, 2008).The release of the non-exchangeable form of K arises when the level of both exchangeable and soluble K in the soil solution decreases due to crop deletion and/or leaching (Sparks,1980).

The total K content of soils varies from <0.01 to about 4% and is commonly about 1% (Wild, 1988). In Aridisols, it ranges from 1.5 to 1.8% (Srinivasarao*et al.*, 2007). Clay soils contain relatively high amounts of the total K as a component of hardly soluble minerals; however, only a small fraction is present in an available form (Shaaban and Abou El-Nour, 2012).

This study aims to evaluate various potassium forms of El-Dakhla oasis soils, New Valley, Egypt and investigated the relations between these forms and the soil properties.

MATERIALS AND METHODS

Location and Soil Sampling

Dakhla oasis is located between latitudes of 25 º 04` to 26 º 09`N and longitudes of 28º 03` to 29°39`E, 450 km far from Assiut city (El-Sayed and Abd Al-Aziz, 2008) and between El Farafra and El Kharga oases. Thirty soil samples were chosen from 15 sites on their characteristics representing the surface (0-30 cm) and subsurface (30-60 cm) layers of El-Dakhla soils (Figure 1). These samples were collected to evaluate the various potassium forms and examine the relations between these forms and the properties of these soils.

The collected soil samples were air-dried, crushed with a wooden roller, sieved to pass through a 2 mm sieve and kept for the physical and chemical analysis as well as the determination of potassium forms. Some physical and chemical properties of these soil samples are present in Tables 1 and 2 respectively.

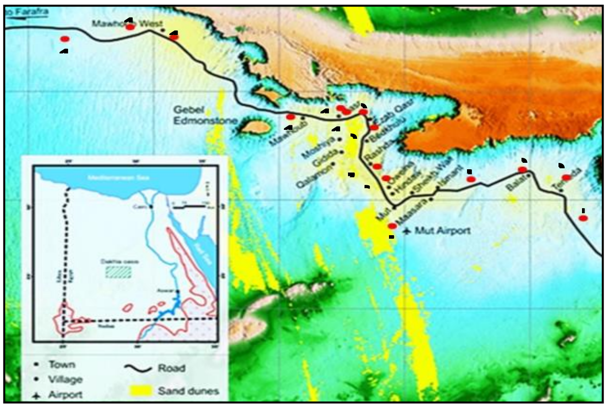

Fig 1. The location map of the sample sites in the study area after DEM of the SRTM-03 (USGS, 2004; NASA, 2005)

Soil Analysis

The particles-size distribution of the soils was performed using the pipette method (Piper, 1950). The organic matter content of the soil samples was determined using the dichromate oxidation method (Jackson, 1973). Soil calcium carbonate was estimated using the calcimeter method according to Nelson (1982). Soil pH was determined in a 1:2.5 of soil to water suspension using a glass electrode (McLean, 1982). The electrical conductivity of the soil paste extract (EC_e) was measured using a conductivity meter (Jackson, 1973).

Table 1. Some physical properties of the studied soil samples

Site no.	Depth (cm)	Location	Particle size distribution(%) Sand	Silt	Clay	Texture	Saturation percentage (%)
1	0-30	Tenida	64	13	23	S.C. Loam	54
	30-60		68	13	19	Sandy Loam	68
2	0-30	Tenida	76	4	20	S.C. Loam	37
	30-60		81	3	16	Sandy Loam	34
3	0-30	Shoash	76	4	20	S.C. Loam	41
	30-60		78	4	19	S.C. Loam	39
4	0-30	Balat	68	13	19	Sandy Loam	52
	30-60		68	13	19	Sandy Loam	56
5	0-30	Mut	41	12	47	Clay	96
	30-60		41	10	49	Clay	99
6	0-30	El-Qalamon	45	18	37	Clay Loam	102
	30-60		47	7	45	Sandy Clay	100
7	0-30	El-Rashda	50	10	40	Sandy Clay	72
	30-60		82	5	13	Sandy Loam	30
8	0-30	Budkholo	70	11	19	Sandy Loam	50
	30-60		65	11	24	S.C. Loam	46
9	0-30	Ezab El-Kasr	90	2	8	Sand	39
	30-60		84	3	13	Loamy Sand	30
10	0-30	Ezab El-Kasr	89	2	9	Loamy Sand	25
	30-60		91	1	8	Sand	24
11	0-30	El-Giza	84	4	12	Loamy Sand	31
	30-60		74	8	18	Sandy Loam	38
12	0-30	El-Mawhob	79	8	13	Sandy Loam	41
	30-60		77	11	12	Sandy Loam	38
13	0-30	El-Mawhob	62	17	20	S.C. Loam	49
	30-60		59	16	25	S.C. Loam	50
14	0-30	Beer 8	78	11	11	Sandy Loam	36
	30-60		72	12	15	Sandy Loam	31
15	0-30	Abo-MonkarWay	29	32	39	Clay Loam	99
	30-60		20	37	43	Clay	105

Soil Potassium Forms.

A potassium fractionation of the selected soil samples was carried out as follows:

Water soluble K was extracted using a 1:10 extract of the soil to distilled water.

Soluble plus exchangeable K (soil available K) was extracted using 1 N NH4OAc at pH 7 as described by Carson (1980). The difference between K extracted using 1N NH4OAc and that extracted using distilled water gave a measure of the exchangeable K.

Table 2. Some chemical properties of the studied soil samples

Site no.	Depth (cm)	Location	EC_e (dS/m)	pH	OM (%)	$CaCO_3$ (%)	CEC (cmol/kg)	SAR_e
1	0-30	Tenida	8.21	7.15	2.25	10.61	21.74	6.09
	30-60		10.31	7.12	4.64	10.38	28.69	4.17
2	0-30	Tenida	0.90	7.44	1.43	4.77	12.32	0.23
	30-60		0.86	7.67	0.41	5.53	7.05	0.24
3	0-30	Shoash	1.21	7.35	1.24	6.52	40.32	0.28
	30-60		2.17	7.54	0.83	5.61	54.97	1.28
4	0-30	Balat	18.08	7.5	0.23	5.30	7.20	16.07
	30-60		37.70	7.75	0.41	7.73	8.61	30.28
5	0-30	Mut	10.53	7.57	2.55	1.29	29.45	3.46
	30-60		0.79	7.57	1.58	3.56	14.98	12.38
6	0-30	El-Qalamon	16.49	7.8	1.13	8.86	27.57	45.01
	30-60		20.70	7.86	0.86	8.33	36.16	54.05
7	0-30	El-Rashda	3.53	7.61	1.69	6.06	20.63	2.29
	30-60		5.36	7.73	0.60	5.68	10.30	6.43
8	0-30	Budkholo	0.59	7.55	1.29	5.76	17.92	0.28
	30-60		0.68	7.62	1.13	6.06	17.31	0.60
9	0-30	Ezab El-Kasr	1.79	7.91	2.14	7.05	33.07	0.88
	30-60		4.34	7.87	1.02	7.50	6.25	2.89
10	0-30	Ezab El-Kasr	0.88	7.47	1.13	4.92	6.01	0.51
	30-60		0.65	7.51	0.62	4.32	4.00	0.39
11	0-30	El-Giza	0.884	7.8	0.65	8.18	21.64	3.51
	30-60		0.654	7.68	1.06	4.70	11.76	6.53
12	0-30	El-Mawhob	2.92	7.39	0.69	5.00	10.33	0.72
	30-60		2.61	7.32	0.59	14.24	16.94	0.38
13	0-30	El-Mawhob	99.60	7.63	0.42	18.94	27.54	15.82
	30-60		100.60	7.5	0.72	18.56	24.19	39.34
14	0-30	Beer 8	2.89	7.44	1.19	16.21	18.51	0.61
	30-60		3.61	7.53	1.09	21.06	15.53	0.54
15	0-30	Abo-MonkarWay	5.31	7.52	0.72	6.67	62.56	7.37
	30-60		7.51	7.6	1.09	6.82	49.90	15.10

Soluble, exchangeable and non-exchangeable K was extracted by boiling 2 g of the soil sample with 20 ml of 1M HNO3 solution for 25 min (Pratt, 1965). The difference between K extracted with 1M HNO_3 and that extracted with 1N NH4OAc gives a measure of the non-exchangeable K..

Total soil K: was obtained by digesting a half gram of the soil sample using concentrated acids of HF, HNO_3 and HCl (Krudsen et al., 1982).

Residual K form: was estimated from the difference between the total soil potassium and sum of the other extracted forms.

RESULTS AND DISSECTION

1-Distribution of Soil Potassium Forms in the Study Area

Table (3) indicated that the investigated soil samples showed a wide variation in soil potassium forms. This variation depends upon the soil texture and the other soil properties.

a- Soluble potassium

The soluble potassium (K) is considered the most available K pool in soils for plant uptake which is affected by the soil properties and the direct application of K fertilizers. The soluble K form in the investigated soil samples ranged from 4.7 to 1332 mg/kg (Table 3). The highest value was found in the surface layer of site 1 (Tenida), while the lowest one was recorded in the surface layer of site 11 (El-Giza) with an average value of 235.76 mg/kg. In most studied cases, it was noticed that the soluble K increased with soil depth. Generally, it was observed presence of some soil samples with a very high soluble K concentration but most of these samples suffered from low levels of soluble K.

b- Exchangeable potassium

The exchangeable K level in the investigated soil samples differed from a location to another and from site to another (Table 3). The highest value of the exchangeable K (1368.8 mg/kg) occurred in the subsurface layer of site 1 (Tenida) while, the lowest one (5.37 mg/kg) was found in the surface layer of site 11 (El-Giza) with an average value of 429.91 mg/kg.

In most cases, the exchangeable K values were higher in the subsurface samples than those of the surface samples. Also, the samples which have a high exchangeable K content were located in the eastern region of the study area. This result may be due to the proximity to river sediments. Generally, about 16.66 % of studied samples had a very low content of the exchangeable K content, 10 % were low in the exchangeable K, 13.33 % had a moderate level of the exchangeable K, 20 % contained a high content of the exchangeable K and 40 % exhibited a very high K content (Fig 2).

Table 3. Distribution of potassium (K) forms in the investigated soil samples

Site no.	Depth (cm)	Location	Potassium forms: Soluble K (mg/kg)	Exch. K (mg/kg)	Sol. k + Exch. k (Available K) (mg/kg)	Non-exch. K (g/kg)	Res. K (g/kg)	Total. K (g/kg)
1	0-30	Tenida	501	583.68	1084.68	2.2	15.3	18.6
	30-60		1332	1368.8	2700.8	4.2	0.9	7.8
2	0-30	Tenida	77	219.56	296.56	0.9	5.4	6.6
	30-60		76	118.38	194.38	0.7	12.9	13.8
3	0-30	Shoash	138	292.78	430.78	1.2	3.8	5.4
	30-60		168	307.11	475.11	1.1	2.7	4.2
4	0-30	Balat	401	808.44	1209.44	2.5	14.9	18.6
	30-60		476	774.06	1250.06	2.4	16.2	19.8
5	0-30	Mut	483	1327.98	1810.98	3.7	9.5	15.0
	30-60		483	1232.89	1715.89	3.5	11.6	16.8
6	0-30	El-Qalamon	78	138.95	216.95	0.5	13.1	13.8
	30-60		149	126.75	275.75	0.7	9.2	10.2
7	0-30	El-Rashda	93	493.77	586.77	2.0	9.4	12.0
	30-60		197	462.86	659.86	1.9	10.1	12.6
8	0-30	Budkholo	24	83.23	107.23	0.5	5.4	6.0
	30-60		59	76.07	135.07	0.4	7.8	8.4
9	0-30	Ezab El-Kasr	155	520.68	675.68	2.2	14.0	16.8
	30-60		203	618.29	821.29	2.1	15.7	18.6
10	0-30	Ezab El-Kasr	274	293.17	567.17	1.0	3.2	4.8
	30-60		97.02	221	318.02	0.7	5.5	6.6
11	0-30	El-Giza	4.7	5.37	10.07	0.3	13.5	13.8
	30-60		45	45.47	90.47	0.4	10.9	11.4
12	0-30	El-Mawhob	346.5	422.03	768.53	1.0	17.4	19.2
	30-60		305.1	341.02	646.12	1.0	10.4	12.0
13	0-30	El-Mawhob	117.3	501.89	619.19	0.5	4.4	5.5
	30-60		108	624.09	732.09	0.8	3.0	4.5
14	0-30	Beer 8	71.05	77.93	148.98	0.5	2.9	3.6
	30-60		70	158.4	228.4	0.6	1.4	2.3
15	0-30	Abo-Monkar Way	269.2	248.38	517.58	1.2	12.9	14.6
	30-60		272	404.17	676.17	1.1	6.2	8.0

Sol. K= soluble K, Exch. K= exchangeable K, Non-exch. K= non-exchangeable K and Res. K= residual K

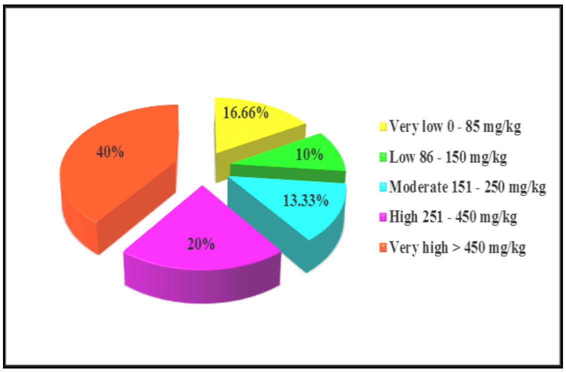

Fig 2. Distribution of the exchangeable potassium form in the study area

C-Soluble + exchangeable potassium (Available K)

Potassium extracted with 1N NH_4OAc is considered as the available K pool for plant uptake. This extract contains the soluble and exchangeable forms of soil K. The lowest value of the available potassium in these soils (10.07 mg/kg) was found in the surface layer of site 11 (El-Giza) while, the highest value (2700.8 mg/kg) was recorded in the subsurface layer of site 1 (Tenida) with an average value of 665.67 mg/kg, (Table 3). As it illustrated in Figure 3, about, 60 % of soil samples had very high amounts of the available K content, 13.33 % were high in the available K , 10 % contained moderate levels of the available K, 13.33 % had a low content of the available K and only 3.33% were very low in the available K (Bashour, 2001). Therefore, the majority of the soils in the study area suffers from potassium deficiency. However, few soil samples in the study area show low and very low contents of the available K. These samples are located in the surface and subsurface layers of sites 8 (Budkholo) and 11 (El-Giza) as well as the surface layer of site 14 (Beer 8). In most cases, the sub surface layer of these soils exhibited a higher level of the available K compared to the surface one (Table 3, Fig. 4 a and Fig. 4 b). In the cultivated soils of this study area the irrigation water could leach the soluble K downward to the subsurface layers. Also, in most cases, the clay fraction is higher in the subsurface layer.

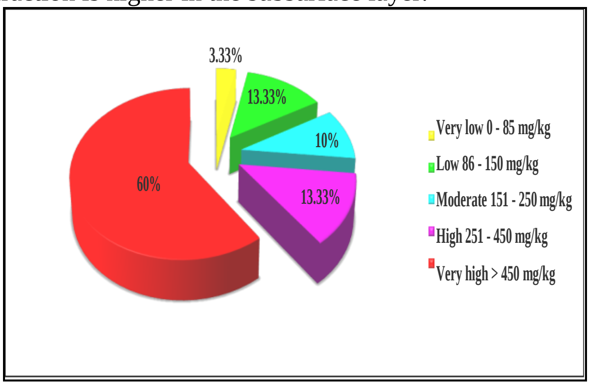

Fig 3. Distribution of the available soil potassium in the study area.

d- Non-exchangeable Potassium

The non-exchangeable K form is considered the K that helds between layers of clay minerals such as micas (Fanning et al., 1989 ; Raghad et al., 2016). In the investigated soil samples, the non-exchangeable K values ranged between 0.3 and 4.2 g/kg with an average value of 1.39 g/kg (Table 3). The highest value of the non-exchangeable k was recorded in the subsurface layer of site 1 (Tenida) while, the lowest one was found in the surface layer of site 11 (El-Giza). In most cases, the non-exchangeable K values decreased with depth. It may be attributed to the nature of the parent material that is rich in potassium such as micas and orthoclase. Some locations also contain a marine sediment, derived shale that has some mica types such as glauconite (Said, 1962; Geological survey of Egypt 1982; Rahim and Ageeb, 2003). The equilibrium reactions among K forms markedly affect whether the applied potassium that becomes available in the soil solution to plants leach to lower soil layers or converts to unavailable forms (Sparks and Huang, 1985; Usman and Gameh, 2008).

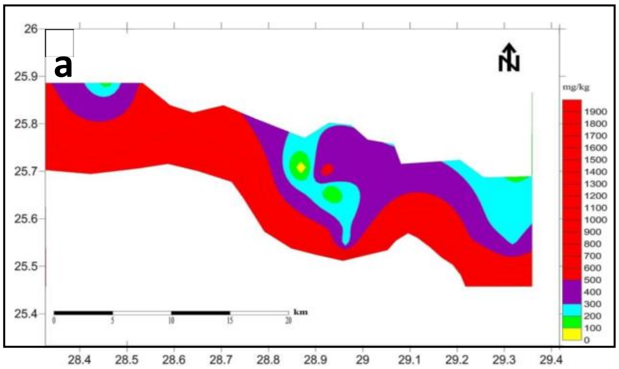

Fig 4 a. A location map of available potassium values in the soil surface layer of the study area

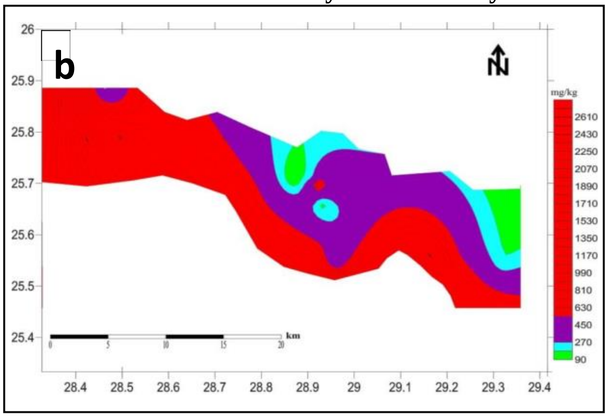

Fig 4 b. A location map of available potassium values in the subsurface layer of the study area

e- Residual Potassium

The results also indicated that the residual K was the dominant form in these soil samples. The residual K levels varied from 0.9 to 17.4 g/kg with an average value 8.99 g/kg (Table 3). The highest value of the residual K was observed in the surface layer of site 12 (El-Mawhob) but the lowest one was found in the subsurface layer of site 1 (Tenida). Also, the residual K showed an irregular trend with soil depth. It was noticed that most of the study area had a high content of the residual K form. The residue K is located in the K bearing primary minerals such as feldspars (Sparks and Huang, 1985). These minerals are considered the K reservoir since they are difficult to be weathered.

f- Total potassium

Table 3 showed that the level of the total potassium in the investigated soil samples differed from site to another and between both surface and subsurface layers due to its contents of clay, silt and sand. The highest value of the total potassium (19.8 g/kg) was observed in the subsurface layer of site 4 (Balat) while the lowest value (2.3 g/kg) was recorded in the subsurface layer of site 14 (Beer 8) with an average value of 11.04 g/kg. Wahba and Darwish (2010) reported that the sandy and calcareous soils are very poor in plant nutrients, especially potassium.

1-Impact of Soil Properties on Potassium Forms

a- Soil texture

Figure 5 clearly showed that the soil texture had a variable effect on the potassium forms. The highest mean level of soluble K form (412.7mg/kg) was observed with clay texture followed by the sandy loam texture (304.0 mg.kg). However, the lowest mean K value of the soluble K form was recorded for the sand and sandy clay textures (126.0 and 121.0 mg/kg, respectively). Also, the sandy clay loam soils had a considerable mean amount (166.9 mg/kg) of soluble K. Clay soils have relatively high exchangeable K levels on their sites which they are in an equilibrium with the soluble K form. Generally, the soluble K in these soils could be ranked in the descending order of clay > sandy loam > clay loam > sandy clay loam > loamy sand > sand > sandy clay.

Also, Figure 5 illustrated that the clay and sandy loam textures had a mean convergent quantity of 988.3 and 423.5 mg/kg, respectively of the exchangeable K form. The sandy clay texture had a less mean exchangeable K level (310.5 mg/kg) than the sand texture (371.0 mg/kg). The lowest mean value of the exchangeable K form was observed for the clay loam (139.5 mg/kg). Generally, the exchangeable K of the different soil textures could be arranged in the descending order of clay > sandy loam > sandy clay loam > sand > sandy clay > loamy sand > clay loam.

In addition, the clay texture had the highest mean value of non-exchangeable K form (2.78 g/kg) followed by the sand and sandy loam textures (1.46 and 1.44 g/kg, respectively). Considerable mean amounts of the non-exchangeable K form were noticed in the sandy clay and loamy sand textures (1.34 and 1.13 g/kg, respectively). However, the mean lowest value of the non-exchangeable K form was found for clay loam soils (0.87 g/kg). Montmorillonite, vermiculite, and weathered micas are the major clay minerals that tend to fix K (Sparks, 1987). Moreover, the non-exchangeable K form in these soils may be arranged in the descending order of clay > sand > sandy loam > sandy clay > loamy sand > sandy clay > loam > clay loam.

The residual K was the dominant K form in the clay loam soils (12.97 g/kg) followed by the loamy sand (10.8 g/kg) and then sand (9.75 g/kg) textures (Fig. 5). On the other hand, there was a small difference in the residual K content between sandy loam (9.38 g/kg) and sandy clay (9.33 g/kg) textures. However, the sandy clay loam had the lowest mean content (6.04 g/kg) of the residual K. Generally, the residual K in these soil textures could be ranked in the descending order of clay loam > loamy sand > sand > clay > sandy loam > sandy clay > clay > sandy clay loam.

b- Organic matter content

The investigated soil samples had an organic matter

(OM) content of less than 1 % showed lower mean levels of all K forms except the residual K than those of the OM content of more than 1 % (Fig. 6). The mean levels of soluble K, exchangeable K and non-exchangeable K increased from 208.83, 381.64 mg/kg and 1.14 g/kg, respectively, in the soil samples of the OM content of < 1 % to 256.36, 466.81 mg/kg and 1.59 g/kg, respectively, in those of the OM content ≥ 1 %. However, the mean level of the residual K decreased from 10.24 g/kg in the soil samples that had the OM content < 1 % to 8.03 g/kg in the samples that contained ≥ 1 % of the OM content. Therefore, the organic matter causes the residual K to transform to the soluble, exchangeable and non-exchangeable K forms on the expense of the reduction of the level of the residual K form. Organic acids that are produced from the organic matter decomposition may attack the residual K that is present in K bearing minerals and release some K levels to become soluble, exchangeable and non-exchangeable K forms. These findings are in a harmony with those obtained by Saini and Grewal (2014) and Machado et al (2016).

c- Electrical conductivity(EC_e)

A slight effect of the soil salinity (EC_e) was observed on the K forms of the studied soil samples (Fig. 6). The soil samples that had an EC_e value of more than 4 dS/m showed higher levels of K forms compared to those of low ECe levels (< 4 dS/m). The mean values of soluble, exchangeable, non- exchangeable and residual K increased from 146.26, 288.76 mg/kg, 1.06, 8.13 g/kg, respectively, in the low EC_e (< 4 dS/m) soil samples to 352.81, 614.49 mg/kg, 1.83, 10.11 g/kg, respectively, in the high EC_e (≥4 dS/m) ones. It may be due to presence of potassium salts in these soil samples. In addition, the equilibrium that occurs between potassium forms results in increases in the other K forms when adequate potassium levels are found in soil solution.

d-Calcium carbonate content

Figure 6 also showed that presence of soil calcium carbonate ($CaCO_3$) affected the soil potassium forms of the samples. Slight effects increases were observed in the soluble, exchangeable and non-exchangeable K forms while, a considerable effect (a decrease) in the residual K form of the soil samples of the high $CaCO_3$ content (≥ 10 %) compared to those of the low $CaCO_3$ content (< 10 %). The samples that had a $CaCO_3$ content of < 10 % showed mean values of the soluble, exchangeable and non-exchangeable and residual K forms of 198.63, 401.80 mg/kg, 1.39 and 10.06 g/kg, respectively. However, those of the $CaCO_3$ content of ≥ 10 % contained mean values of the respective K forms of 357.78, 522.26 mg/kg, 1.40 and 5.47 g/kg, respectively.

e- Cation exchange capacity

The cation exchange capacity (CEC) of the investigated soil samples showed no change effects on both soluble and exchangeable K forms except those of the high CEC soil samples which exhibited slight increases in both K forms (Fig 6). Also, the non-exchangeable K form was slightly influenced by the CEC of the soil samples. The value of the residual K form showed dissimilar changes induced by various CEC levels of the soil samples. These changes may be not depended upon the ion-exchange characteristics but upon the internal composition of the mineral that are present in these samples. The weathering differences among minerals may result in variations in residual K form levels.

3-Relations Between Potassium Forms and Soil Properties

The correlations between the potassium forms and soil properties are listed in Table 4. The soluble K form showed highly significant positive correlations with organic matter (r = 0.699**), and available K (r = 0.927**).However, it showed a non- significant negative correlation with the sand content. Also, the exchangeable K was significantly positive correlated to organic matter (r = 0.561**) and available K (r = 0.965**) but it had a negative correlation with the sand content (r = - 0.273).

Concerning the non-exchangeable K form, it was significantly positively correlated to the soluble K (r = 0.808**), the exchangeable K (r = 0.938**), the available K (r = 0.932**) and organic matter (r =0.643**). On the other hand, the non- exchangeable K was significantly negatively correlated to the $CaCO_3$ content (r = - 0.292).

Regarding both residual and total forms of the investigated soil samples showed highly significant positive correlations with the other potassium forms. However, both of them were significantly negatively correlated to the $CaCO_3$ content. These results agree with those obtained by Ajiboye and Ogunwale (2008), Ngwe et al. (2012), Tsozué et al.(2016) and Uzoho et al. (2016). They reported that the potassium forms were affected with each other and with the soil properties.

Table 4. Correlation matrix of potassium forms and some soil properties

Properties	Available K	Soluble K	Exchangeable K	Non- exchangeable K	Residual K	Total K
Soluble K	0.927	-	-	-	-	-
Exchangeable K	0.965	0.796	-	-	-	-
Non- exchangeable k	0.932^{**}	0.808^{**}	0.938^{*}	-	-	-
Residual K	0.057	0.006	0.087	0.186	-	-
Total K	0.340	0.263	0.365^{*}	0.464^{**}	0.956	-
EC_e	0.114	-0.016	0.194	-0.085	-0.174	-0.165
pH	-0.383	-0.518	-0.257	-0.217	0.366	0.250
OM	0.650	0.699	0.561	0.643	-0.243	-0.027
$CaCO_3$	-0.116	-0.078	-0.133	-0.292	-0.379	-0.415
CEC	0.020	0.062	-0.011	-0.001	-0.213	-0.195
Sand	-0.242	-0.169	-0.273	-0.205	-0.042	-0.105
Silt	0.151	0.179	0.118	0.022	-0.012	0.010
Clay	0.261	0.135	0.326	0.292	0.073	0.152

***= Significant **= High significan**

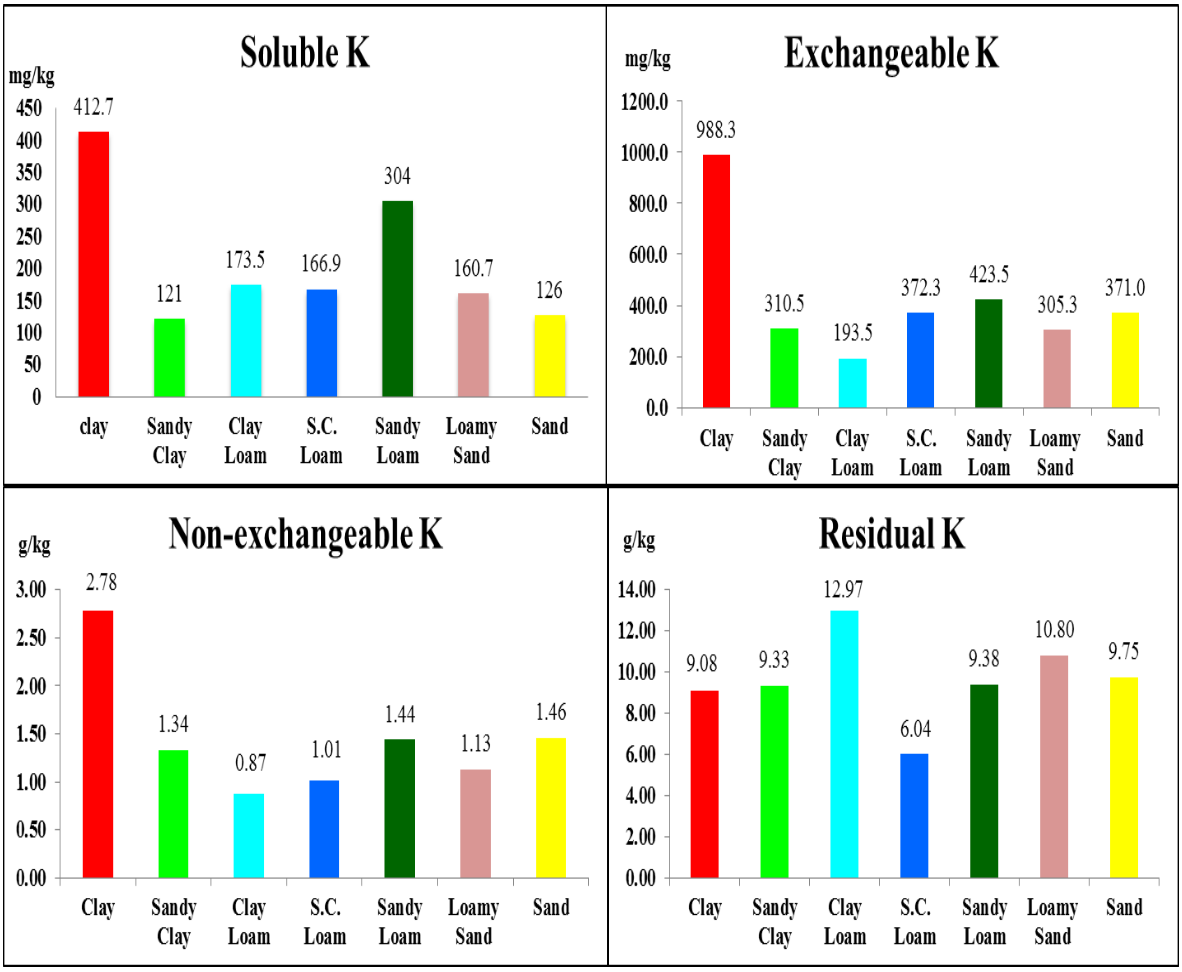

Fig 5. Effect of the soil texture on the mean values of soluble, exchangeable, non-exchangeable and residual K of the studied soil samples.

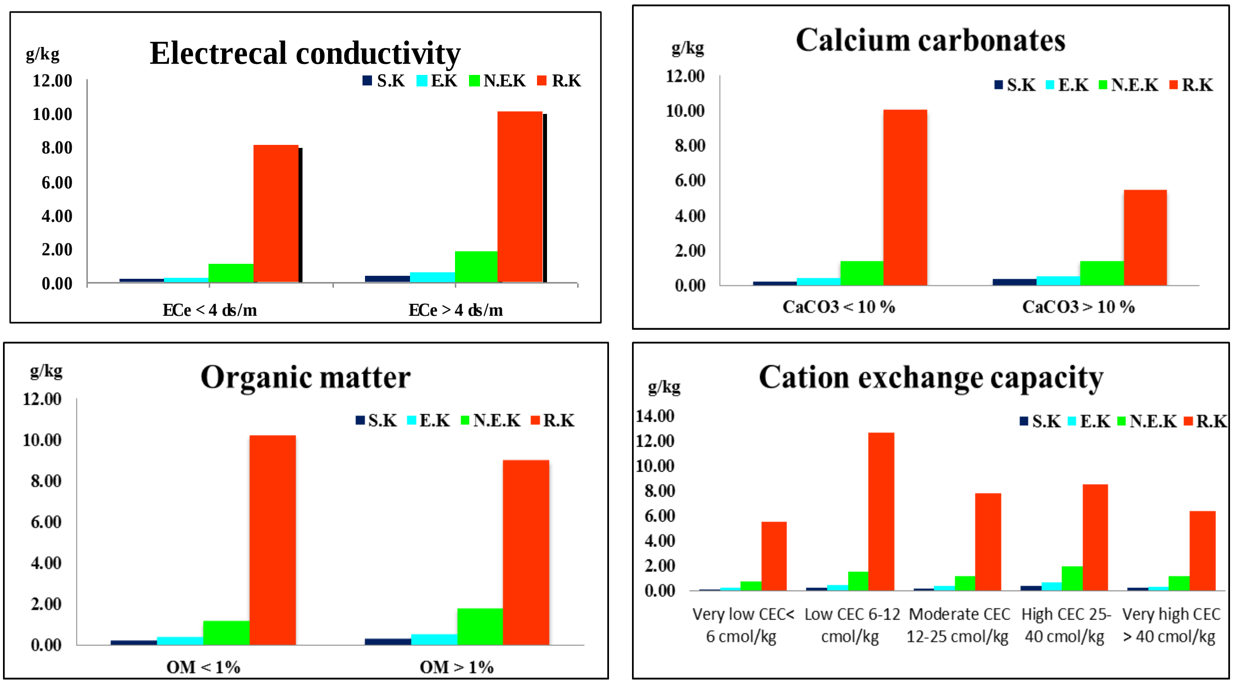

Fig 6. Effects of the organic matter (OM), calcium carbonates ($CaCO_3$), electrical conductivity (EC_e) and cation exchange capacity (CEC) on soluble (S.K), exchangeable (E.K), nom-exchangeable (N.E.K) and residual (R.K) K forms of the studied soil samples

CONCLUSION

All K forms had highly significant positive correlations with each other and with soil properties. According to these findings, the soil content of rapidly available K forms in studied area was adequate. Also, for other slowly available K forms (non- exchangeable and residual K) of the most of the study area had very high contents of K but needs to expand the use of organic fertilizers to increase the bioactivity and then raise the weathering rates of potassium-bearing minerals which leads to more potassium availability at the long-term. Generally, all potassium forms decrease towards western direction of the study area

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صور البوتاسيوم فى أراضى واحة الداخلة ، محافظة الوادي الجديد ، مصر

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تم جمع ثلاثين عينة تربة سطحية وتحت سطحية من 15 موقعا من ترب واحة الداخلة، مصر بهدف دراسة صور البوتاسيوم وعلاقتها بالخواص الطبيعية والكيميائية لهذه الترب. وأشارت النتائج إلى أن عينات التربة المدروسة أظهرت اختلافا واسعا في صور البوتاسيوم ،اعتمد هذا الاختلاف على محتوى الطين والطمي والرمل وكذلك على الخواص الطبيعية والكيميائية لهذه العينات. تراوحت الكمية الميسرة من 4.7- 1332ملجم/كجم والمتبادل من 5.37 –1368.8 ملجم/كجم. كما تراوحت قيم الصورة الغير متبادلة من 0.3- 4.2 جم/كجم والكلى من 2.3 – 19.89 جرام / كجم. كما أن حوالي 16.66٪ من العينات المدروسة كانت منخفضة جدا ، 13.33% متوسطة بينما حوالى 20% كانت مرتفعة ، 40% من هذه العينات مرتفعة جدا فى محتواها من الصورة المتبادلة. أثرت قيم التوصيل الكهربي تأثيرا ملموسا على الصورة الميسرة بينما كان تأثيرها طفيفا عل باقى الصور. العينات التى لها محتوى من المادة العضوية أكبر من 1٪ لم يكن لها تأثير ملحوظ على الصور الميسرة والمتبادلة بينما كان التأثير واضحا على الصورة المتبقية وعموما ارتبطت كل صور البوتاسيوم مع بعضها البعض ارتباطا موجبا عالى المعنوية وكذلك مع المادة العضوية والpH ومحتوى التربة من الطين والسلت. كما أظهرت جميع صور البوتاسيوم باستثناء المتبادل ارتباطا سالبا عالى المعنوية مع كربونات الكالسيوم ومحتوى التربة من الرمل.