

Impact of Clay Mineralogy and Landscape on Potassium Forms in Calcareous Soils, Urmia Region

S. Rezapour¹, A. Samadi^{1*}, A. A. Jafarzadeh², and Sh. Oustan²

ABSTRACT

The potassium pools of five major physiographic units of Urmia region in Western Azarbaijan Province were studied to investigate the distribution of K forms as a function of clay mineralogy and physiographic units. For this, soil samples from different horizons of ten pedons were selected and analyzed for physicochemical properties, mineralogy of clay fraction, and forms of K. Analyses of XRD revealed that the soils are similar in their clay mineralogy, consisting of illite, smectite, chlorite, and kaolinite, but with different in contents. Illite was higher in the Piedmont Plains (PP) followed by Plateaux (PI), River Alluvial Plains (RAP), Colluvial Alluvial Plains (CAP), and Lowlands (LL) units, whereas a higher content of smectite was observed available in the PI followed by PP, LL, RAP, and CAP units. Several such simultaneous processes as mineral weathering and soil forming, biocycling processes, and geomorphologic conditions had resulted in significant difference in K forms in the soils studied. A wide variation in total K (HF-extractable K) (0.54-1.1%), non-exchangeable K (280-450 mg kg⁻¹), and exchangeable K (217-330 mg kg⁻¹) were recorded among different physiographic units. Statistically significant differences ($P \leq 0.05$) were observed in the levels of mineral K, HNO₃-extractable K, and non-exchangeable K in soils of high illite (30-50%) as compared with those of low illite contents (10-30%). A highly significant positive relationship was recorded between total K and illite content ($r^2 = 0.85$, $P \leq 0.001$) and as well between non-exchangeable K and illite contents ($r^2 = 0.84$, $P \leq 0.001$) suggesting that these pools of K are mainly released from the frayed edges and wedge zones of illite. The soils were categorized into two major groups based on the physiographic unit's assertion and soil solution K content: first group comprised of PI and PP units while the second group of RAP, CAP, and LL units.

Keywords: Clay mineralogy, Forms, Physiographic units, Potassium.

INTRODUCTION

It has long been recognized that clay minerals and environmental conditions strongly influence the major physicochemical properties of soils but relationship between the type and abundance of clay minerals as well as landscape properties as independent variables, and the distribution of nutrient elements, specifically K (in arid and semi-arid regions) as the dependent variable has received less attention (Gosh and Singh, 2001; Sharma *et*

al., 2006; Srinivasarao *et al.*, 2007). Sekhon *et al.* (1992) noted that variation of total K content among soil types could be attributed to the levels of clay, silt and sand and as well as to the variations in mineralogical composition of these three size particles. Srinivasarao *et al.* (2007) found that total K was highest in Inceptisols, followed by Aridisols, Vertisols, Alfisols, and Oxisols in soils of India as a result of the diversity of distribution pattern of clay minerals. Sharma *et al.* (2006) suggested that the spatial

¹ Department of Soil Science, College of Agriculture, Urmia University, P. O. Box: 165, Urmia, 57134, Islamic Republic of Iran.

² Department of Soil Science, College of Agriculture, Tabriz University, 51664, Tabriz, Islamic Republic of Iran.

*Corresponding author; e-mail: a.samadi@mail.urmia.ac.ir



distribution of K fractions was closely associated with landforms.

Soil K is nowadays commonly divided into four interrelated forms; namely: water-soluble, exchangeable, non-exchangeable, and mineral. In solution and exchangeable K forms are directly and readily available to plants, although their levels are generally low, not enough to meet the K requirements of plants. Non-exchangeable K pool becomes available (at low exchangeable levels) for plant uptake while mineral K can very slowly become available to plant through weathering (Sparks, 1987). Exchangeable K, (exchangeable with NH_4 in 1N NH_4OAC solution), is held through electrostatic charges present on organic matter and on clay particles (Conyers and Mclean, 1969). Exchangeable K is held more tightly by expanding phyllosilicates and 2:1 type clay minerals than by the external surface charge of 1:1 type clays (Sharply, 1989). Non-exchangeable K is that proportion of total K which is extractable with nitric acid, exhibiting exchangeable K plus K extracted from within phyllosilicates (mainly K trapped in the interlayer of nonexpanding 2:1 clay minerals), and from within tectosilicate mineral structures. Mineral K, as a major portion of total K (> 90), is present in such K-bearing minerals as muscovite, biotite, feldspars, microcline and orthoclase (Parker *et al.*, 1989).

It is generally accepted that K is found as a component of several minerals and upon release it will go to soluble and exchangeable forms (Huang, 1977); although, some of these minerals also have the capability to fix K added through fertilizers or other sources into the non-exchangeable pool (Gosh and Singh, 2001). Mica/illite is a very common K-bearing mineral in soils where K can be released either by transformation into 2:1 expandable layer silicates or by dissolution (Zhou and Huang, 2007). Potassium release through mineral dissolution occurring especially in the rhizosphere and in the immediate vicinity of fertilizer zones (Huang, 2005) is more complex than the release through

transformation of illite into 2:1 expandable layer silicates. Borchardt (1989) and Aoudjit *et al.* (1995) suggested that favorable drainage, enough leaching, and suitable weathering are factors that can strongly influence the release of K from illite, resulting in transformation of illite into other minerals, mainly smectite. According to Steffen and Sparks (1997), fixation and release of soil potassium depends on the type of clay minerals present in the soil, the level of K in the soil solution, and as well as the processes of wetting and drying.

Illite, chlorite, smectite, and kaolinite are predominant clay minerals in Urmia region (Samadi *et al.*, 2008), exhibiting their capacity to release K. The diversity of parent material and clay mineralogy as well as physiographic units in Urmia plain of Iran offer a good environment to study the effects of clay minerals and landscape conditions on forms of K in a semi-arid climate. The objectives of the present study were to: (i) assess the content, forms, and distribution of K as a function of clay mineralogy in different physiographic units; (ii) to investigate the relationship between the K fractions and their physiographic units.

MATERIALS AND METHODS

Description of the Study Area

The study was carried out in the Urmia plain in the north of Urmia, covering about 70,000 hectares within the catchments of the Urmia Lake. The plain stands between $45^\circ 00'$ and $45^\circ 10'$ E longitude and $37^\circ 38'$ and $37^\circ 48'$ N latitude in western Azerbaijan Province, north-west of Iran (Figure 1). This area is part of the Zagros orogenic zone with an elevation of 1,220 to 1,330 m a.s.l. The Zagros mountain range with a northwest to southeast direction is characterized by the diversity of sedimentary rocks from the Cretaceous (grey limestone, calcareous sandstone, marl, and shale) to Quaternary rocks (Darvishzadeh, 1991). During the late Cretaceous, the Tethys seaway was cut off

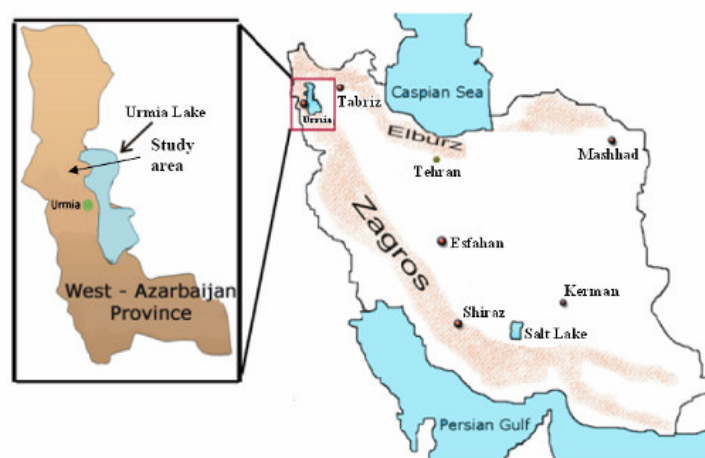


Figure 1. Location map of the study area.

from the ocean, leading to shallow intermountain lakes and lagoons in the Tertiary era (Owliaie *et al.*, 2006). Thus, the study area is a remnant of the Post-Tethyan sea environments, rich in different sedimentations.

The present climate of the region is of Mediterranean type characterized by hot and dry summers; cold and wet winters, with average annual rainfall of about 330 mm of which 80% fall during the 5 months period

between December and April, mainly as snow. In the spring thawing period (May and June) a relatively high amount of water infiltrates into the soil. Mean annual temperature varies between -6 and 14°C in winter, to between 14 and 28°C in summer, with an annual average of 11°C. Mean annual evapotranspiration is about 1,270 mm with a maximum occurring at the end of summer and a minimum in December to February. According to present data (Banaei,

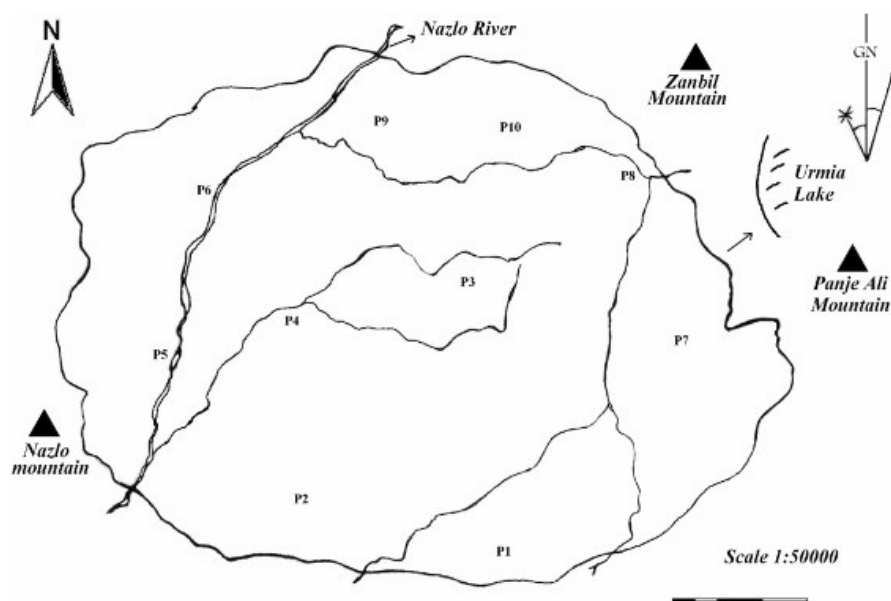


Figure 2. Map of the area showing the location of the pedons studied.



1998), soil moisture and temperature regimes of the study area are of the xeric and mesic types, respectively.

The main land use in the region is agriculture, consisting of different fruit tree species and such annual crops as: corn, sugar beet, wheat, sunflower, and vegetables. Site selection for profile studies was based on a reconnaissance survey from different physiographic units (Figure 2) namely: pedons 1 and 2 located on Plateau (Pl), pedons 3 and 4 on Piedmont Plain (PP), pedons 5 and 6 on River Alluvial Plain (RAP), pedons 7 and 8 on Colluvial-Alluvial Plain (CAR) at the base of the mountains, as well as pedons 9 and 10 on Lowland (LL). Soils were described and classified based on Soil Survey Manual (Soil Survey Staff, 2003) and Key to soil Taxonomy (Soil Survey Staff, 2006), respectively. Samples were taken from different horizons, air-dried, crushed, passed through a 2 mm sieve, with the fine fraction being saved for the analyses.

Physicochemical Analyses

Particle-size distribution was determined through Pipette Method (Day, 1965) using wet sieving and sedimentation after the removal of carbonates (dissolution through 2N HCl), organic matter (oxidation by 30% H₂O₂), free iron and aluminum oxides (dissolution through dithionite-citrate-bicarbonate), and as well were determined the soluble salts. Total carbonates expressed as Calcium Carbonate Equivalent (CCE) was determined through rapid titration (Nelson, 1982). Organic carbon was measured through a wet digestion method (Walkley, 1947). Acidity (pH) and EC were determined in saturated paste and in saturated extract, respectively. Cation Exchange Capacity (CEC) was determined using sodium acetate (1M NaOAc) at pH 8.2 (Chapman, 1965).

The extents of different K pools in each soil sample were assessed using flame photometer (Kundsen *et al.*, 1982). Water-

soluble K was determined through shaking of a 5 g soil sample in distilled water (25 cm³) overnight, followed by centrifugation and filtration. NH₄-exchangeable K was measured by shaking a 10 g of soil sample in 25 cm³ ammonium acetate (buffered at pH 7, 1M), followed by centrifugation and filtration. Exchangeable K was calculated as the difference between NH₄OAc-extractable and K in solution. Nitric acid-extractable K was determined using 2.5 g of soil boiled in 25 cm³ of 1M HNO₃ solution for 10 minutes. The difference between K extracted through HNO₃ and NH₄-exchangeable K was taken as non-exchangeable K. Total K was found out by digestion of soil with acid mixture (48% HF+6M HCl). Mineral K was calculated by subtracting total K from HNO₃ extractable K. Analyses were carried out in three replications and the results for each K form were recorded as means. Statistical analyses were performed using Mstat-C (Michigan University, 1991) and SPSS (Microsoft Windows, 2006) softwares.

Mineralogy Analysis

Separation of clays for mineralogical analysis was achieved through sedimentation of dispersed soil materials. Prior to soil mineral fractionation, samples (< 2 mm) were treated with 1N sodium acetate, buffered at pH 5, to remove carbonates, and treated with 30% H₂O₂ and Na-dithionite-citrate-bicarbonate to oxidize organic matter and to remove Fe oxides, respectively (Kunze, 1965; Mehra and Jackson, 1960). Sand was separated from silt and clay through wet sieving while clay being separated through centrifugation and decantation. The < 2 µm fraction was treated with Mg-saturation, Mg-saturation plus glycerol-saturation, K-saturation, and K-saturation plus being heated at 550°C. X-ray diffractograms were obtained through a Shimadzu XRD 6000 diffractometer employing a Ni-filtered Cu_{Kα} radiation source from oriented clay (40 kV, 30 mA). Samples were scanned from 3 to 30°2θ,

at a scan speed of $2^\circ 2\theta \text{ min}^{-1}$ with a 2 s time constant. The content of clay minerals was estimated according to Biscaye methods (1965). Random powder diffraction patterns were recorded using powdered samples and scanning from 3 to $65^\circ 2\theta$.

RESULTS AND DISCUSSION

Overall Mineralogy of Soils

The soils were all calcareous, calcium carbonate between 10 and 25%, with relatively high clay content, ranging from 29 to 43%. Variations in soil characteristics are considerable, which is most likely as affected by physiography. This variation is especially noticeable in clay minerals and as well in K pools. The XRD data for the less than $2 \mu\text{m}$ fractions of the studied soils showed (Figure 3 and Table 1) similar mineralogy in the type, consisting mainly of illite, smectite, chlorite, kaolinite, and quartz, but differed in the relative abundance, reflecting dynamic and variable soil environments. Smectite is characterized by the d value of $18 \text{ \AA}$ in the glycerol-treated samples. The $10 \text{ \AA}$ peak in the Mg-treated samples showed the presence of illite. The $14 \text{ \AA}$ peak that gets stabilized after any treatment identified for chlorite and while the presence of kaolinite being

characterized by the disappearance of the $7.2 \text{ \AA}$ peak in K 550°C treatment. The decrease in kaolinite peak ($7.2 \text{ \AA}$) in the glycerol-treatment *vis-a-vis* Mg and K-treatment along with the apparition of very low angle peak of $18.4 \text{ \AA}$, suggested that probably some smectite was interstratified with kaolinite. Illite content was, in general, high in PP followed by PI, RAP, CAP and LL, while greater smectite content was observed in PI followed by P.P, L.L, R.A.P and C.A.P units (Table 1). This is likely due to the presence of stable geomorphic surface and a lack of the cycle of erosion-depositional processes, allowing enough time for the development of these minerals in the plateau and piedmont plain physiographic units. Chlorite and kaolinite do not indicate any regular pattern of variation among different physiographic units.

The occurrence of illite, chlorite and kaolinite which together accounted for more than 70% of the clay fraction in these soils is probably largely related to their presence in parent material (Owliaie *et al.*, 2006). Transformation of illite mainly in PI and PP, as indicated by the presence of interstratified clay minerals, seems to be the main pathway to the formation of smectite, although inheritance from parent material could also be the possible cause (Khormali *et al.*, 2005). A broad $23.2\text{--}25 \text{ \AA}$ peak that collapsed to 14 and $10 \text{ \AA}$ after being heated (to 550°C) and K-saturation treatment

Table 1. Percentage distribution of clay minerals in the soils studied.

Pedon	Physiographic unit	Illite	Smectite+ Interstratified clays	Chlorite	Kaolinite
Typic Calcixerepts	PI	42 ^a	30	16	12
Sodic Calcixerepts	PI	45	28	14	13
Humic Haploxerepts	P.P	42	21	22	15
Fluventic Haploxerepts	P.P	48	22	18	12
Aquic Haploxerepts	R.A.P	29	14	28	29
Fluvaquentic Epiaquepts	R.A.P	27	12	35	26
Typic Haploxerepts	C.A.P	25	11	31	33
Fluventic Haploxerepts	C.A.P	18	10	35	37
Typic Epiaquepts	L.L	23	22	25	30
Typic Endoaquepts	L.L	19	16	30	35

^a The contents appearing in the table are the mean contents obtained from different soil horizons.

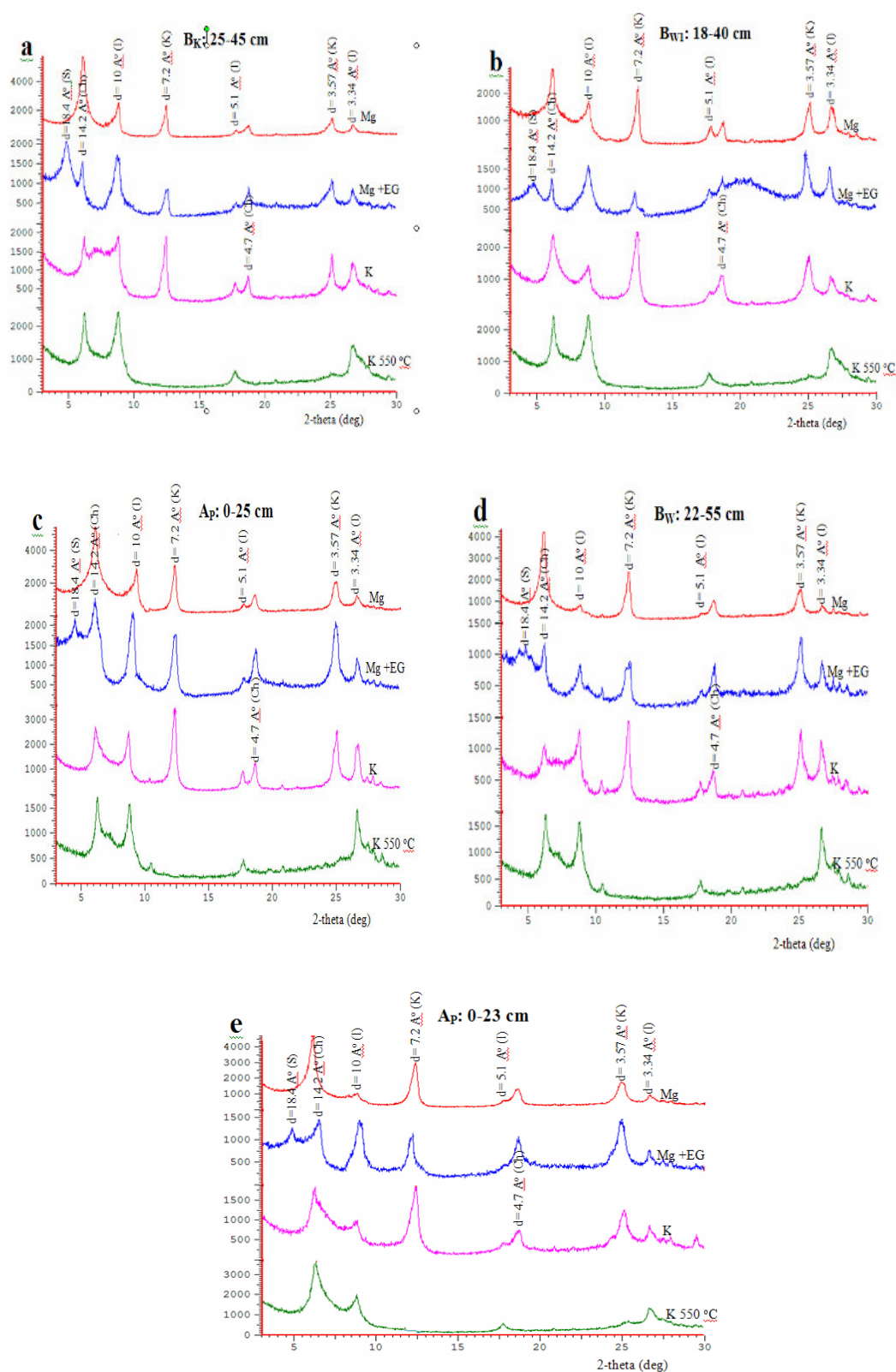


Figure 3. XRD pattern of the clay fraction from different horizons: (a) Pl, (b) PP, (c) RAP, (d) CAP, and (e) LL.

suggested that the smectite was randomly interstratified with illite. Daily and seasonal fluctuations in temperature and moisture as well as in soil available water along with the activity of plant roots in this area can provide a relative favorable environment for the depotassification of illite. Therefore, it seems there occurred a simple transformation of illite into other clay minerals (mainly smectite). Quartz, feldspar mica, chlorite, and kaolinite were also the major observed minerals in random powder XRD patterns (not shown here).

K Status and Clay Mineralogy

The mean contents of the various K forms, CEC, pH, EC, clay and organic carbon for the five main physiographic units are presented in Figure 4 and in 2. A wide variation in HF-extractable K (total K), ranging from 0.54 to 1.1%, as well as mineral K, ranging from 0.49 to 1%, was recorded among physiographic units (Figure 4). Mineral K accounted for the major portion of total K in all soils, on an average of 92.5, 92.7, 91.5, 91.3, and 91.1% for Pl, PP, RAP, CAP, and LL units, respectively.

Mineral K content was closely related to the amount and type of clay minerals. This assertion is confirmed by a significant relationship between mineral K and illite (semiquantities) contents ($r^2 = 0.85$, $P \leq$

0.001) and as well between mineral K and clay contents ($r^2 = 0.61$, $P \leq 0.01$) which are consistent with results obtained by other authors (Officer *et al.*, 2006; Nabiollahy *et al.*, 2006; Barre *et al.*, 2007). The findings of exchangeable K varied greatly among the different physiographical units. A higher content of exchangeable K was observed in Pl followed by PP, RAP, CAP, and LL (Figure 4). In spite of having greater content of illite, PP indicated a lower content of exchangeable K in comparison with Pl unit. This could be attributed to a higher stability of geomorphologic surface in Pl than in PP, followed by a lower mobility of K from illite clay structure to the exchange complex in PP unit.

The higher clay and smectite contents (Table 1), smectite relation with illite as an interstratified clay mineral, and the corresponding large surface area and CEC resulted in larger exchangeable K in Pl unit, as also suggested by Srinivasarao *et al.* (2006). Dominance of kaolinite and chlorite clay minerals along with lower CEC in CAP and LL units in comparison with other soils resulted in their lower exchangeable K. On average, 74% of non-exchangeable K, 42% of HNO_3 extractable K, 3.7% of mineral K, and 3.4% of HF extractable K could be accounted for as exchangeable.

Non-exchangeable K, consisting mainly of K trapped in the interlayers of non

Table 2. Mean values of selected physicochemical properties of the pedons studied.

Pedon	Physiographic unit	pH	OC	CCE	Clay	CEC	EC
				%		cmol _c Kg ⁻¹	dS m ⁻¹
Typic Calcixerepts	Pl	7.5 ^a	1.4	15	42	19	0.85
Sodic Calcixerepts	Pl	7.9	1.3	18	39	18	2.8
Humic Haploxerepts	PP	7.4	1.3	20	40	17	0.95
Fluventic Haploxerepts	PP	7.3	1.4	16	33	14	1.1
Aquic Haploxerepts	RAP	7.5	0.89	12	43	14	0.54
Fluvaquentic Epiaquepts	RAP	7.3	0.91	10	39	15	0.67
Typic Haploxerepts	CAP	7.6	0.81	23	29	12	0.45
Fluventic Haploxerepts	CAP	7.5	0.78	25	38	13	0.51
Typic Epiaquepts	LL	7.7	0.94	17	32	12	1.4
Typic Endoaquepts	LL	7.5	0.96	16	29	11	1.6

^a The mean values appearing in the table are the mean contents obtained from different soil horizons.

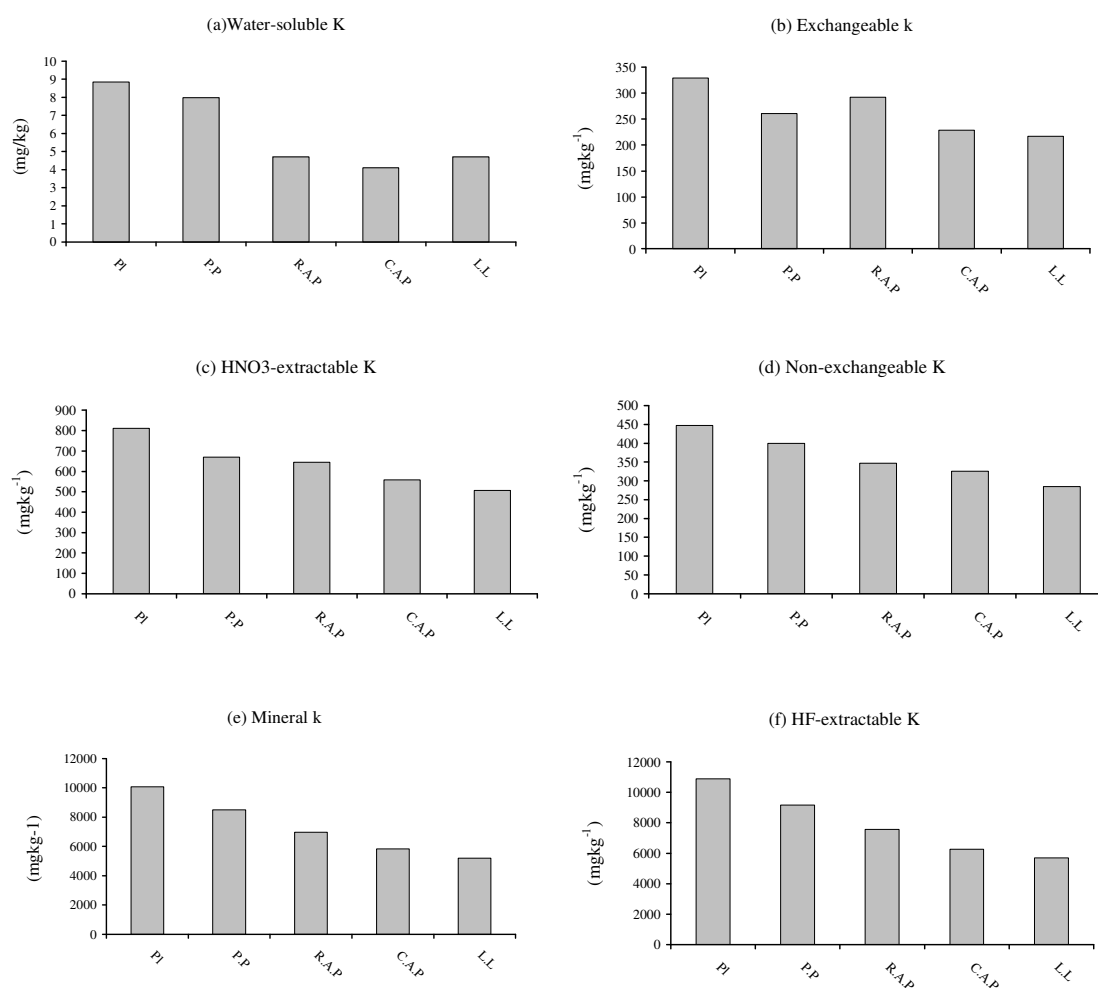


Figure 4. Potassium fractions in soils from various physiographic units. Plateaux (PI), Piedmont Plains (PP), River Alluvial Plains (RAP), Colluvial Alluvial Plains (CAP), and Lowlands (LL).

expanding 2:1 clay minerals, exhibited a similar trend to HF-extractable K and almost mineral K in the different soil types. The release rate of non-exchangeable K is the result of the type and particle size of K bearing minerals and of soil conditions (Scott, 1968). The soils of PI and PP units contained much non-exchangeable K, reflecting high contents of illite as one of their most important sources of soil K. A high significant relationship between the content of non-exchangeable K and illite content ($r^2 = 0.84$, $P \leq 0.001$) indicated that this fraction of K is mainly released from the frayed edges of illite, as confirmed in other earlier works. Srinivasarao *et al.* (2007) reported that the abundance of non-

exchangeable K in the different soil types broadly following the same trend as their total K in soils of India, could be due to the presence of different levels of illite/mica. Cimrin *et al.* (2004) suggested that non-exchangeable K of soils originated from illite in Gavas region. Non-exchangeable K is almost in equilibrium with all K forms acting as an important reservoir of K. Based on the exchangeable and non-exchangeable K interpretation scheme of Srinivasarao *et al.* (2007), the soils studied were classified into high in exchangeable K vs. low (LL unit) to medium (PI, PP, RAP and CAP units) in non-exchangeable K categories. On average, non-exchangeable K constituted

56% of HNO_3 extractable K, 4.9% of mineral K, and 4.5% of HF-extractable K.

Pl unit showed the greater water-soluble K, followed by PP, RAP, LL and CAP (Figure 4). With regard to the high level of exchangeable K present in this area and the fact that water-soluble K is in equilibrium with exchangeable K, low contents of water-soluble K were surprising. This was presumably due to the high affinity of reactive surfaces and as well as specific surface site of 2:1 clay minerals to adsorbed K (Gawander *et al.*, 2002). On average, water-soluble K constituted 2.2% of exchangeable K, 1.7% of non-exchangeable K, and 0.07 % of HF-extractable K which is in agreement with results obtained by Samadi *et al.* (2008).

Correlation coefficients (r) of K forms and clay content are given in Table 3. As can be observed, all K forms, except water-soluble K, show high correlations with clay content which is consistent with other research findings (Sharpley, 1989; Samadi *et al.*, 2008). Significant positive relationships between different K forms revealed the fact that K fractions are in dynamic equilibrium (Sharma *et al.*, 2006).

Analysis of variance indicated that mineral K, HNO_3 extractable K, non-exchangeable K, and clay contents of the soils with a higher illite content (30-50%) were significantly different from those in soils of less illite content (10-30%) (Figure 5). These results also confirmed the fact that illite is a major source of K in the soils studied.

K Forms and Soil Processes

Relationships among pools of K and physiographic units are presented in Table 4. In view of the fact that forms of K are often functions of K-bearing minerals, several processes (as a result of variations in physiographic units) may account for the trends of K pools. Different degrees of weathering, in particular, under the effect of large daily and seasonal fluctuations in moisture and temperature and as well in soil available moisture; variations in biocycling processes of K; variations in geomorphological conditions, and soil genesis processes that have affected the rate of depotassification processes (as a result of simple transformation of illite into other clay minerals, mainly smectite) could be mentioned as some of such processes.

The contents of HF-extractable K and mineral K were significantly different in all the physiographic units whereas HNO_3 extractable K, non-exchangeable K, and exchangeable K were significantly different among Pl, PP and RAP units, reflecting the variation in soil conditions and the type and abundance of K-bearing minerals. As discussed earlier, in Pl and PP units, condition of more stable geomorphologic environment, greater activity of soil formation processes and lower erosion as compared with other units had a more pronounced effect on the higher level of K forms in these soils. The X-ray patterns of these soils (Pl and PP units) are different and show a more abundance of such silicate clay

Table 3. Correlation coefficients of linear relationships between K forms and clay contents.

	Water-soluble K	Mineral K	HF K	NH_4OAc K	HNO_3 K
Clay	0.346	0.706**	0.708**	0.704**	0.734**
Water-soluble K		0.836**	0.834**	0.537*	0.722**
Mineral K			0.999**	0.803**	0.946**
HF K				0.812**	0.952**
NH_4OAc K					0.922**

* and **, Significant at the 0.05 and 0.01 levels, respectively.

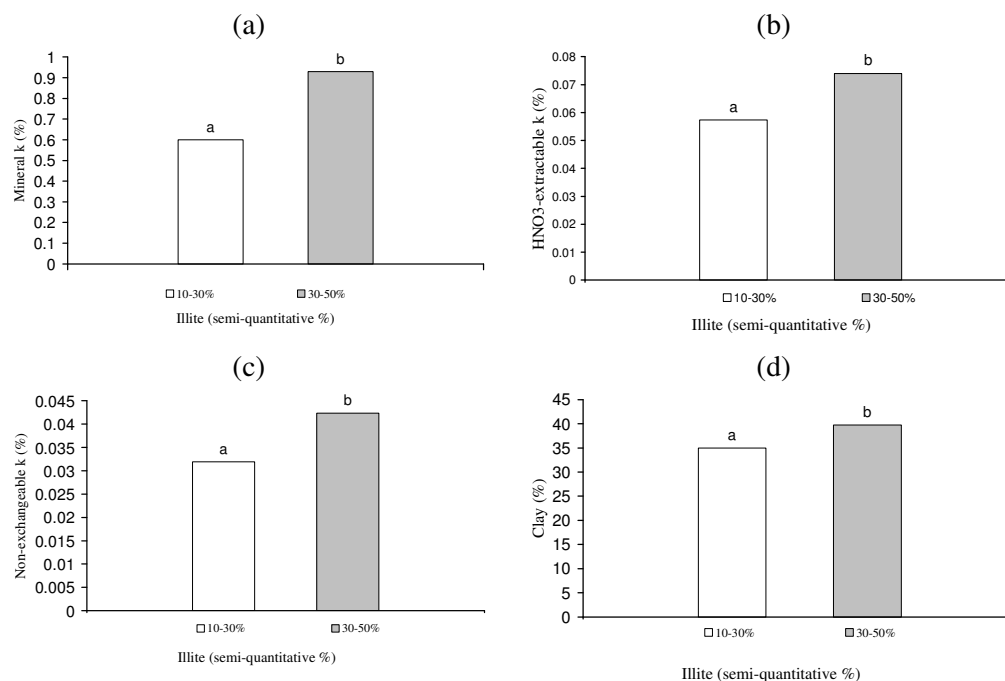


Figure 5. Analysis of variance of: (a) Mean mineral K, (b) HNO₃-extractable K, (c) Non-exchangeable K, and (d) Clay content of soils with different illite contents ($P \leq 0.05$).

minerals as illite and smectite that are responsible for the differences in their K pools *vis-a-vis* other soil units. Due to similar soil clay-fraction distribution and mineralogy (Tables 1 and 2), the quantities of non-exchangeable and exchangeable K were similar in C.A.P as compared with LL unit.

Soils were categorized into two groups based upon the relationship between water-soluble K and physiographic units. The first group consisted of PI and PP units, while the second one of RAP, CAP and LL units. While the content of water-soluble K in the

first group significantly differed from that in the second group, there was no significant difference observed between PI and PP and neither was so among RAP, CAP and LL units. Water-soluble K is an immediate source of plant available K, its concentration being affected by soil weathering, plant cover, labile release of K from organic residues, and as well from the added farmyard manure (Srinivasarao *et al.*, 2007; Samadi *et al.*, 2008). Similarity in weathering processes reflected in the clay content, and in organic matter can be responsible for the

Table 4. Grouping of studied soils in physiographic units according to different form of K and clay contents.

	PI	P.P	R.A.P	C.A.P	L.L
HNO ₃ - extractable K (%)	0.0811 ^a	0.0669 ^b	0.0654 ^b	0.0558 ^c	0.0507 ^d
Non-exchangeable K (%)	0.0338 ^a	0.0269 ^{bc}	0.0279 ^b	0.0233 ^{cd}	0.0222 ^d
HF-extractable K (%)	1.089 ^a	0.9162 ^b	0.760 ^c	0.640 ^d	0.5694 ^e
Mineral K (%)	1.007 ^a	0.8996 ^b	0.6956 ^c	0.5842 ^d	0.5187 ^e
NH ₄ OAc-extractable K (%)	0.0447 ^a	0.0399 ^b	0.0347 ^c	0.0326 ^{cd}	0.0285 ^d
Exchangeable K (%)	0.330 ^a	0.0261 ^{bc}	0.0292 ^{ab}	0.0228 ^c	0.0217 ^c
Water soluble K (%)	0.00088 ^a	0.00080 ^a	0.00047 ^b	0.00041 ^b	0.00047 ^b
Clay (%)	40.5 ^a	36.5 ^{ab}	41 ^a	33.5 ^{bc}	30.5 ^c

^a Means followed by the same small letter in each row are not significantly different as determined through Duncan's test ($P \leq 0.05$).

insignificant difference in water-soluble K content in these soils.

CONCLUSIONS

It becomes apparent from the present study, that physiographic units exhibit different capabilities in provide K, this being due to variations in degree of weathering, geomorphological and topographical conditions, and as well as pedogenetic processes. In fact, diversity of physiographic units, reflecting mainly on K-bearing minerals and clay content, have resulted in a noticeable difference in content, forms, and distribution of K. Units PI and PP which occurred on a more stable landform position, contained a higher content of all forms of K along with clay and illite. The statistically significant relationships between mineral K, HNO_3 extractable K, and as well between non-exchangeable K, and soil illite content suggest that those forms of K are greatly influenced by the presence of illite. In spite of K removal by such high nutrient requiring crops as sugar beet and sunflower in different physiographic units, the potential of Kbearing minerals, with respect to both non-exchangeable and exchangeable, is high enough to be sufficient for the current cropping practices.

ACKNOWLEDGEMENTS

This research was supported by the Ministry of Science, Research and Technology of the Islamic Republic of Iran and the Universities of Tabriz and Urmia for which authors are thankful to.

REFERENCES

1. Aoudjit, M., Robert, M., Elsass, F. and Curmi, P. 1995. Detailed Study of Smectite Genesis in Granitic Saprolites by Analytical Electron Microscopy. *Clay Miner.*, **30**: 135-147.
2. Banaei, M. H. 1998. *Soil Moisture and Temperature Regime Map of Iran*. Soil and Water Research Institute, Ministry of Jihad-e-Agriculture, Iran.
3. Barre, P., Velde, B. and Abbadie, L. 2007. Dynamic Role of "Illite-like" Clay Minerals in Temperate Soils: Facts and Hypothesis. *Biogeochemistry*, **82**: 77-88.
4. Biscaye, P. 1965. Mineralogy and Sedimentation of Recent Deep Sea Clay in the Atlantic Ocean and Adjacent Seas and Oceans. *Geological Soc. Am. Bull.*, **76**: 803-832.
5. Borchardt, G. 1989. Smectite, In: "*Minerals in Soil Environment*", Dixon, J. B. and Weed, S. B., (Eds.). SSSA, ASA, Madison, WI. PP. 675-727.
6. Chapman, H. D. 1965. Cation Exchange Capacity, In: "*Methods of Soil Analysis*". Black, C. A., (Ed.). Part 2, ASA, Madison, WI, PP. 891-900.
7. Cimrin, K. M., Akca, E., Senol, M. B. and Kapur, S. 2004. Potassium Potential of the Soils of the Gaves Region in Eastern Anatolia. *Turk. J. Agric.*, **28**: 259-266.
8. Conyers, E. and Mclean, E. 1969. Plant Uptake and Chemical Extractions for Evaluating Potassium Release Characteristics of Soils. *Soil Sci. Soc. Am. Proc.*, **33**: 226-230.
9. Darvishzadeh, A. 1991. *Geology of Iran*. Amirkabir Publication, Tehran, Iran.
10. Day, P. 1965. Particle Fractionation and Particle-size Analysis, In: "*Methods of Soil Analysis*" Black, C. A. (Ed.). Part 1, ASA, Madison, WI, PP. 545-566.
11. Gawander, J., Gangaiya, P. and Morrison, R. 2002. Potassium Studies on Some Sugarcane Growing soils in Fiji. *South Pacific J. Natural Sci.*, **20**: 15-21.
12. Gosh, B. and Singh, R. 2001. Potassium Release Characteristics of Some Soils of Ultra Pradesh Hills Varying in Altitude and Their Relationship with Forms of Soil K and Clay Mineralogy. *Geoderma*, **104**: 135-144.
13. Huang, P.M. 1977. Feldspars, Olivines, Pyroxenes and Amphiboles, In: "*Minerals in Soil and Environments*", Dixon, J. B., and Weed, S. B. (Eds.). SSSA, ASA, Madison, WI, PP. 533-602.
14. Huang, P. M. 2005. Chemistry of Soil Potassium, In: "*Chemical Processes in Soil*", Tabatabai, M., and Sparks, D. (Eds.). SSSA, ASA, Madison, WI, [PP. 221-292.



15. Khormali, F. and Abtahi, A. 2005. Correlation of the Clay Mineral Distribution in the Sedimentary Rocks of South and Western Zagros, Iran. Geophysical Research Abstract, 1607-7962/gra/EGU05-A-00063 . European Geosciences Union.
16. Knudsen, D., Peterson G. and Pratt, P. 1982. Lithium, Sodium, and Potassium, In: "Methods of Soil Analysis", Black, C. A. (Ed.). Part 2, ASA, Madison, WI, PP.225-246.
17. Kunze, G. 1965. Pretreatment for Mineralogical Analysis, In: "Methods of Soil Analysis" Klute, A. (Ed.). Part 1, ASA, Madison, WI, pp.210-221.
18. Mehra, O. and Jackson, M. 1960. Iron Oxide Removal from Soils and Clays by a Dithionite Citrate System with Sodium Bicarbonate. *Clays Clay Miner.*, **7**: 317-327.
19. *MSTAT-C*, 1991. Michigan State University, East Lansing, MI.
20. Nabiollahy, K., Khormali, F., Bazargan, K. and Ayoubi, Sh. 2006. Forms of K as a Function of Clay Mineralogy and Soil Development. *Clay Miner.*, **3**: 739-749.
21. Nelson, R. 1982. Carbonate and Gypsum, In: "Methods of soil analysis", Page, A. L. (Ed.). Part 2, ASA, Madison, WI, PP. 181-199.
22. Officer, S. J., Tillman, R. W., Palmer, A. S. and Whitton, J. S. 2006. Variability of Clay Mineralogy in Two New Zealand Steep-land Topsoils under Pasture. *Geoderma*, **132**: 427-440.
23. Owliaie, H. R., Abtahi, A. and Heck, R. 2006. Pedogenesis and Clay Mineralogical Investigation of Soils Formed on Gypsiferous and Calcareous Materials, on a Transect, Southwestern Iran. *Geoderma*, **134**: 62-81.
24. Parker, D., Sparks, D. L., Hendricks, G. and Sadusky, M. 1989. Potassium in Atlantic Coastal Plain Soils: I. Soil characterization and Distribution of Potassium. *Soil Sci. Soc. Am. J.*, **53**: 392-396.
25. Samadi, A., Dovlati, B. and Barin, M. 2008. Effect of Continuous Cropping on Potassium Forms and Potassium Adsorption Characteristics in Calcareous Soils of Iran. *Aust. J. Soil Res.*, **46**: 265-272.
26. Scott A. D. 1968. Effects of Particle Size on Interlayer Potassium Exchange in Mica. Pp. 649-660 in: 9th World Congress of Soil Science, Adelaide, Australia.
27. Sekhon, G., Brar, M. S. and Subba Rao, A. 1992. *Potassium in Some Benchmark Soils of India*. PRII Special Publication 3., Potash Res. Institute of India, Gurgaon, India, PP. 1-82.
28. Sharma, B. D., Mukhhopadhyay, S. S. and Sawhney, J. S. 2006. Distribution of Potassium Fractions in Relation to Landforms in a Himalayan Catena. *Archives Agron. Soil Sci.*, **52**: 469-476.
29. Sharply, A. N. 1989. Relationship between Forms of Potassium with Mineralogy. *Soil Sci. Soc. Am. J.*, **53**: 1023-1027.
30. Soil Survey Staff. 2003. *Soil Survey Manual, Agric. Handbook, No. 19*. U.S. Government Printing Office, Washington, D.C.
31. Soil Survey Staff. 2006. *Keys to Soil Taxonomy*. 9th Edition, United States Department of Agriculture, Natural Resources Conservation Service, Washington, D.C.
32. Sparks, D. L. 1987. Potassium Dynamics in Soils. *Adv. Soil Sci.*, **6**: 1-63.
33. *SPSS*, 15. 2006. Microsoft Windows, SPSS Inc., Chicago, USA.
34. Srinivasarao, C. H., Rupa, T. R., Subba Rao, A., Ramesh, G. and Bansal, S. K. 2006. Release Kinetics of Nonexchangeable Potassium by Different Extractants from Soils of Varying Mineralogy and Depth. *Commun. Soil Sci. Plant Anal.*, **37**: 473-491.
35. Srinivasarao, C. H., Vittal, K., Tiwari, K. N., Gajbhiye, P. N. and Kundu, S. U. 2007. Categorisation of Soils Based on Potassium Reserves and Production System: Implications in K Management. *Aust. J. Soil Res.*, **45**: 438-447.
36. Steffens, D. and Sparks, D. L. 1997. Kinetics of Nonexchangeable Ammonium Release from Soils. *Soil Sci. Soc. Am. J.*, **61**: 455-462.
37. Walkely, A. 1947. A Critical Examination of a Rapid Method for Determining Soil Organic Carbon in Soils. *Soil Sci.*, **63**: 251-263.
38. Zhou, G. M. and Huang, P. M. 2007. Kinetics of Potassium Release from Illite as Influenced by Different Phosphates. *Geoderma*, **38**: 221-228.

اثر کانیهای رسی و زمین نما بر توزیع شکلهای پتاسیم در خاکهای آهکی دشت ارومیه

س. رضاپور، ع. صمدی، ع. جعفرزاده، و ش. اوستان

چکیده

به منظور بررسی تاثیر کانی های رسی و واحدهای فیزیوگرافی بر توزیع شکل های پتاسیم، پنج واحد فیزیوگرافی غالب در دشت ارومیه، استان آذربایجان غربی مورد مطالعه قرار گرفت. بدین منظور نمونه های خاک از افق های مختلف ده بدون انتخاب و مورد آزمایش های فیزیکوشیمیایی و کانی شناسی قرار گرفت و شکل های پتاسیم در آنها تعیین شدند. پراش پرتو ایکس نشان داد که کانی های رسی میان واحدهای مختلف فیزیوگرافی از نظر نوع تقریباً یکسان، اما فراوانی نسبی آنها تفاوت داشت. میزان ایلیت به ترتیب در دشت های دامنه ای (PP)، تراسها (PI)، دشت های آبرفتی رودخانه ای (RAF)، دشت های آبرفتی واریزه ای (CAF) و اراضی پست (LL) بیشتر بود. در حالیکه میزان اسمکتیت به ترتیب در واحدهای PI، PP، LL، RAF و CAF بیشتر مشاهده شد. چندین فرآیند توام تحت تاثیر اختلاف در واحدهای فیزیوگرافی مانند تفاوت در میزان هوادهی، فرآیندهای چرخه زیستی پتاسیم، شرایط ژئومورفولوژیکی و فرآیندهای تشکیل خاک باعث تفاوت معنی داری در همه شکل های پتاسیم شد. تفاوت زیادی در پتاسیم کل ($1/1-0/54$ درصد)، پتاسیم غیر قابل تبادل ($280-450$ میلی گرم در کیلوگرم) و پتاسیم قابل تبادل ($217-330$ میلی گرم در کیلوگرم) میان واحدهای فیزیوگرافی مشاهده شد. تفاوت معنی داری (در سطح ۵ درصد) در مقادیر پتاسیم ساختمانی، پتاسیم قابل عصاره گیری با اسید نیتریک و پتاسیم غیر قابل تبادل در خاکهای با میزان ایلیت بیشتر ($30-50$ درصد) در مقایسه با میزان ایلیت کمتر ($10-30$ درصد) مشاهده شد. یک رابطه مثبت معنی داری بین پتاسیم ساختمانی و ایلیت ($0/001$ ، $R^2=0/85$ ، $P\leq 0/001$) و بین پتاسیم غیر تبدلی و ایلیت ($0/84$ ، $P\leq 0/001$) مشاهده شد که بیانگر آنست که این شکل های پتاسیم مخصوصاً از مکان های لبه ای و فضاهای بین لایه ای ایلیت آزاد شده اند. خاکها بر اساس واحدهای فیزیوگرافی و مقدار پتاسیم محلول در دو گروه طبقه بندی شدند: گروه اول شامل واحدهای PI و PP و گروه دو واحدهای RAF، CAF و LL بودند.