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Effect of various land uses on potassium forms and some soil properties in Kohgiluyeh and Boyer-Ahmad Province, Southwest Iran

A. Azadi*[1], S. Shakeri[2]

[1]Department of Soil and Water Research, Khuzestan Agricultural and Natural Resources Research and Education Center, AREEO, Ahvaz, I. R. Iran
[2]-Department of Agriculture, Payame Noor University, Tehran, I. R. Iran

* Corresponding Author: abolfazl_azadi@yahoo.com

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ABSTRACT - Changing pasture and forest land use to agricultural land use can effect on many properties of the soil and its productivity. The present research aimed to investigate various forms of K (soluble, exchangeable, non-exchangeable, and structural forms) and some soil properties in various land uses of three areas including Choram, Kakan and Bahmaei in Kohgiluyeh and Buyer-Ahmad Province. The study areas covered various land uses types including agriculture, gardens, and uncultivated soils. Four pedons were excavated in various land uses of each area (in total, 12 pedons). All pedons were described and classified based on the Keys to Soil Taxonomy. The results showed that there was not any significant positive correlation between the clay and silt contents in various land uses, while the lowest content of clay was observed in agricultural land use. The percentage of organic carbon was in its highest level in pasture land use (1.01%), and in its lowest level in agricultural (0.7%) and fallow-wheat (0.4%) cultivation. The highest and lowest pH levels were obtained in paddy soil (8.1) and garden (6.8), respectively. The maximum level of soluble, exchangeable, non-exchangeable, structural and total forms of K in the studied area were 0.5-6.1, 45-262, 86-366, 835-5197 and 967-5555 mgkg^{-1} of the soil, respectively. The studied soils of Kakan and Choram areas had the lowest and highest levels of non-exchangeable, structural, and total forms of K, respectively. In addition, the highest levels of soluble and exchangeable forms of K were observed in Bahmaei and Kakan areas, respectively. The soluble and exchangeable forms of K had significant changes in various land uses, so that their highest levels were observed in wheat and forest land use, respectively. The highest level of non-exchangeable K was related to forest use, and its total and structural forms were related to paddy land use in Choram area.

INTRODUCTION

The soils in arid and semi-arid areas, especially Iran, are faced with different problems, which should be studied. In addition, the optimum use of soil should be prioritized regarding the increasing growth of population and meeting the people's foodstuff needs. The soil quality depends mainly on the soil response in various land uses and the management operations, so that it is possible to reform most of the soil properties, especially its physical and chemical ones, and consequently its productive capacity through management and applying the proper use (Vahidi et al., 2012). In order to understand the effects of land use and management methods on the soil, the changes in soil properties should be shown qualitatively and quantitatively. The land use includes the kind and method of using the land in present condition, which is appeared in the form of one of the land use including agriculture, garden, forest, pasture, meadow, residential, industry, mine and so on.

The land use change is one of the measures, which can be influencing on the soil quality. The effect of the kind of land use on the performance of the soil in ecosystem would be possible through the study and investigation of soil quality indices changes (Doran et al., 1996). Potassium (K) is considered as the third main nutrient for the plant growth. It plays an important role in enzymatic activity, proteins synthesis, and photosynthesis (Basak and Biswas, 2009) and forms about 2.6% of the Earth crust. K plays an excellent and wonderful role in the soil. This role depends on the dynamic nature of different forms of K, under different conditions of the soil (Khan et al., 1993). The total content of K is generally high in most of the soils; however, only a little part of it is rapidly provided to plant. The availability of K for the plant is reduced in soluble, exchangeable, non-exchangeable and structural forms, respectively (Malakouti and Homaee, 2003).

Many physical, chemical, biological and climatic factors effect on different forms of K and their balances in the soil, which is generally attributed to soil clay mineralogy (Barre et al., 2008). It has been reported that the distribution of soil total K in surface soil layer is distinctly influenced by soil formation processes i.e., parent materials and soil types, and exchangeable and available K forms are mostly influenced by land use changes i.e., agricultural practices (Blanchet et al., 2017). The exchangeable and soluble forms compose a little part of total K in the soil, and the remained part is composed of non-exchangeable and structural forms. Releasing the K from non-exchangeable part depends on distribution of soil particles size and kind of minerals, and decreasing in K due to plant uptake or leaching and increasing due to fertilization (Tophighy, 1995). In order to maximize the plant growth, the soluble and exchangeable forms should be steadily replaced through releasing the non-exchangeable K, because of weathering or adding the K fertilizers (Bertsch and Thomas, 1985). In order to determine the capacity of K in the soils composed of parent materials in Nigeriye Delta, Logantan et al. (1995) determined different forms of K in the soil and showed that the difference between total K and unavailable K among the parent materials depends on the kind of minerals and the soil order.

The Inceptisols and Entisols formed on the sediments containing Mica and Feldspar minerals and high level of total and unavailable k forms. However, the Ultisols formed on the sediments of severely weathered minerals and contained low level of total and unavailable K. In their research in Kohgiluyeh and Boyerahmad Province, Shakeri and Abtahi (2018) reported that illite plays more important role to determine the level of structural K in the soils of more arid areas; and smectite and vermiculite play more important role to determine the level of structural K in the soils of more the wetter areas. The reason is that the kaolitite and palygorskite, which have not the capacity to preserve the K, are minerals associated with illite in more arid areas. Unlike, smectite and vermiculite, with high content of K, are the minerals associated with illite in wetter areas. Also, they declared that the exchangeable and non-exchangeable form of K are seen in surface horizons more than underlying ones, and the Alfisols have the highest content of these two kinds of K. In order to study the relationship between the kind of clay minerals and different kinds of K, Alamdari et al. (2016) stated that all kinds of K are higher in physiographical unit of piedmont plains, which have more level of illite and smectite. To investigating the effect of the usage kind and different agriculture on different kinds of K, Hashemi (2017) reported that the paddy soils had the maximum content of soluble, non-exchangeable and total K than non-paddy soils. It seems that, illite and vermiculite are the main minerals keeping K in paddy soil.

Regarding the special climatic condition of Kohgiluyeh and Boyer-Ahmad Province and its various land uses, no study has been done so far on the changes of the soil properties and forms of K in various land uses. Therefore, this research aimed to compare some of the physical and chemical properties and changes in different forms of K in soils with various land uses in three areas including Choram, Bahmaei and Kakan of this province. The results of this study can be important and practical in managing and predicting undesired changes due to land use change in similar areas of the province.

MATERIALS AND METHODS

Studied Areas

In order to investigate some of the soil properties and different forms of K in different cultivations (land use), three areas of the province were selected with the following situations: 1- Kakan plain with the extent of 2800 hectares, which is located within geographical range of 51° 47 ' - 51° 5 ' of east longitude and 30° 33 ' - 30° 38 ' of north latitude; 2- The Bahmaei county which is located in west and southwest of the province, within the geographical range of 30° 39 ' - 31° 11 ' of north latitude and 49° 51 ' - 50° 26 ' of east longitude; 3- Choram plain, which is located in 160 km of the west and northwest of Yasuj, within the longitude of 50° 47 ' and latitude of 30° 75 '. According to meteorological information, the Kakan plain has the moisture and very cold and glacial winters, and dry and mild summers. The average annual precipitation is about 1009 mm and the average annual temperature is 11.2° C. The moisture and temperature regimes of the area soils are xeric and mesic, respectively. The uses available in the area included garden, wheat, fallow and pasture. According to meteorological information, the Bahmaei area has warm and semi-arid weather. The average annual precipitation is about 649 mm and the average annual temperature is 23.4° C. The moisture and temperature regimes of the area soils are xeric and thermic, respectively. The study area covers various land uses types including wheat, forest, and fallow soils. Choram plain, with the height of 736 m above sea level, is located in geographical center of the province. Its average annual precipitation is about 499 mm, and its average annual temperature is 21.7°C. The moisture and temperature regimes of the area soil are ustic and hyperthermic, respectively. The land use available in the area included paddy soils, wheat, and pasture.

Physical and Chemical Experiments

In order to conduct this study, at first the physiographic units were separated based on information obtained from aerial photographs and topographic maps. Then, a pedon was excavated on each unit and different horizons were sampled. The samples were air-dried and then sieved through a mesh size of 2 mm. A number of physical and chemical experiments were conducted on the samples. Soil particle-size distribution was determined using the hydrometer method (Rowell, 1994). Calcium carbonate equivalent (CCE) was measured by neutralization with HCl (Loeppert and Suarez, 1996), and organic carbon (OC) was determined by wet oxidation method (Nelson and Sommers, 1996). Soil pH was measured using the saturated paste extract, electrical conductivity (EC) was measured in soil saturation extract using a conductometer, cation exchangeable capacity (CEC) was analyzed by replacing exchangeable cations by NaOAc and exchanging Na^+ with NH4OAc (Chapman, 1965), and gypsum was measured by precipitation with acetone (Richards, 1954).

Measurement of Different Forms of K

The measurement of soluble form of the soil K was done by distilled water with the ratio of 1 to 5 (soil to water) in the saturated extract, and exchangeable K was extracted by 1M NH4OAc at pH 7.0. The exchangeable K level was obtained through subtraction of ammonium acetate-extractable K and soluble K (Helmke, and Sparks 1996). The non-exchangeable K was determined by normal boiling 1M nitric acid (HNO3) (Knudsen et al. 1982). The non-exchangeable form of K was measured by subtraction of ammonium acetate-extractable K and nitric acid-extractable K. The structural K was calculated from subtracted nitric acid – extractable K and HF method K. The level of K in the obtained extracts was measured through flame photometry by flame photometer of corning 405 models.

Mineralogical Analysis

In order to study the mineralogical properties, the methods describe by Kittrick and Hope (1963) and Jackson (1975) were used. Prior to mineralogical analysis, samples were repeatedly washed with water to remove gypsum and soluble salts. The carbonates were initially removed using 1 N sodium acetate buffered at pH 5. Neutralization was performed in a water bath at 80°C. The organic matter was then oxidized by treating the carbonate-free soils with 30% H_2O_2. Free Fe oxides were removed from samples using the citrate dithionate method described by Mehra and Jackson (2013). After separation of clay (750 rpm, centrifuge for 5 minute and 30 seconds), the samples were saturated with magnesium (Mg) and K, then they were treated with ethylene glycol and the temperature of 550° C, respectively, and finally tested with X-ray dispersion. The relative frequency of clay minerals was measured by a method described by Johns et al.'s (1954) with the help of Xpert Highscore software. The minerals were determined with maximum accuracy in this software, using the area under minerals-related peaks in glycerol treatment.

RESULTS AND DISCUSSION

The Physicochemical and Mineralogical Properties of the Studied Soils

Some properties of the studied soils are shown in Table 1. Soils were classified into four orders, including Entisols, Inceptisols, Alfisols and Mollisols (according to Soil Survey Staff, 2014). The specified horizons of the soils included the mollic and ochric surface horizons, and the cambic, calcic and argillic subsurface ones. Among the studied areas, the Kakan area with 64% of $CaCO_3$ content has the highest content of calcium carbonate. The soils of Kakan plain have been formed by severely calcium carbonate parent materials and as a result of weathering of cretaceous primary lime stones, dolomite, clay, shale and marl in anticlines of Zagros mountain chain and transferred to the plain and deposited there under the influence of water power and gravity. The average $CaCO_3$ in Choram and Bahmaei areas were 61.5 and 56.6%, respectively. The highest amounts of organic matter (1.05%), clay (45%), and pH (7.78) were obtained, in Choram area; and the lowest amount of organic matter (0.56%) was observed in Bahmaei; and the lowest amount of clay (23.5%) and pH (7.64) were obtained, in Kakan area. The XRD data for the less than 2 μm fractions of the studied soils are showen in Fig. 1 and Table 2. As you can see, the smectite is the most important and abundant mineral in the studied soil. The mineralogical results showed that the smectite, illite, chlorite and kaolonite are the main minerals of Choram area. Kakan studied area has high precipitation, and it seems that there is enough condition to change the primary minerals to some other minerals such as smectite. The pedons in the low parts of the area have fine texture. Therefore, according to high drainage, pH and high activity of silica ion in this condition, the neo-formation origin can be considered as one of the most important reasons for smectite proportion in these pedons, especially in Kakan area. Another origin, which can be mentioned for high percentage of this mineral in low lands of the area, is conversion of the palygorskite to smecite, which is observed in the areas with high precipitation. The mineralogical results of Bahmaei soils showed that the clay minerals of this area terms of quantity are smectite, chlorite, illite, palygorskite, and kaolinite in order. Therefore, smectite is considered as the main mineral of this area soils. Regarding the climate of the area, most probably the smectite content of the soils has been inherited from parent materials and parent rock. To investigate the type of minerals of the soils in south of Iran, the areas with low to medium precipitation, Shakeri and Abtahi (2018, 2019) attributed the high level of smectite to parent materials and parent rock. Moreover, the smectite content showed the increasing process following the increasing of depth. This can indicate that this mineral is inherited in this area. Of course, the conversion of other minerals such as illite and palygorskite to smectite on the soil surface and its transferring to lower horizons- due to finer structure of smectite- can be another reason for increasing of smectite following the increasing of depth in this area. It has been also reported that chlorite, kaolinite and illite minerals in the soils of this area have inherited source (Shakeri et al., 2020).

The Effect of Various land uses on the some Soil Properties

Soil Texture

The soil texture is an important property of the soil, which can effect on the soil capacity to keep the water, ventilation, temperature, CEC, the capability to provide foodstuff, and consequently on the plant growth and reproduction (Mahmoodi and karimian,1999). The changes of some physical and chemical properties of the soil in various land uses are shown in Fig. 2. As it can be seen, the soil texture has been changed from the heavy clay class in pasture land use to a relatively light loamy-clay class in agricultural land use (agricultural land use and rice). The results are corresponded with the results obtained by Nazari (2013) and Shamsi et al. (2011). They reported that this change is attributed to erosion of the natural surface coating of the soil, or to decomposition of the aggregates, due to decomposition of cultivated organic matters, transferring the finer particle through erosion, and remaining the coarse particles. Considering the content of clay and silt that showed no significant difference among various land uses (Fig. 2); meanwhile, the lowest amount of clay was observed in agricultural land use.

Table 1. Mean values of selected physicochemical characteristics of the pedons studied.

Soil No.	Studied regions	Soil orders	Physiographic units	CEC (cmol kg-1)	OC (%)	Gypsum (%)	CCE (%)	EC (dSm^{-1})	pH	Clay (%)	Sand (%)	soil texture
1	Choram	Mollisols	Piedmont plain	15.9	1.0	0.4	54.3	0.6	8.1	40.7	24.3	C
2	Choram	Entisols	Alluvial Fan	10.6	0.7	0.4	81.1	0.6	8.0	21.8	57.5	SCL
3	Choram	Inceptisols	Alluvial Plain	11.9	0.9	0.4	73.9	0.4	8.1	34.3	45.5	SCL
4	Choram	Entisols	Alluvial Fan	12.1	0.8	0.5	72.7	0.5	7.9	36.1	30.9	CL
5	Kakan	Inceptisols	Plateau	26	1.3	0.4	61.3	0.4	7.3	43.7	22.3	C
6	Kakan	Alfisols	Plateau	35	1.0	0.4	32	1	6.8	48.7	18.6	C
7	Kakan	Alfisols	Piedmont plain	34.3	1.0	0.4	59.8	0.6	7.8	58.9	7.9	C
8	Kakan	Mollisols	Piedmont plain	37	0.7	0.4	45	0.3	7.4	46.7	12.8	SiC
9	Bahmaei	Inceptisols	Hill	20.8	0.2	1.6	77.3	0.4	7.7	39	35.5	CL
10	Bahmaei	Alfisols	Plateau	28	0.5	0.8	38.8	0.3	7.8	43.8	19.8	C
11	Bahmaei	Inceptisols	Piedmont plain	17	0.6	0.4	56	0.4	7.5	26.7	21.3	SiL
12	Bahmaei	Inceptisols	Hill		1.0	0.4	60.7	0.3	7.7	43	28	C

C: clay; CL: clay loam; SCL: sandy clay loam; SiC: silty clay; SiL: silty loam

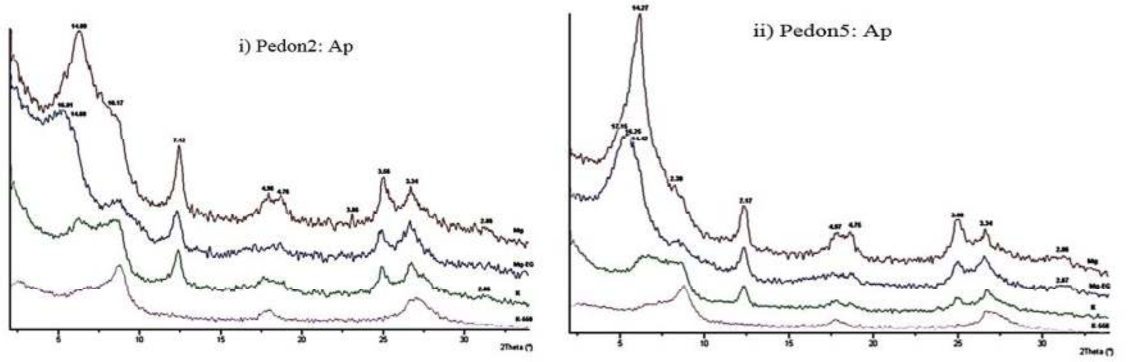

Fig. 1. XRD pattern of the clay fraction from different horizons in the study area: (i) Choram, (ii) Kakan

Table 2. Semi quantitative results of clay minerals in some horizons in the studied pedons.

Pedon	Horizon	Palygorskite	Vermiculite	Smectite	Chlorite	Illite	Kaolinite
2	Ap	+	+	+++	++	+	+
2	C_1	++	-	+	++	++	++
3	Ap	+	++	+++	-	+	+
3	Bw_1	+	++	+++	-	+	+
5	Ap	+	+	+++	++	+	+
5	Bk_1	+	+	++++	++	+	+
6	Ap	+	+	+++	++	+	+
6	Bw	+	+	++++	++	+	+
7	Ap	+	+	+++	++	+	+
7	$Btkg_1$	+	+	++++	++	+	-
9	Ap	+	-	++++	+++	+	+
9	Bky	+	-	+++	++	+	+
10	Ap	+	-	+++	+++	+	+
10	Bt_2k	+	-	+++	++	++	+
11	Ap	-	-	++++	+++	+	+
11	Bk	+	-	+++	++	+	+
12	Ap	+	-	++++	++	+	-
12	Bw	+	-	++++	++	+	+

Note: –, trace or not detected. +, content <15%; ++, content in the range of 15%–30%; +++, content in the range of 30%–50%; ++++, content >50%.

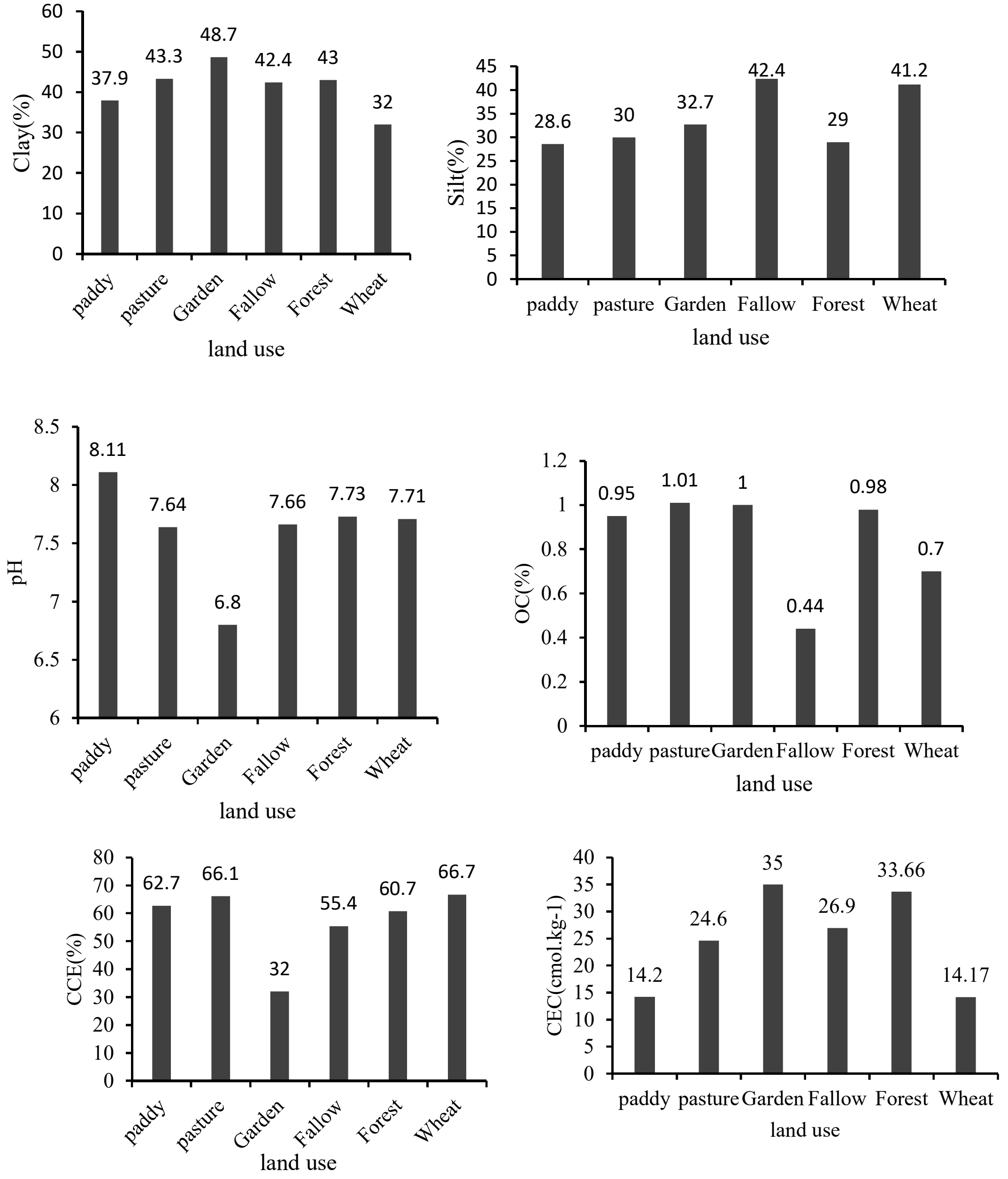

Fig. 2. Some soil properties in various land uses

Ajami et al. (2008) and Martinez-Mena et al. (2008) reported similar results. i.e. lower amount of clay in agricultural lands than that in forest ones, In similar to Ajami et al. (2008) and TajKhalili et al. (2011) that did not observed any significant difference in terms of the silt percentage among various land uses, Wu and Tiessen (2002) and Evrendilek et al. (2004) also reported the same results based on the lack of significant difference in terms of silt part in various land uses.

Organic Carbon

Amount of organic matter is an important indication of the soil productivity. Organic matter has a determining role in the soil quality stability, crop production and the environment quality (Whalen and Chang, 2002), due to its determining effects on the physical, chemical and biological properties of the soil such as the capability to keep and provide the water, foodstuff cycle, the plant root growth, the gases current intensity and preserving the soil. Any intervention with natural condition of ecosystem shows sensibly its negative effect on the soil carbon reserve. Also, in agricultural and garden conditions, after unconscious and unscientific changes of these land uses, the use of different tillage systems results in undesired conditions. Commixing and decomposing the soil mass through plow and groove, accelerate the analysis of organic matter and effect on its other physical, chemical, and biological properties as well as the dynamic soil quality (Doran, 1987).

The results of this study showed that the percentage of organic matter was in the highest level in pasture land use (1.0%) and in the lowest level in agricultural (0.7%) and fallow wheat (0.4%) land use (Fig. 2). Probably, in pastures higher amount of organic matter is added to the soil, because of short and often one-year grasses coating. In other words, the results confirmed that the human intervention and the land use change decrease the process of organic matter content. The soil evolution status, the climate variety, topography, and management of the lands are some factors making these extensive changes in the soil organic matter. Similar results have been reported by several authors (Nazari, 2013; Ajami, 2007). They believed that declining the physical preservation of the soil organic matters because of crashing the coarse aggregates during the plow operation, as well as increasing the soil temperature because of decreasing the shading vegetation, are effective on analysis of organic matter of agricultural lands soils. More sensitivity of agricultural lands against erosion is considered as a factor decreasing the soil organic carbon, so that a main part of the soil organic carbon becomes inaccessible through erosion, in soluble form associated with runoff (Martinez-Mena et al., 2008; Tejada and Gonzales, 2008). Moreover, the tillage operations mix the underlying layers of the soil, which has lower percentage of organic matter, with the surface soil, which has organic carbon. As a result, it decreases the organic carbon in surface soil comparing to the first state. of course, Liu et al. (2011), unlike the studies conducted, reported that the amount of organic carbon in agricultural lands use is higher than in forest and pasture land use. They attributed it to good condition of agricultural lands, the lack of slope as well as adding the organic and non-organic fertilizers to agricultural lands by the farmers.

Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) is one of the important parameters of soil quality. The average of the soil CEC changes in various land uses is shown in Fig. 2. As can be seen in the figure, the average of soil CEC in paddy soils, agriculture and pasture land uses were 14.2, 14.17, and 24.6 cmol.kg^{-1}, respectively, and CEC of the agricultural soils showed some changes compared to non-agricultural soils. In general, the reduction of organic matters due to sequential and long-term cultivation of crops has decreased the CEC of the agricultural soil compared to non-agricultural one. On the other hand, the significant reduction of clay particles in agricultural soil, the type, and amount of available clay minerals are important parameters of high CEC in agricultural use. Having studied on Kechik plain, Niknahad Ghormakhar and Marmayi (2011) concluded that CEC has been decreased significantly due to the use change of natural ecosystems (forest) to managed ecosystems (pasture and agriculture). Ajami (2007) stated that reduction of soil organic matters as well as clay particles in soil decreased significantly the CEC in agricultural land use.

pH

Soil reaction or pH indicates soil acidity or alkalinity. The agricultural land use change can cause changes in the profitability of elements such as Nitrogen (N), Phosphorus (P), Potassium (K), Iron (Fe), Manganese (Mn), Copper (Cu) and Zinc (Zn), through affecting on some soil properties such as texture, structure, organic matters and pH. The land use change is one of the measures affecting the soil quality. Since pH affects many soil properties and as the land use change can affect on pH level and soil calcium carbonate, the pH of the soil was investigated in various land uses. The results confirmed that the land use change has changed significantly the soil pH (Fig. 2). The highest (8.11) and the lowest (6.8) soil reactions were obtained in the rice cultivated (paddy lands) and the garden land use, respectively. This increase in pH in paddy lands is probably related to management activities such as fertilization. This could be due to the addition of chemical fertilizers, more and faster decomposition of organic matter, and increased concentrations of carbon dioxide and soluble carbonate leaching due to the soil degradation. In addition, Balesdent et al. (2000) stated that cultivation would increase soil reaction due to its influence on the activity of microorganisms and soil carbon.

Calcium Carbonate

The dominant mineral carbonate in soils of arid and semi-arid areas is Calcium Carbonate ($CaCO_3$). It has been reported that the amount of $CaCO_3$ in soils indicated the type and existence of calcic horizons and the status of their nutrients (Malakouti and Homaee, 1994). The results of this study indicated that all the studied soils were calcareous soil, but the land use change caused a significant difference in the amount of calcium carbonate in the soils, so that the highest amount of $CaCO_3$ was observed in wheat agricultural land use (66.7%) and the lowest amount was observed in fallow (55.4%) and garden (32%) land use (Fig. 2). The highest amount of $CaCO_3$ in agricultural land use has also been reported by Nazari (2013) and Shamsi et al. (2011). They believed that one of the reasons for high level of $CaCO_3$ in the agricultural land use is tillage action, which removes surface horizons with less calcium carbonate due to erosion, and causes outcropping of the bottom horizons with more calcium carbonate. On the other hand, more moisture in less commixed soils of garden use, as well as dissolution of carbon dioxide resulting from biological activities, probably caused to dissolve $CaCO_3$ and to its accumulate in deeper soils, resulting in the formation of deeper calcium carbonate at accumulation horizons. Vafaeizadeh et al. (2016) indicated that the amount of CaCO3 in agricultural soils is more than pasture and forest lands, which is consistent with the present research results. However, regarding the precipitation condition in the studied areas, probably the precipitation significantly leached the $CaCO_3$ from the studied soil in all land uses. Ghorbani et al. (2013) declared that the land use change from pasture to agriculture, did not change significantly the availability of Ca, Mg, P, pH, salinity, $CaCO_3$ and organic carbon. However, it increased the amount of sodium, potassium (K), sulfur(S), clay and CEC.

Land-use Changes and Dynamics of Potassium

Mineralogy and weathering play a significant role in the dynamics of potassium in soils. The order of the different forms of K in terms of amount and percentage was similar in all studied pedons, which was as follows as shown in Table 3: Structural-k> non-exchangeable> exchangeable> soluble. The average of soluble, exchangeable, non-exchangeable, and structural K percentage to the total K percentage was changeable up to 0.1, 3.9, 7.3 and 88.8%, respectively. Investigating the process of changes in K forms in various land uses (rice and wheat) in Choram area indicated that different forms of the soluble, exchangeable and non-exchangeable K in paddy land use were 0.5, 70.1 and 236.7 mg $.kg^{-1}$, respectively, which were the lowest levels compared to those observed at other land uses. This indicates that the soil is poorer in terms of K amount in the above-mentioned forms of the rice cultivation. The high amount of total K in paddy lands can be attributed to the higher illite in these soils (Table 2) and their clay contents. The high amount of clay in the Choram area leads to a large increase in clay minerals in the area, and the higher relative percentage of the clay increases the amount of this section in various forms. In Kakan and Bahmaei areas, the highest amounts of K forms, especially exchangeable and non-exchangeable ones, were found in garden and forest land use, respectively. The high amount of smectite and vermiculite in these land use (Table 2) is the main reason for increasing the exchangeable and non-exchangeable K, so that the correlation results also confirm the positive correlation between exchangeable and non-exchangeable forms of K with smectite and vermiculite minerals in Kakan and Bahmaei areas (Table 5). The amount of soluble K was also varied depending on the type of management, especially the amount of fertilization recommendations in various land uses. The highest amount of available K was observed in the soils of garden, forest and pastures land uses, respectively. They have high organic matter and CEC in addition to K-bearing minerals, and their lowest amount is observed in paddy lands cultivated densely by rice. Various land uses, especially paddy fields, are severely deficient in terms of available K; therefore, it seems to be necessary to have an optimal management including the appropriate consume of K-bearing minerals fertilizer to restore the soil fertility, based on the soil test or sufficient fallow period. Compared to other land uses, the paddy land use has higher total K, but less available K. Table 3 and Fig. 3 show the values of different forms of soil K affected by various land uses. The amount of soluble K in the studied soils varied from 0.5 to 6.1 mg/kg (with the average of 1.9 mg/kg). Soluble K is considered as a form of K that is easily available for plant and has a high leaching potential. The results of studying various land uses in the three selective areas showed that the amount of soluble K in the various land uses was different, so that the highest amount of this form of K was observed in the wheat land use, which can be attributed to the management method and using of K-contained fertilizer. The lowest amount of this form of K was observed in rice land use in the Choram area, because rice is one of the products that requires high levels of K, and absorbs this element a lot. On the other hand, some part of decreasing in soil soluble K of this kind of land use may be due to the leaching process. The reason can be that the soils cultivated by this kind of land use are generally waterlog- irrigated, and the soil surface horizons are usually affected by leaching. In other words, the K content is decreased in the surface soils of paddy lands pedon, due to dense cultivation and the lack of K fertilizer application. However, significant reduction of K due to long-term cultivation and agricultural operations has also been reported by Samadi et al. (2008) and Taghipour et al. (2015). The exchangeable form of K is adsorbed by the charged soil surfaces (clay and organic matter) and can easily enter the soil solution and be absorbed by the plant root. As shown in Fig. 3, the exchangeable K diagram indicates that exchangeable K has significant variations in some various land uses, so that paddy land use had the lowest value. This is mainly due to leaching and K removal from paddy fields because of dual saturation (saturation from surface and high groundwater level), higher K uptake in paddy fields due to higher density of rice root at soil surface, and smectite dominance with high-layer charge and vermiculite in paddy fields soils that fix K.

Table 3. Mean content of different forms of K in soils with various land uses

pedon	*Studied area*	*Land use*	*Total K ($mg.kg^{-1}$)*	*Structural K ($mg.kg^{-1}$)*	*Non-exchangeable K ($mg.kg^{-1}$)*	*Exchangeable K ($mg.kg^{-1}$)*	*Soluble K ($mg.kg^{-1}$)*
1	Choram	Rice	5556	5198	286	72	0.5
2	Choram	Pasture	4088	3739	247	101	1.4
3	Choram	Rice	3320	3080	171	68	0.5
4	Choram	Wheat	5556	5198	286	72	1.8
5	Kakan	Pasture	1457	1180	151	125	1.8
6	Kakan	Garden	2929	2343	332	254	1.7
7	Kakan	Pasture	3066	2745	192	130	1.2
8	Kakan	Fallow	4370	3938	273	171	2.4
9	Bahmaei	Fallow	967	836	87	46	1.6
10	Bahmaei	Fallow	3739	3273	312	155	2.1
11	Bahmaei	Wheat	3200	2806	289	105	6.1
12	Bahmaei	Forest	3835	3206	366	262	2.3

However, the exchangeable K diagram in Fig. 3 also indicates that no significant different at ($P > 0.05$) level was observed between paddy land use and wheat, fallow and pasture land uses.

The smectites with high-layered charge are of high strength to fix the soil K even in wet conditions. One of the factors increasing the K stabilization following the increasing of smectite can be indirectly attributed to relationship between the increasing of the soil clay and smectite (Shakeri, 2018; Azadi et al., 2016). Moreover, since the exchangeable form of K is preserved through electrostatic bond on clays as well as organic matters, and as the content of organic matter in forest and pasture land use is higher than other land uses, the high content of this form of K in these land uses is not unexpected. In this study, the exchangeable form of K had a significant positive correlation with CEC of the soil, which is consistent with the results of Azadi et al., (2014, 2015) in Fars province, and Shakeri and Abtahi (2018) in soils of Kohgiluyeh and Boyer-Ahmad province. The non-exchangeable K is placed among the layers of minerals such as mica, vermiculite and smectite, and can enter the exchangeable solution phase over time, and can provide some part of the K required by plants. The results of non-exchangeable K analysis indicated that although no significant differences were observed between various land uses (Fig. 3), the lowest content of non-exchangeable K was observed in pasture land use, which is similar to the results reported by Hashemi (2017).

The reasons can be attributed to low potassium fertilizers application to the pastures soil, the lack of soil disturbance and the lower weathering rate of K-bearing minerals. On the other hand, the low degree of weathering of K-bearing minerals and low CEC in pasture soils has resulted in decreasing the K in the exchangeable and non-exchangeable parts.

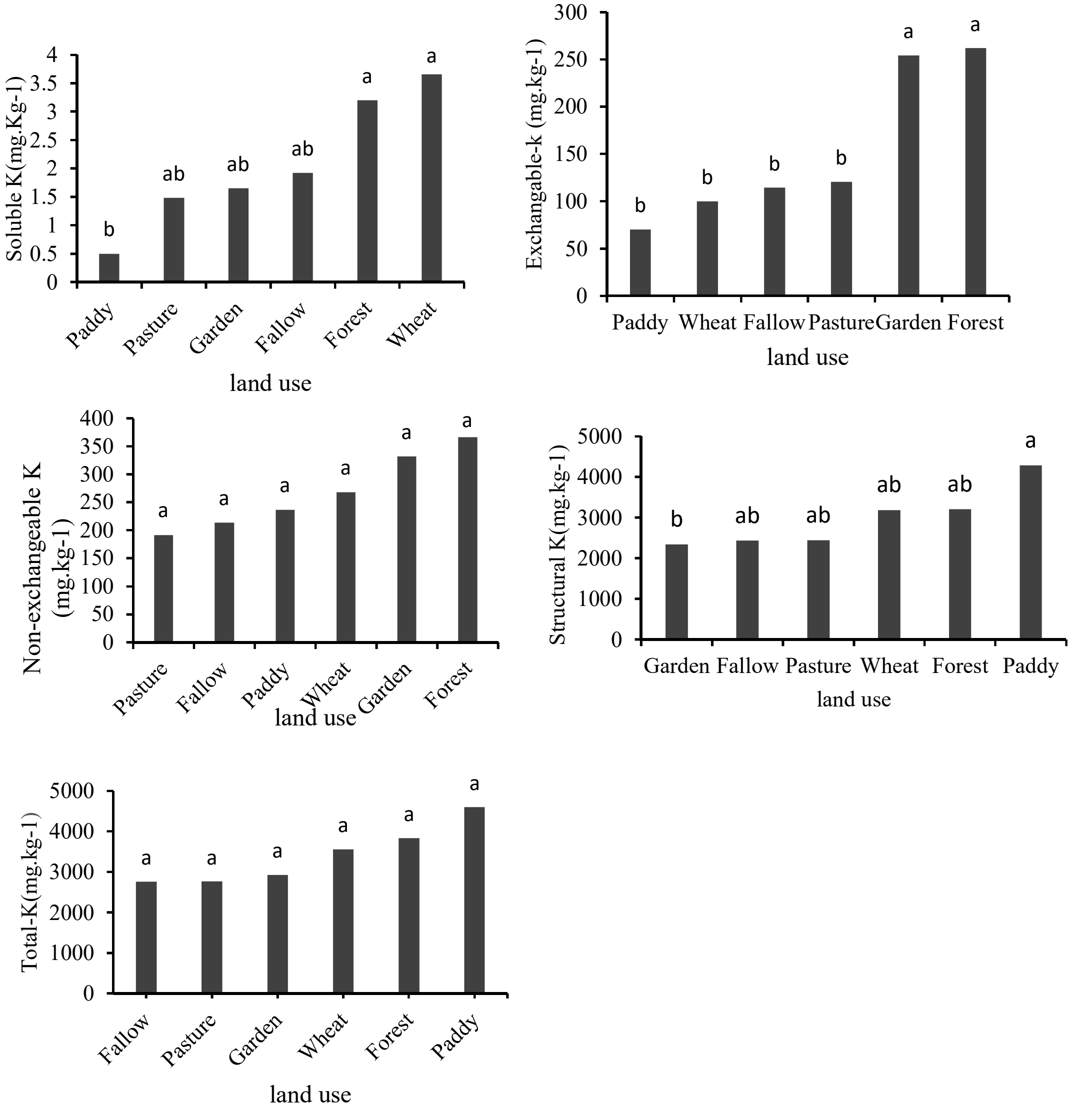

Fig. 3. Comparison of mean values of potassium forms in various land uses (Means followed by different letters are significantly different at *P<0.05* by Duncan's Multiple Range Test).

In addition, poor pastures of the area, the lack of vegetation and consequently less organic matter have resulted in the reduction of the minerals degradation and decomposition, and finally, lower amount of K would be released from the minerals. Non-exchangeable K had a positive correlation with CEC and organic matter in the studied areas. Soil organic matter can be considered as a rich origin of ions. Moreover, the decomposition of organic matter in the soil is the most important factor for producing the organic acids in the soil, which cause weathering of clay minerals (a major origin of non-exchangeable K) and non-exchangeable K release, and consequently increasing of soluble K. The structural form of K would be very slowly available to the plant, depending on the surface of other forms of mineral and the degree of weathering of the K-bearing minerals such as Mica and Feldspars. Although no significant difference was observed in total K among the land uses, the structural K had significantly changed the studied land use, so that the highest amount of total and structural K was obtained in the paddy lands of the Choram area. The total and structural forms of K in paddy lands can also be attributed to the greater illite in these soils and their clay texture.

The high clay amount in the Choram area compared to other studied areas increases significantly the clay minerals in the area, and the higher relative percentage of clays increases the amount of this section in different forms. Having investigated the rice land use (paddy land use) mineralogy, it can be said that the rice cultivation has resulted in reduction of palygorskite mineral, conversion of this mineral to smectite, and conversion of chlorite to vermiculite in some horizons (Table 2). Hashemi (2017) reported that long-term waterlogging and low-slope physiographic units are factors that provide the undesired drainage conditions for smectite. In their studies on waterlogging culture, Raheb and Heidari (2012) reported the high content of different forms of K in these soils. They also declared that the clay minerals have a great influence on the soil nutrients.

Relationship between the Different Forms of Potassium and Other Soil Properties and Clay Mineralogy

Correlation examination of different forms of K with soil texture components in the study area showed that different forms of K, except the soluble K, have a significant correlation with the clay content and a negative correlation with sand content (Table 4).

Table 4. Pearson Correlation coefficient between different K forms and some physico-chemical properties of soils in the studied areas.

	Soluble K	Exchangeable K	Non-exchangeable K	Structural K	CCE	CEC	OC	Clay
				Kakan				
Exchangeable K	0.487							
Non-exchangeable K	0.640*	0.948**						
Structural K	0.528	0.466	0.678**					
CCE	-0.576*	-0.668**	-0.712**	-0.510				
CEC	0.611*	0.574*	0.694**	0.838**	-0.644*			
OC	-0.054	0.241*	0.078	-0.343	-0.009	0.395		
Clay	0.107	0.092	0.182	0.353	-0.006	0.602*	-0.368	
Sand	-0.054	-0.022	-0.091	-0.470	-0.076	-0.598*	0.526	-0.767**
				Bahmaei				
Exchangeable K	0.147							
Non-exchangeable K	0.483	0.844**						
Structural K	0.502	0.686	0.928**					
CCE	-0.407	0.054	-0.275	-0.561				
CEC	-0.298	0.803*	0.617	0.459	0.187			
OC	0.424	0.793*	0.642	0.571	-0.096	0.518		
Clay	-0.287	0.153	0.015	0.022	0.448	0.281	0.232	
Sand	-0.530	-0.139	-0.431	-0.487	0.483	-0.086	-0.520	0.082
				Choram				
Exchangeable K	0.868**							
Non-exchangeable K	0.710**	0.744**						
Structural K	0.003	0.178	0.641*					
CCE	-0.010	-0.106	-0.587*	-0.864**				
CEC	0.232	0.577**	0.661*	0.726**	-0.746**			
OC	0.375	0.669**	0.642	0.205	-0.264	0.734**		
Clay	0.085	0.037	0.365	0.625*	-0.838**	0.721**	0.316	
Sand	-0.105	-0.224	-0.554*	-0.663**	0.815**	-0.754**	-0.438	-0.905**

**significant at the 0.01 level, *significant at the 0.05 level

Different forms of K were negatively correlated with sand percentage, and positively correlated with clay percentage. Therefore, it can be said that the sand part of the soil has not so much level of K, and the K-bearing minerals are mainly observed in the clay part. It has been reported that clay particles were the most important origin particles for providing K in the soil (Sparks, 2000). It has been declared that the fertility of clay soils was due to the exchangeability and more stabilization of clay minerals (Zehtabian et al., 2005).

The K-bearing clay minerals were reported to be included illite or hydrous mica, vermiculite, chlorite, and interstratified minerals (Malakouti and Hamedani, 1991). The results of correlation analysis between different forms of K, and some of the soil properties and clay minerals in the studied areas obtained in this study are presented in Tables 4 and 5. The results revealed that the amount of soluble K in the pedons of studied soils was different; however, its content in surface horizons was more than the subsurface ones. Also, this form of K had a significant relationship with non-exchangeable K (0.640*) and CEC (0.611*) in the Kakan area and with exchangeable K (0.868**) and non-exchangeable K (0.710**) in the Choram area. Soluble K did not show significant correlation with other soil physical-chemical properties. As it can be seen, although organic matter is available in the soils of area, even in very low amount, it had a positive correlation with exchangeable K (Table 4).

The exchangeable K in all samples had a significant negative correlation with $CaCO_3$ (negative correlation, because of its dilution effect) and a significant positive correlation with HNO3-extractable K, CEC and organic matter. In addition, although there was a positive association between exchangeable potassium and amount of smectite and vermiculite mineral, but it was not significant. Shakeri et al. (2015) stated that the organic matters play more important role than smectite to preserve the exchangeable K

Table 5. Pearson correlation coefficients between soil K forms and clay minerals in studied areas

	Soluble K	Exchangeable K	Non-exchangeable K	Structural K	Illite	Vermiculite
Kakan						
Exchangeable K	0.487					
Non-exchangeable K	0.640*	0.948**				
Structural K	0.528	0.466	0.678**			
Illite	0.878*	0.721	0.744	0.647		
Vermiculite	0.099	0.193	0.285	0.355	0.136	
Smectite	-0.895*	0.765	0.752	0.136	-0.707	0.095
Choram						
Exchangeable K	0.868**					
Non-exchangeable K	0.710**	0.744**				
Structural K	0.003	0.178	0.641*			
Illite	-0.460	-0.632	0.564	0.425		
Vermiculite	-0.119	0.012	0.022	0.108	-0.704	
Smectite	0.420	0.569	0.625	0.531	-0.980**	0.716*
Bahmaei						
Exchangeable K	0.147					
Non-exchangeable K	0.483	0.844**				
Structural K	0.502	0.686	0.928**			
Illite	0.087	-0.029	0.315	0.488		
Vermiculite	0.027	0.184	0.271	0.304	0.125	
Exchangeable K	0.348	0.545	0.488	0.279	-0.555	0.131

**significant at the 0.01 level, *significant at the 0.05 level

The organic matters role seems to be even greater than clay in surface horizons with higher organic matter, so that the correlation between clay and exchangeable K in the current study has not been significant in the surface horizons. The high specific surface area of the organic matters increases the CEC, and consequently increases the ability to preserve more cations such as K in the soil. in the soils of Choram area, as shown in Table 4 had the higher amount of non-exchangeable K, so the higher amount of exchangeable K should be added in the soils of this area. Successive cultivation of rice and wheat results in increasing of organic matter percentage at the surface horizons. Therefore, the exchangeable K was observed to higher in the horizons containing higher organic matter. According to Table 4 and 5 the non-exchangeable and mineral K in the study area in all land uses were positive correlated with illite, vermiculite, smectite, clay content, CEC and OC (Table 4).

CONCLUSIONS

The change of land use from forest and pasture to agricultural cultivation has caused significant effects on the chemical soil properties and fertility of the series of studied soils. It is concluded that most studied land uses had considerable contents of different potassium fractions. So that the highest level of soluble K (3.7 mg/kg) was found in wheat land use, However, the highest level of exchangeable K (262 mg/kg) and non-exchangeable K (366 mg/kg) concentrations were found in forest land use. It was also observed that the paddy field soils of the Choram area had the highest amount of total and structural K as compared to other land uses. This may be attributed to the high clay amount and low $CaCO_3$ amount of this studied area. It seems that illite and vermiculite are the main minerals for K-bearing in paddy soils. Due to different demands for K and agricultural operations, the agricultural cultivation had a significant effect on the K status in the studied soils. The variation in the available K concentration is related to the effect of management, land use, and variation in the factors effecting on the absorbability of this element (CEC, particle size distribution, etc.). The highest amount of available K was found in soils of forest land use, which were composed of K-bearing minerals in parent materials, and had high organic matter and CEC; and the lowest amount of available K was found in paddy land use cultivated densely by rice. Therefore, agricultural and mineralogical frequency of clay should be considered for better management of K fertilization. Finally, in order to prevent soil degradation and nutrients depletion, it is necessary to periodical investigate the complete properties of the studied soils. Therefore, the appropriate management operations would be considered to deal with soil degradation factors, through observation of these changes.

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اثر کاربری‌های مختلف زمین بر شکل‌های پتاسیم و برخی خصوصیات خاک در استان کهگیلویه و بویر احمد، جنوب غرب ایران

ابوالفضل آزادی*[1]، سیروس شاکری[2]

[1]بخش تحقیقات خاک و آب، مرکز تحقیقات و آموزش کشاورزی و منابع طبیعی استان خوزستان، سازمان تحقیقات، آموزش و ترویج کشاورزی، اهواز، ج. ا. ایران
[2]گروه کشاورزی، دانشگاه پیام نور، تهران، ج. ا. ایران

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*نویسنده مسئول

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واژه‌های کلیدی:
کاربری اراضی
کانی شناسی
شکل‌های پتاسیم
ویژگی‌های خاک

چکیده- تغییر کاربری اراضی مرتع و جنگل به اراضی کشاورزی، می‌تواند بر بسیاری از ویژگی‌های خاک و حاصلخیزی آن اثر بگذارد. این پژوهش با هدف بررسی شکل‌های مختلف پتاسیم (محلول، تبادلی، غیرتبادلی و ساختمانی) و برخی ویژگی‌های خاک در کاربری‌های مختلف سه منطقه چرام، کاکان و بهمئی استان کهگیلویه و بویراحمد انجام گرفت. مناطق مورد مطالعه شامل انواع مختلف کاربری‌ها از جمله کشاورزی ، باغ ها و اراضی بایر بود. در هر منطقه ۴ خاکرخ در کاربری‌های مختلف حفر شد (جمعا ۱۲ خاکرخ). تمام خاکرخ‌ها تشریح و بر اساس کلید سیستم جامع طبقه‌بندی خاک طبقه‌بندی شدند. نتایج نشان داد تفاوت معنی داری بین مقدار رس و سیلت در کاربری‌های مختلف وجود ندارد، در حالی‌که کمترین مقدار رس در کاربری زراعی مشاهده شد. درصد کربن آلی در کاربری مرتع بیشترین مقدار (۱/۰۱درصد) و در کاربری‌های زراعی (۰/۷ درصد) و آیش- گندم (۰/۴ درصد) کمترین مقدار بود. بیشترین و کمترین مقدار pH خاک به ترتیب در کاربری شالیزار (۸/۱۱) و باغ (۶/۸) بدست آمد. در مناطق مورد مطالعه میانگین مقدار پتاسیم محلول، تبادلی، غیر تبادلی، ساختمانی و کل به ترتیب از ۰/۵ تا ۶/۱ ، ۴۵ تا ۲۶۲، ۸۶ تا ۳۶۶، ۳۵ تا ۵۱۹۷، ۹۶۷ تا ۵۵۵۵ میلی‌گرم در کیلوگرم خاک متغیر بود. خاک‌های مورد مطالعه در منطقه کاکان کمترین و منطقه چرام بیشترین مقدار شکل‌های غیر تبادلی، ساختمانی و کل پتاسیم را دارشتند و بیشترین مقدار پتاسیم محلول در منطقه بهمئی و پتاسیم تبادلی در منطقه کاکان بدست آمد. پتاسیم محلول و تبادلی در کاربری‌های مختلف دارای تغییرات معنی دار بود بطوریکه بیشترین مقدار آن به ترتیب در کاربری‌های گندم و جنگل مشاهده شد. بیشترین مقدار پتاسیم غیر تبادلی مربوط به کاربری جنگل و پتاسیم کل و ساختمانی مربوط به کاربری شالیزار برنج منطقه چرام بدست آمد.