

Degradation of Mollisols in Western Iran as Affected by Land Use Change

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ABSTRACT

The present study was carried out in Kharkeh Research Station, Kurdistan Province, western Iran to investigate the effects of the change in land use on the degradation of Mollisols, their organic carbon content, clay mineralogy and K⁺ status. The study area was partly under cultivation (for over 40 years) and partly preserved as rangelands. The results revealed that Mollisols are the dominant soils in non-cultivated natural rangelands. The adjacent cultivated soils, however, lack enough organic carbon to meet the requirements of Mollisols. Cultivation practices had exerted adverse effects on some such major soil properties as organic carbon, cation exchange capacity, as well as macro- and micro-structure. Clay minerals and different forms of potassium did not show significant differences in the two land uses. Parent material rich in such potassium bearing minerals as feldspars and mica, as well as the dominance of illite in soils, were probably the main factors responsible for adjustment of the soil K⁺, rendering the changes relatively non-significant.

Keywords: Clay mineralogy, Land use change, Mollisols, Potassium.

INTRODUCTION

Soil organic matter levels decrease in most cases through a conversion of natural ecosystems to agriculture as well as through an increase in the intensity of tillage. Guo and Gifford (2002) reported that soils lost 42 and 59% of their organic carbon stock upon a conversion from either forest to crop or from grassland to crop cultivation, respectively. Soil organic carbon and N stocks were assessed on a Mollisol in central Ohio in an 8-year period of tillage experiment as well as under two relatively undisturbed land uses; a secondary forest and a pasture on the same soil type. Cropped systems had 51±4 mg ha⁻¹ (equiv. mass) lower soil organic carbon, and 3.5±0.3 mg ha⁻¹ lower N (equiv. mass) in the top 30 cm soil layer, as compared with under forest land use.

Different forms of soil K have been a key focus in studies of soil fertility. Many works

have addressed the solution chemistry and mineralogy (Sharpley, 1989; Bouabid *et al.*, 1991; Dhillon and Dhillon, 1991; Buhmann, 1993). Clay minerals are the source of plant nutrients and due to their specific surface characteristics, determine the release pattern of some such important nutrients as K⁺. A knowledge of clay minerals and their origin, therefore, is very helpful for an understanding of the nutritional status and nutrient supplying power of soils.

Experiments have revealed that plants can uptake both the exchangeable and nonexchangeable (fixed) forms of potassium (Bonsel, *et al.*, 1992). Fixed or nonexchangeable form is the main source of potassium provision to plants. Potassium ion (K⁺) release from the fixed form is determined by many such factors as the type and abundance of the K bearing minerals, mineral size and weatherability, soil solution potassium, as well as soil pH. Mica and feldspars are the

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major primary mineral sources of potassium in soils.

Smectite, illite, chlorite, kaolinite and palygorskite are the major clay minerals in the arid and semiarid regions (Khormali and Abtahi, 2003). Illite is generally considered as a major K bearing clay mineral. These clay minerals are usually the foundation base of parent rocks and soils in arid and semiarid regions (Khormali *et al.*, 2005). There are few reports on the land use change effects on the degradation of soils, their clay mineralogy and K status in arid and semiarid regions (Pal *et al.*, 2001). The present study was carried out in Kharkeh Research Station, Kurdistan Province, western Iran to investigate the effects of the change in land use on the degradation of Mollisols, their organic carbon content, clay mineralogy and K⁺ status.

MATERIALS AND METHODS

Soil and Profile Description

Kharkeh Research Station is located 80 km north of Sanandaj in Kurdistan Province (Figure 1). The area has been partly under cultivation of wheat and barley (for over 40 years) and partly preserved as natural rangeland, referred to as non-cultivated soils. Po-

tassium fertilizers have never been applied to soils in the study area. Based upon previous soil surveys, eight representative pedons were selected for the investigation. Along with each selected pedon, 3 extra pits were sampled as replications. Soils were described and classified according to the Soil Survey Manual (Soil Survey Staff, 1993) and Keys to Soil Taxonomy (Soil Survey Staff, 2006), respectively. Soil moisture and temperature regimes in the study area are determined as xeric and mesic, respectively. Mean annual precipitation is approximately 570 mm. Soils were formed on the plateaus and alluvial valleys surrounded by limestone and schist deposits of the Cretaceous.

Chemical and Physical Analyses

Particle-size distribution was determined following a removal of CaCO₃ with 2N HCl and decomposition of organic matter with 30 % H₂O₂. Following repeated washings to remove salts, samples were dispersed using sodium hexametaphosphate for determination of particle size through pipette method (Day, 1965). Alkaline-earth carbonate was assessed through acid neutralisation (Salinity Laboratory Staff, 1954). Organic carbon was measured by wet oxidation with chromic acid and back titration with ferrous ammonium sul-



Figure 1. Location map of the study area.

Table 1. Classification of the soils studied.

Soil Groups ^a	Geomorphic description	Non-cultivated soils	Adjacent 40 year cultivated soils
1	Lowland	Fine, smectitic, mesic, <i>Vertic Haploxerolls</i>	Fine, smectitic, mesic, <i>Typic Haploxererts</i>
2	Valley bottom, lower section	Fine-loamy, mixed (calcareous), superactive, mesic, <i>Typic Xero-fluvents</i>	Fine, mixed (calcareous), superactive, mesic, <i>Typic Xerothents</i>
3	Plateau	Fine, mixed, superactive, mesic, <i>Typic Calcixerolls</i>	Fine, carbonatic, mesic, <i>Typic Calcixerpts</i>
4	Valley bottom, upper section	Fine-loamy, mixed, superactive, mesic, <i>Typic Haploxerolls</i>	Fine, mixed, mesic, <i>Typic Haploxerepts</i>

^a Each group consists of two types of soils, left is non-cultivated, while on the right is cultivated counterpart e.g. *Vertic Haploxerolls* has been modified to *Typic Haploxererts* through cultivation.

phate (Nelson, 1982). Soil pH was measured in a saturation paste (Salinity Laboratory Staff, 1954). Cation Exchange Capacity (CEC) was determined using sodium acetate (NaOAC) at a pH of 8.2 (Chapman, 1965).

The amounts of K forms in each sample were determined through methods using Knudsen *et al.* (1982). Total K was determined following a digestion of soil with 48 % HF and 6M HCl. Water soluble K was measured in a saturated extract after shaking of a 2 g soil sample end-to-end with 20 ml of water for 1 hour. Exchangeable K was then extracted from the same soil sample with an application of 20 ml of 1.0M NH₄OAC (pH 7.0) for 5 minutes. Nitric acid-extractable K was measured through an extraction from a soil sample boiled in 1.0 M HNO₃ for 1 hour. Potassium was measured on fall filtered (0.45 µm) extracts through atomic absorption application. Analyses were carried out in duplicate, the averages being presented. Mineral K was calculated as the difference between total and HNO₃-extractable K. Potassium saturation was determined as the ratio of exchangeable K over the sum of exchangeable cations and represented on a percent basis.

Mineralogical Analyses

Removal of chemical cementing agents and separation of clay fractions was performed according to Mehra and Jackson (1960), Kittrick and Hope (1963), and Jack-

son (1975). Samples were grinded and treated with sodium acetate (pH 5) to remove carbonates. The addition of 1N sodium acetate was continued until no effervescence observed with an addition of 1N HCl (Jackson, 1975). The reaction was performed in a water bath at 80°C. The organic matter was oxidized by treating the carbonate-free soils with 30% H₂O₂, and subsequent digestion in a water bath. This treatment caused a dissolving MnO₂ too. Free iron oxides were removed from the samples by an application of citrate dithionate method (Mehra and Jackson, 1960), iron being determined in the filtered solution by means of atomic absorption application. Iron-free samples were centrifuged at 750 rpm for 5.4 minutes (RCF= 157 g, International IEC Centrifuge), clay separates being removed. XRD studies were carried out using a Philips X-ray diffractometer.

The 001 reflections were obtained following Mg-saturation, ethylene glycol solvation and K-saturation. The K-saturated samples were studied both after drying and heating at 350°C and 550°C for 4 hours. To identify kaolinite in presence of tri-octahedral chlorite, samples were also treated with 1N HCl at 80°C, overnight (Moore and Reynolds, 1989). Percentages of the clay minerals were estimated according to Johns *et al.* (1954). 18 Å° and 10 Å° Peaks refer to smectite and illite respectively. 14 Å° peak in this treatment indicate the presence of chlorite and/or vermiculite. Vermiculite can be determined



if the k saturated 10 A° peak intensity increases. Finally kaolinite can be detected by the decrease in 7.1 A° peak after 550°C treatment. Alkaline-earth carbonate (lime) was measured by acid neutralization, while gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) determined through precipitation with acetone (Salinity Laboratory Staff, 1954).

Micromorphological Analyses

Thin sections of about 80 and 40 cm^2 were prepared from air-dried, undisturbed and oriented clods using standard techniques described by Murphy (1986). A mixture of polyester resin, catalyst, and cobalt was used together with acetone as diluting agent. Micromorphological descriptions were made according to Bullock *et al.* (1985) and Stoops (2003). A Euromex polarising microscope was employed for micromorphological studies.

RESULTS AND DISCUSSION

Soil Classification and Physico-chemical Properties

Soils were grouped as cultivated and non-

cultivated (rangelands Table 1). As seen, soils were placed in four groups, the groupings being made according to geomorphic descriptions. Groups 1 through 4 soils are formed on lowlands, lower section of valley bottom, plateau and upper section valley bottom, respectively. All the non-cultivated pedons except one in group 2, are Mollisols. In group 1; Vertic Haploxerolls has been modified to Typic Vertisols under cultivation practices. This indicates that tillage has led to thinning of mollic epipedon, losing much of its organic matter and finally being changed to an ochric epipedon. As presented in Table 2, this modification is reflected in such soil properties as weakening of structure, hardening of consistency, brightening of color, and more compaction or higher bulk density as a result of cultivation. These findings are also true for other soil groups. In group 3 for instance, Typic Calcixerolls was modified to Typic Calcixerepts with the mentioned morphological and physical changes having occurred in these soils. The main modification occurred, as a result of cultivation practices, in soil organic carbon content.

A study of different land uses including forest, rangeland, degraded rangeland and farmland in Northern Iran showed that the amount of organic matter content decreased

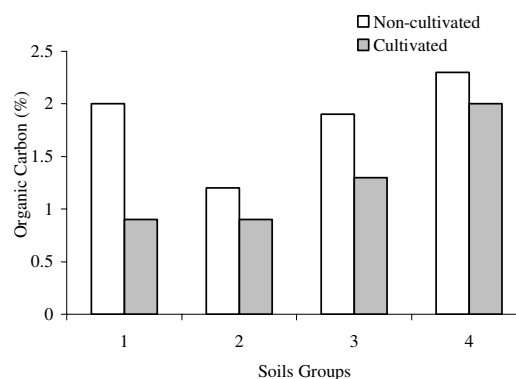


Figure 2. Organic carbon content of the surface horizons in the studied soils. Refer to Table 1 for nomenclature of the soils in each group (mean differences between the two land uses are significant at $\alpha = 0.01$).

Table 2. Bulk density and some other selected morphological properties of the surface soils of the study area.

Soil groups	Non-cultivated					Cultivated				
	Pedons	Structure ^a	Color, moist	Consistence, moist	BD ^b g cm ⁻³	Pedons	Structure	Color, moist	Consistence, moist	BD g cm ⁻³
1	Vertic haploxerolls	2mgr	10YR3/2	Very friable	1.50	Typic haploxererts	1fgr	7.5YR4/4	Hard	1.58
2	Typic xerofluvents	2mgr	10YR4/4	Very friable	1.45	Typic xerothents	1fgr	10YR4/4	Friable	1.55
3	Typic calcixerolls	3mrg	10YR3/3	Very friable	1.40	Typic calcixerpts	1fgr	10YR4/6	Slightly hard	1.56
4	Typic haploxerolls	3mgr	10YR3/2.5	Very friable	1.48	Typic haploxerpts	1fgr	10YR4/6	Friable	1.54

^a Soil Survey Staff, (1993) and ^b Bulk density.

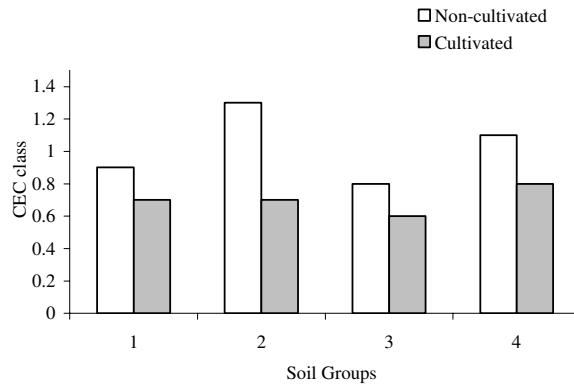


Figure 3. Cation exchange activity classes in control sections of the studied soils. Refer to Table 1 for nomenclature of the soils in each group (mean differences between the two land uses are significant at $\alpha=0.01$).

three percentage points when it turned from forest to farmland, while increasing two units when changed from farmland to rangeland (Kiani *et al.*, 2004). Almost all the studied rangeland soils had enough organic carbon content and bore other pertained properties to be classified as Mollisols (Figure 2). In contrast, none of the adjacent cultivated soils had the requirements of a mollic epipedon but ochric predominates. They were classified as Typic Xerorthents, Typic Calcixercepts, Typic Haploxercepts and Typic

Haploxererts (Tables 1 and 2).

Soil structure was also greatly influenced by the change in land use. Very well developed strong granular and angular blocky structure of Mollisols was replaced by weak granular and angular blocky structure in the cultivated soils (Table 2). The cation exchange capacity class in the Soil Taxonomy (Soil Survey Staff, 2006) is a key criterion reflecting the chemical and physical behavior of the soils. As shown in Figure 3, CEC class is significantly higher in non-cultivated soils. This could be related to the higher organic

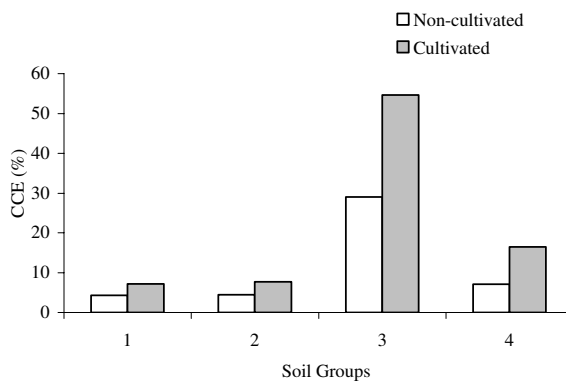


Figure 4. Calcium Carbonate Equivalent (CCE) of the studied soils. Refer to Table 1 for nomenclature of the soils in each group (mean differences between the two land uses are significant at $\alpha=0.01$).

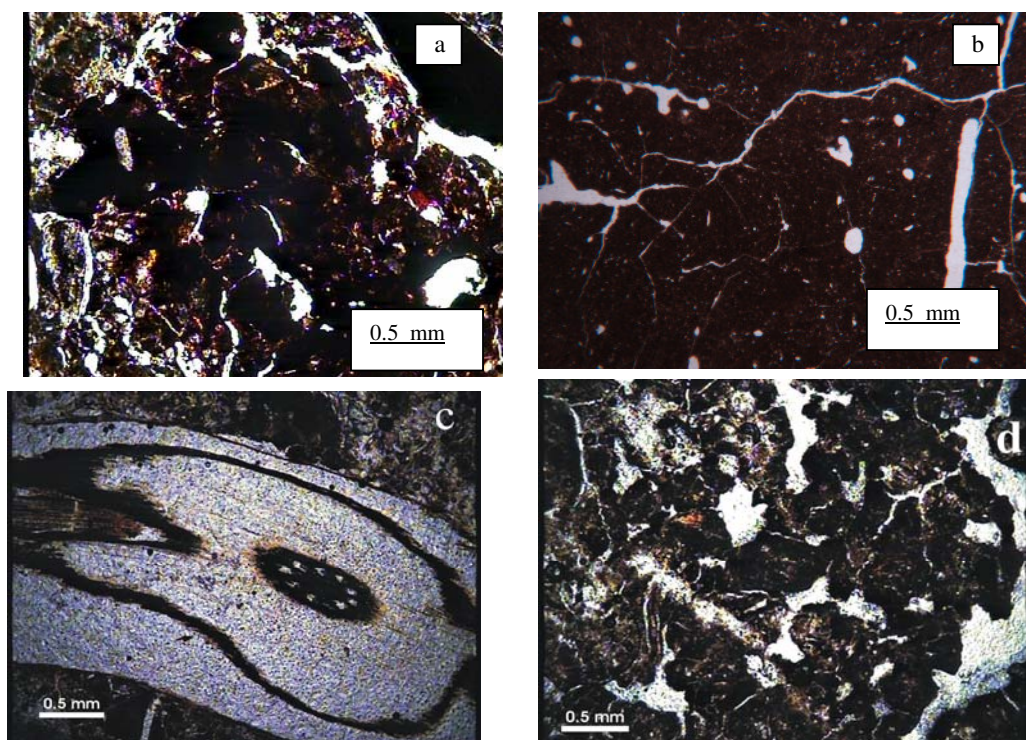


Figure 5. Micromorphology of the epipedons (under plain polarized light) in Typic Calcixerolls (a, c, d) and Typic Haploxerepts (b). a: Shows the well developed crumb microstructure; b: A demonstration of the high shrink swell properties reflected as dominance of planes; c: A section of a root cells at depth of 60 cm, and d: Shows high excremental pedofeatures.

matter content of the rangelands. A comparison of the calcium carbonate, in control section of the soils studied, also revealed that it is significantly higher in the cultivated soils (Figure 4).

The accumulation of carbonates in soils involves complex processes of dissolution (weathering), translocation and precipitation. Lithogenic carbonate dissolves under ambient moisture and a relatively high soil CO_2 partial pressure and the dissolved Ca^{2+} , Mg^{2+} and CO_3^{2-} ions move downward with the percolating soil water. As the moisture content decreases, calcite precipitates (Wang and Anderson, 1998; Khormali *et al.*, 2005).

Water availability together with vegetation create higher soil respiration and providing extra acidity, which controls the dissolution/precipitation of calcium carbonate in soils (Treadwell-Steitz and McFadden, 2000). In non-cultivated rangelands, therefore, car-

bonate could move to deeper horizons. In the cultivated soils, however, either the downward percolating water was not enough to leach the carbonate deeper, as in the case of Mollisols, and/or the erosion of the surface layers, induced by cultivation, caused the outcropping of the underneath highly calcareous parent material.

Micromorphology

Soil microstructure is concerned with the size, shape and arrangement of primary particles and voids in both aggregated and non-aggregated material and the size, shape and arrangement of any aggregates present (Stoops, 2003).

Miomorphological studies confirmed that very strong and well developed granular and

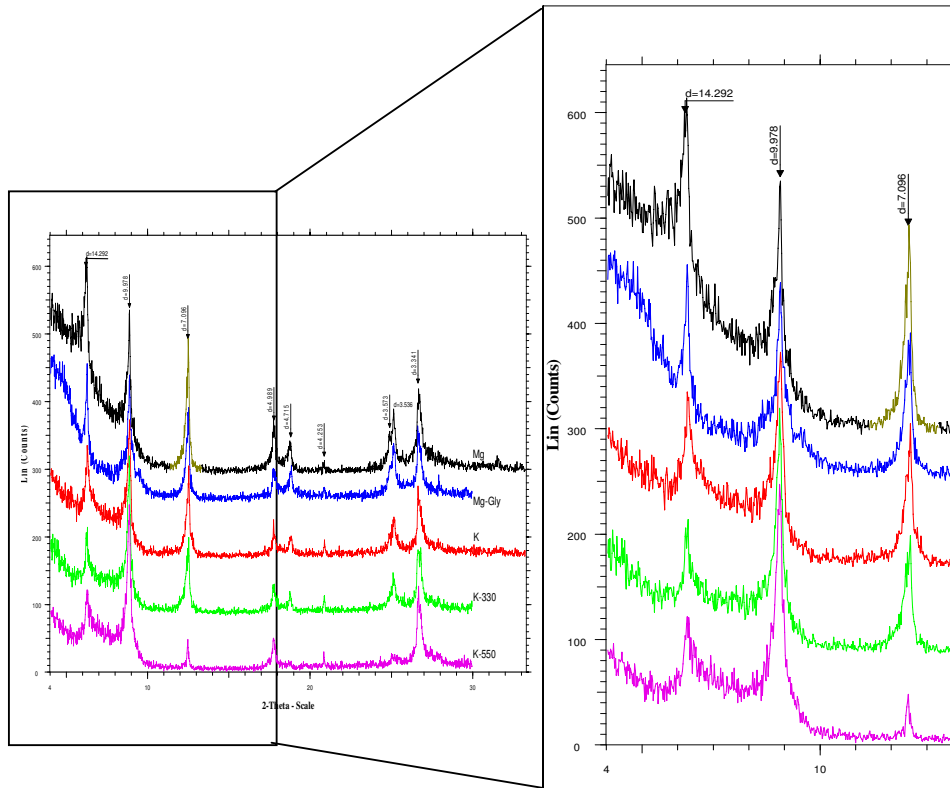


Figure 6. X-ray diffractogram of the shale parent material showing high illite contents (10 Å peak) and chlorite (14 Å peak stable in all treatments) as dominant clay fractions.

angular blocky structures of the Mollisols studied were replaced with a weak granular and angular blocky structure in the cultivated soils as shown in Figure 5. In well developed mollic epipedon of the Mollisols there exist well developed crumb and granular microstructures. In other cultivated soils, weak microstructures, as in the case of Vertisols in Figure 5b, high shrink-swell properties have resulted in the disturbance of peds. Voids are mostly channels in rangelands while they are dominated by planes in the cultivated soils (Figure 5).

Image analysis of the thin sections in both types of land uses revealed that the total porosity in non-cultivated soils was significantly higher than that in their cultivated counterpart adjacencies. The better physical conditions of the non-cultivated soils provided by the well developed microstructure,

higher organic matter has resulted in a higher biological activity even in the deeper horizons (Figures 5c and 5d).

Clay Mineralogy

XRD studies confirmed the presence of illite, chlorite, smectite, and kaolinite as the major silicate clay minerals in the soils studied (Figure 6). The relative amounts of the clay minerals are shown in Table 3. All the pedons studied showed to be almost of the same clay mineralogy with their abundances not showing any significant difference between the two land use groups. The observed differences in abundance of clay minerals were mostly related to the topography and the internal drainage of the soils. In the low lying soils, e.g. group 4, the smectite

Table 3. Clay mineralogy and their semiquantitative occurrences in the control section of the soils.

Soil groups	Non-cultivated		Cultivated	
	Pedons	Major clay minerals in soils	Pedons	Major clay minerals in soils
1	Vertic haploxerolls	Illite> Smectite> Chlorite > Kaolinite> Mica-Vermiculite	Typic haploxererts	Illite> Chlorite> Smectite> Kaolinite> Mica-vermiculite
2	Typic xerofluvents	Illite> Smectite> Chlorite> Kaolinite> Mica-Vermiculite	Typic xerothents	Illite> Chlorite> Smectite> Kaolinite> Mica-vermiculite
3	Typic calcixerolls	Illite> Chlorit > Smectite> Kaolinite	Typic calcixerpts	Illite> Chlorite> Smectite> Kaolinite
4	Typic haploxerolls	Illite> Smectite> Chlorit> Kaolinite	Typic haploxerepts	Illite> Smectite> Chlorite> Kaolinite

Table 4. Mean values of the different forms of potassium in the soils.

Soil groups	Non-cultivated				Cultivated					
	Pedons	Mineral K (mg kg ⁻¹)	HNO ₃ extractable K (mg kg ⁻¹)	NH ₄ OAc ⁻ extractable K (mg kg ⁻¹)	Water soluble K (meq L ⁻¹)	Pedons	Mineral K (mg kg ⁻¹)	HNO ₃ extractable K (mg kg ⁻¹)	NH ₄ OAc ⁻ extractable K (mg kg ⁻¹)	Water soluble K (meq L ⁻¹)
1	Vertic haploxerolls	12146	481	285	0.088	Typic haploxererts	15940	639	502	0.194
2	Typic xerofluvents	9130	310	202	0.098	Typic xerothents	10930	399	253	0.220
3	Typic calcixerolls	9395	260	230	0.136	Typic calcixerpts	8930	221	225	0.125
4	Typic haploxerolls	9947	290	173	0.095	Typic haploxerepts	10230	335	157	0.107

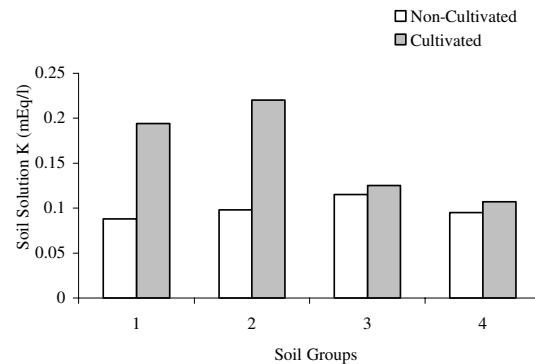


Figure 7. Mean soil solution potassium status in the studied soils. Refer to Table 1 for a nomenclature of the soils in each group.

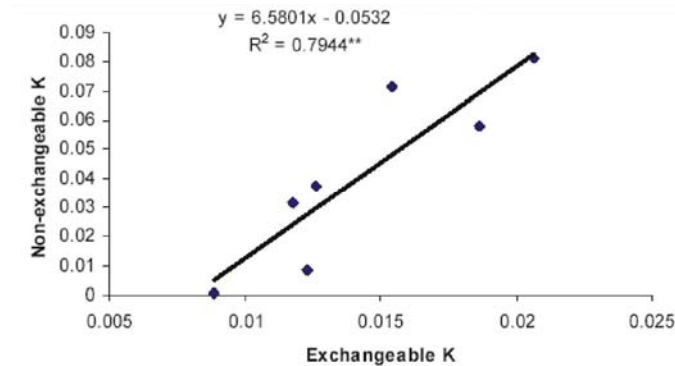


Figure 8. Mean exchangeable versus non-exchangeable K^+ in the illitic cultivated soils.

content was higher than in the other soils. In well-drained soils, however, illite was the dominant silicate clay mineral.

An increasing soil-available moisture and consequently the provision of a relatively vaster leaching environment for the release of K^+ from micaceous minerals, mainly illite, in the calcareous environment with high Mg^{++} and a high Si mobility might have provided favourable conditions for the formation of smectite through the process of transformation (Khormali and Abtahi, 2003). XRD studies of the major parent rocks of the area studied confirmed that illite, smectite and kaolinite are the dominant silicate clay minerals. These findings are consistent with those by Khormali *et al.*

(2005) in their study of the parent rocks of southern Iran. The parent rocks likely acted as a main source for the soil silicate clay minerals.

Potassium Status

Table 4 shows the different forms of the soil K in either one of the land use types. Although the different forms of K in the cultivated soils are relatively higher than in the non-cultivated soils, the differences were not statistically significant. The plant uptake might have induced a higher release of the reserve potassium into the soil solution (Figure 7). As discussed earlier, the soils and the parent rocks contained large amounts of K

bearing minerals such as illite and K-feldspars. The lack of a significant difference in the potassium status in the two land use cases, therefore, suggests that the silicate clay minerals in either the parent rocks or in soils could have acted as buffers and released K^+ from the mineral structure into the exchangeable sites or soil solution. The source of clay minerals as well as their abundance had a significant relationship with different forms of potassium. Exchangeable K^+ versus structural K^+ , as the potassium reservoir of the soils, showed also a significant relationship with the steeper slope for illitic soils (Figure 8). Illite could, therefore, release higher plant available K^+ .

CONCLUSIONS

Land use change from natural rangelands to agriculture could result in a considerable change in soil properties, mainly through an oxidation of the soil organic carbon, a weakening of soil macro- and microstructure, soil compaction, and a decrease in cation exchange activity. The soil clay mineralogy and consequently the potassium status of the soils appeared to be unaffected by land use change. Silicate clay minerals in the parent rocks are the major source of soil clay minerals. Clay minerals, therefore, in turn control the K status in soils. The illitic mineralogy of both types of soils and of the parent rocks, could therefore act as a powerful buffering agent to keep the K level in the soils relatively unchanged. In fertility management, therefore, one should consider clay mineralogy from a standpoint of geochemistry of plant nutrients.

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تخریب خاکهای مالی سولز غرب ایران در اثر تغییر کاربری

ف. خرمالی و ک. نبی الهی

چکیده

مطالعه حاضر به منظور بررسی آثار تغییر کاربری اراضی بر تخریب خاکهای مالی سولز، کربن آلی، کانیهای رسی و وضعیت پتاسیم آنها در ایستگاه تحقیقات کشاورزی خرکه در استان کردستان صورت گرفت. قسمت عمده منطقه مورد نظر تحت کشت و زرع (به مدت چهل سال) و قسمتی نیز به صورت مرتع طبیعی می باشد. نتایج نشان دادند که مالی سولز خاکهای عمده مراتع طبیعی است حال آنکه اراضی تحت کشت مجاور فاقد ماده آلی و شرایط لازم برای این خاک می باشند. کشت و کار و تغییر کاربری تأثیر سوئی بر ماده آلی، ظرفیت تبادل کاتیونی و ساختمان میکروسکوپی و ماکروسکوپی خاک داشته است. کانیهای رسی و شکلهای مختلف پتاسیم تغییر معنی داری را در دو کاربری نشان ندادند. این امر می تواند به دلیل غنی بودن مواد مادری از کانیهای پتاسیم داری همچون فلدسپار و میکا و از طرفی غالب بودن کانی ایلیت در خاکها باشد که سطوح پتاسیم را در خاکها کنترل می نمایند.