

*Maryam MAHMOUDI LAMOUDI, Shahla MAHMOUDI,
Farhad KHORMALI*, Ali CHERATI ARAEI¹*

**STUDY OF THE EVOLUTION OF CLAY MINERALS IN PADDY (Pa)
AND NON-PADDY (NP_a) SOILS ON A TOPOSEQUENCE IN
GHAEMSHAHR CITY, MAZANDARAN PROVINCE**

SUMMARY

This research was carried out to investigate the effect of rice cultivation and topography on the development of soil clay minerals in Ghaemshahr City in Mazandaran province. A total of 10 profiles were selected on a toposequence—five profiles with rice fields and five with rangeland land uses. The soils studied were classified as Inceptisols and Mollisols. The results of clay mineralogy show that the amount of smectite is higher in paddy (Pa) soils, while the amount of vermiculite is higher in non-paddy (NP_a) soils. The higher presence of smectite in rice fields is probably due to the neoformation process. Also, smectite was found to be higher in lower regions with shallow groundwater. The cation exchange capacity, clay content, and bulk density are higher in the Pa soils. Rice cultivation increases the amount of iron extracted in oxalate (Fe_o) form and decreases the amount of iron extracted in dithionate (Fe_d) form. Also, during the toposequence from lower areas to areas with higher altitudes, the amount of Fe dithionate increased while Fe oxalate decreased respectively. The amount of pedogenic iron (Fe_d) has a direct correlation with the degree of evolution of the soil; this amount increased during the toposequence from low to higher regions.

Keywords: Clay mineralogy, evolution, toposequence, paddy soil, Ghaemshahr City

INTRODUCTION

Rice is an annual plant that is often cultivated under hydromorphic conditions. It is the most important source of food for more than 50% of the world's population and is cultivated across 155 million hectares in 114 countries. Pa soils are affected by intense human activities (Gong, 1983) because rice cultivation requires specific management (flooding, puddling, and drainage). The formation of Pa soil under the influence of flooding, puddling, and drainage generates redoximorphic properties. The formation of redoximorphic

¹ Maryam Mahmoudi Lamouki, Department of Soil Science, Science and Research Branch, Islamic Azad University, Tehran, Iran, Shahla Mahmoudi, Department of Soil Science, Tehran University, Tehran, Iran, Farhad Khormali, (corresponding author: khormali@yahoo.com), Department of Soil Science, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran, Ali Cherati Araei, Department of Soil and Water, Mazandaran Agricultural and Natural Resources Research and Education Center, AREEO, Sari, Iran,

complications occurs with the accumulation and depletion of iron and manganese with the fluctuation of groundwater level in the soil (Zeng-Yei and Zeng-Sang 2001). In the management of rice cultivation, the soil is under flooding condition for a long time, resulting in different morphological, physical, chemical, and mineralogical characteristics.

The quantitative and qualitative identification of soil clay minerals is important in terms of not only their usage and management but also their evolution process. In addition to determining the soil genesis, evolution, and development manner, it can throw a broad scientific light on their formation and evolutionary process. These studies also provide valuable information on the status of the absorption, stabilization, and release of cations (Torabi Golsefidi, 2001).

Clay mineralogy studies in Pa soils have been extensively performed by Chang (1961), Egashira *et al.* (1997), Hassannezhad *et al.* (2008), Chen *et al.* (2011), and Han and Zhang (2013). By studying the Pa soils in China, Chang (1961) report that the combination of clay minerals in Pa soils is based on the combination of their parent materials. Hassannezhad *et al.* (2008) investigated the effect of rice cultivation on the clay mineralogy characteristics of soils in the Amol region of Mazandaran province, in which the hydromorphic conditions cause smectite neoformation. The study by Han and Zhang (2013) on the chronosequence of Pa soils in southern China shows that the evolution of clay minerals can be determined based on their compounds, which are strongly influenced by their parent materials. They also found that due to complex oxidoreduction processes, long-term rice cultivation could create major differences in the soil's morphology and properties; in contrast, in younger rice field soils, the combination of clay minerals is similar to the primary soils without cultivation. Comparing the physicochemical and mineralogical characteristics of Pa soils in the region of Noorabad and the adjacent virgin lands, Owliaie *et al.* (2014) found that rice cultivation has led to a sharp reduction in palygorskite and an increase in smectite in the Pa soil. The increase in smectite content in Pa soil, in addition to the deformation of palygorskite to smectite, is also likely to be related to the alteration of the illite and neoformation of smectite in the soil solution.

Absolute amounts of iron compounds, in addition to the pedogenic processes, are dependent on the parent material. Therefore, the values of Fe_d-Fe_o (iron oxide crystallization degree), Fe_o/Fe (amorphous iron to free iron ratio), and Fe_d-Fe_o/Fe_t (crystalline iron ratio) are used to compare the evolution of soils. The Fe_d-Fe_o index represents the amount of crystalline iron oxides. The largeness of this value indicates that most of the iron compounds are crystalline (Hassannezhad *et al.* 2008).

So far, no study has been done regarding the effect of rice cultivation and topography on the evolution and clay mineralogy of soil in the region of Ghaemshahr in Mazandaran province, this study was performed to investigate the aforementioned cases.

MATERIAL AND METHODS

Study area and sampling

The study took place in Qaemshahr, Mazandaran province, Northern Iran (Figure 1). The average annual temperature and precipitation in this region are 16 °C and 734 mm respectively. The soil moisture and temperature regimes in the study area are xeric and thermic respectively (Banaei, 1998). The study area is related to the fourth period of geology. The parent materials are alluvial. They are transported to the region due to the flow of rivers and floods; in proportion to the slope of the lands and the speed of the river water, coarse and fine sediments are left. For the purpose of this study, 10 profiles were selected during a toposequence—five profiles in Pa soils and five in NPa soils. Excavated profiles are described based on the American classification (soil taxonomy, 2014) (Table 1). From its different horizons, an intact and a non-intact sample have been prepared to measure the physical and chemical parameters of the soil.

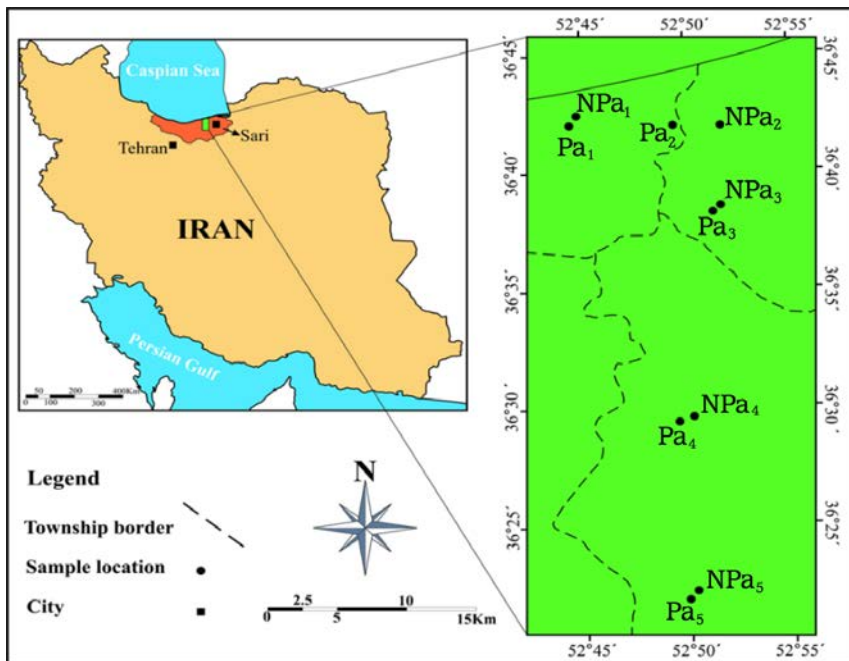


Figure 1. Location of the study area and sampling sites

Physicochemical analysis

The distribution of soil particles size was determined using the hydrometer method (Bouyoucos, 1962). The organic carbon content of the soil samples was evaluated by wet oxidation using chromic acid and by return titration with ferrous ammonium sulfate, based on Nelson's method (1982). The pH of the soil samples was measured with a pH electrode in a suspension of 1:1 (soil: H₂O). The sodium acetate method was used at pH 8.2 to measure soil CEC (Chapman,

1965). The titration method was used to determine the amount of carbonate (US Salinity Laboratory Staff, 1954). The amount of iron extractable by dithionate (Fed) in soil samples was determined using the Mehra and Jackson method. Soil samples were dried and weighed in oven for 24 hours at 105 °C and the paraffin method was used to determine the bulk density (Blake and Hartge 1986). The iron extractable by ammonium oxalate was measured using 0.3M ammonium oxalate at pH 3 in a dark place (McKeague *et al.* 1971).

Mineralogy analysis

The methods given by Mehra and Jackson (1960) and Kittrick and Hope (1963) were used to eliminate the cementations chemical agents and separate the clay particles from each other. To separate clay particles (<2 µm), iron-free samples were centrifuged for 4.5 minutes at 750 rpm (Kittrick and Hope 1963). For X-ray analysis on the clay section, a Phillips diffractometer was used (Jackson, 1975). To obtain an acceptable comparison between the relative intensity of the peaks in different samples, equal concentrations of clay suspensions were used. After saturation with potassium, magnesium, and ethylene glycol, the 001 reflection was considered. Potassium-saturated samples were heated at 550 °C for four hours. The semi-quantitative evaluation of clay minerals was performed based on the levels of sub-peaks resulting from X-ray diffraction in the glycerol treatment of samples (Johns and Grim, 1954).

RESULTS AND DISCUSSION

Physico-chemical properties

The major physicochemical and morphological properties of the studied soils are presented in Table 1. As shown in Table 1, the studied Pa soils and NPa soils are classified in two categories of Inceptisols and Mollisols respectively, according to the soil taxonomy (2014).

The color of the soils varies from 2.5Y to 10YR according to the Munsell soil chart. Pa soils have poor drainage and the presence of hydromorphic conditions over the years causes the 2.5Y hue. There is a great difference between the textures of Pa and NPa soils (from clay to silty clay). The highest amount of clay was observed in the lowland of the region (Table 1), which can be explained by the sedimentation of clay-sized particles leached from higher regions (Khormali and Ajami 2009). Wilding *et al.* (1982) report that the soil texture in the lowland is heavier than other areas in the same region. According to Table 1, the NPa₅ profile has the coarsest texture in comparison to other profiles (silty clay loam). The cation exchange capacity (CEC) in Pa soils is higher than that in rangeland fields due to the higher percentage of clay in rice-cultivated land.

This case can also be justified on the basis of the clay mineralogy, because NPa soils have a greater amount of smectite than others. The percentage of calcium carbonate varies from 2% on the horizon C of the NPa₄ profile to 27% on the horizon A of the Pa₄ profile. The bulk density (BD) has been shown to be very variable in both land uses; it is higher in the Pa soils than in rangeland soils.

Table 1. Morphological and physicochemical properties of the studied soils

horizon	Depth (cm)	Color (moist)	pH	CEC ^a (cmol(+) kg ⁻¹)	sand (%)	silt (%)	clay (%)	Textural class ^b	CCE ^c (%)	OC ^d (%)	BD ^e
NP _{a1} , Haplaquolls											
A	0-20	10YR3/2	7.76	32	4	44	52	SiC	15	1.26	1.78
AB	20-40	2.5Y3/2	7.80	34.1	8	44	50	SiC	16	1.19	1.81
B _g	40-60	2.5Y5/3	8.02	34.1	6	48	46	SiC	14	0.86	1.84
BC _g	60-100	2.5Y4.5/3	8.22	34.5	6	44	50	SiC	18	2.15	1.80
Pa ₁ , Haplaquepts											
A _p	0-15	2.5Y4.5/4	7.79	41.8	10	32	58	C	19	1.02	1.89
AB _g	15-40	2.5Y4.5/4	7.89	38	8	33	59	C	18	1.06	1.96
B _g	40-70	2.5Y4.5/3	7.82	37	7	37	56	C	23	0.16	1.95
BC _g	70-100	2.5Y4/2	7.93	32	8	42	50	SiC	20	0.62	1.94
NP _{a2} , Calciaquepts											
A	0-10	10YR4/4	6.04	38.3	14	40	46	SiC	4	3.06	1.83
AB	10-35	2.5Y3/2	7.65	35.8	10	41	49	SiC	7	1.17	1.82
B _{kg1}	35-70	2.5Y4/2	7.57	30.0	14	42	44	SiC	18	0.66	1.80
B _{kg2}	70-100	2.5Y4/1.5	7.50	34.9	13	42	45	SiC	14	0.64	1.81
C _g	100-130	2.5Y4/1.5	7.47	21.6	12	40	48	SiC	12	0.46	1.78
Pa ₂ , Haplaquepts											
A	0-20	10YR4/3	8.04	45	10	36	54	C	13	2.03	1.99
B _{wg1}	20-50	2.5Y3/4	7.83	35	12	38	58	C	5	0.47	1.99
B _{wg2}	50-70	2.5Y3/4	7.78	28.3	14	40	56	C	5	1.40	1.91
C _g	70-90	2.5Y3/5	7.70	31	8	42	50	SiC	10	1.63	1.89
NP _{a3} , Calciaquolls											
A	0-25	10YR3/2	7.24	38	9	42	49	SiC	11	3.54	1.78
B _g	25-55	2.5Y3.5/2	7.80	33	11	41	48	SiC	13	0.78	1.72
C _{kg}	55-80	10YR4/2	7.99	32	14	34	52	C	18	0.51	1.70
Pa ₃ , Cslciaquepts											
A _{pg}	0-20	2.5Y4/1	7.75	41	12	36	52	C	13	1.62	1.90
B _g	20-45	2.5Y4/1	7.70	42	12	34	54	C	12	1.24	1.92
B _{kg}	45-65	2.5Y4/2	7.81	44.1	10	34	56	C	13	0.62	1.91
C _g	65-90	2.5Y4/2	8.01	40	18	32	50	C	9	0.64	1.89
NP _{a4} , Haploxerolls											
A	0-19	10YR3/2	7.67	30	17	41	42	SiC	9	1.48	1.70
B _{w1}	19-45	10YR3/3	7.78	28.7	17	43	40	SiC	10	0.78	1.68
B _{w2}	45-65	10YR3/4	7.84	27.9	19	42	39	SiCL	5	0.55	1.72
C	65-100	10YR3/3.5	7.69	31.2	23	35	42	C	2	0.4	1.71
Pa ₄ , Endoaquepts											
A _g	0-18	2.5Y4/1	7.65	40	20	29	51	C	27	1.87	1.97
CB _g	18-45	2.5Y4/4	7.85	32	17	30	53	C	24	0.66	1.95
C _g	45-90	10YR4/6	7.77	30	26	34	40	C	25	0.35	1.92
NP _{a5} , Calcixerolls											
A	0-27	10YR3/2	7.75	32.4	16	44	40	SiCL	9	1.37	1.67
AB	27-44	10YR3/3	7.81	29.9	18	43	39	SiCL	3	0.73	1.65
B _k	44-66	10YR3/4	7.77	32	20	41	39	SiCL	12	0.8	1.68
CB	66-90	10YR3/3.5	7.65	22.8	21	37	42	C	13	1.0	1.63
Pa ₅ , Haplaquepts											
A _{pg}	0-21	2.5Y3.5/2	7.28	37	18	32	50	C	16	1.84	1.92
B _{g1}	21-47	2.5Y3/3	7.82	32	15	35	50	C	18	1.18	1.93
B _{g2}	47-65	2.5YR4/1	7.81	30	19	34	47	C	17	1.08	1.90
C _g	65-95	2.5YR3/1	7.92	30	20	35	45	C	10	0.62	1.91

^aCEC: Cation Exchange Capacity^bC: clay, si: Silty, L: loam, S: sandy.^cCCE: Calcium Carbonate Equivalent^dOC: Organic Carbon^eBD: Bulk Density

Table 2. Concentration of various forms of iron and their ratio in studied soils

horizon	Fe _d	Fe _o	Fe _o /Fe _d
(g/kg)			
NPa ₁ , Haplaquolls			
A	20.55	5.62	0.27
AB	20.36	5.45	0.26
B _g	20.20	4.92	0.24
BC _g	19.78	4.86	0.24
Pa ₁ , Haplaquepts			
A _p	15.15	5.82	0.38
AB _g	15.86	5.66	0.35
B _g	15.52	5.35	0.34
BC _g	15.01	5.01	0.33
NPa ₂ , Calciaquepts			
A	20.48	4.2	0.20
AB	21.86	3.56	0.16
B _{kg1}	21.14	3.92	0.18
B _{kg2}	20.20	3.47	0.17
C _g	20.14	3.04	0.15
Pa ₂ , Haplaquepts			
A	18.47	4.5	0.24
B _{wg1}	17.52	4.42	0.25
B _{wg2}	17.12	4.7	0.27
C _g	16.96	4.83	0.28
NPa ₃ , Calciaquolls			
A	23.33	3.01	0.12
B _g	23.1	2.60	0.11
C _{kg}	22.61	2.45	0.10
Pa ₃ , Calciaquepts			
A _{pg}	19.94	3.35	0.16
B _g	19.36	3.18	0.16
B _{kg}	19.62	2.95	0.15
C _g	19.20	2.80	0.15
NPa ₄ , Haploxerolls			
A	25.40	2.62	0.10
B _{w1}	25.24	2.65	0.10
B _{w2}	24.87	2.44	0.09
C	24.48	2.33	0.09
Pa ₄ , Endoaquepts			
A _g	22.8	2.73	0.11
CB _g	22.62	2.65	0.11
C _g	21.89	2.48	0.11
NPa ₅ , Calcixerolls			
A	25.02	2.45	0.09
AB	24.56	1.90	0.07
B _K	26.95	1.75	0.06
CB	25.24	1.50	0.05
Pa ₅ , Haplaquepts			
A	23.95	2.34	0.09
B _{g1}	23.78	2.71	0.08
B _{g2}	23.2	2.65	0.08
C _g	23.45	2.15	0.07

Table 2 shows the concentrations of different forms of iron (Fe_d and Fe_o) and their ratios (Fe_d/Fe_o) in all studied soils. In most studies, soil age is measured based on the morphological characteristics and the amount of pedogenic iron and clay (Costantini and Damiani 2004). Detier et al. (2012) report that the most important forms of iron in the soil are Fe_t (total iron), Fe_d , and Fe_o . Therefore, (Fe_d-Fe_o) shows the amount of crystalline form of Fe, Fe_o/Fe_d indicates the degree of iron crystallization, and Fe_d-Fe_o/Fe_t represents the ratio of crystallized iron to total iron (Schaetzl, 2005). Rezapoor et al. (2010) studied different forms of Fe oxides and their dispersion in the Northwest of Iran, and report that increased weathering leads to increased Fe_d and decreased Fe_o/Fe_d ratio. In this study, Pa soils were found to have a higher Fe_o content than NPa soils, while NPa soils had a higher content of Fe_d . Based on the results obtained, the Fe_o content in all profiles decreases with increasing depth. Decreasing organic matter in depth leads to microbial activity reduction, resulting in a decrease in the conversion rate of Fe^{3+} to Fe^{2+} (Bouma, 1990). In hydromorphic conditions, the possibility of converting amorphous iron oxides and hydroxides into crystals is minimal (Scarciglia et al. 2011). The Fe_d amount is reduced from surface to depth in all profiles, except NPa₅. Fe_o/Fe_d ratios for all profiles except Pa₂ decreases with increasing depth. The amount of Fe_d increases with the increase in the weathering of iron-containing minerals, but the Fe_o/Fe_d ratio—which indicates the ratio of amorphous iron to crystalline iron—decreases. This index, which is used to compare the evolution of soils, decreases with increasing evolution.

In hydromorphic conditions and lack of oxygen, iron is formed as Fe (II); in such conditions, formation of iron oxides is less, resulting in an increase in Fe_o/Fe_d ratio. According to McKeague and Day (1966), if the Fe_o/Fe_d ratio is greater than 0.25, it indicates hydromorphic conditions. In old Pa soils, the continuation of iron accumulation leads to the formation of a rich horizon of iron (Gong, 1986). In this study, the B_k horizon of NPa₅ profile has the highest amount of Fe_d and the lowest amount of Fe_o ; in contrast, the C_g horizon of Pa₁ profile has the lowest amount of Fe_d and the highest amount of Fe_o . Compared to rangeland soils, Pa soils had more amounts of Fe_o , resulting in higher Fe_o/Fe_d values (as much as 1.36 times). During the topography row, this ratio is reduced from lower regions to regions at higher altitudes, indicating that the soils of regions at higher altitudes are more developed.

Mineralogy analysis

The results of clay mineralogy of the studied soils are shown in Table 3 and Figure 2. According to this table, illite, chlorite, smectite, kaolinite, vermiculite, and interlayer minerals such as illite-smectite and illite-vermiculite have been observed in clay fraction of soils.

Illite is dominant in most of profiles due to its heritable origin in these soils (Wilson, 1999; Khormali and Abtahi 2003). This mineral has the highest frequency in almost all profiles (Table 3 and Figure 2). In almost all profiles, the amount of illite increases with increasing depth, indicating that the mineral has

hereditary origin. Due to the relatively poor condition of moisture in the xeric moisture regime compared to that in the udic regime for the conversion of illite to other minerals, the amount of illite is high. Khormali *et al.* (2003) argue that illite is converted to other minerals, which are often smectite.

Table 3. Mineralogical composition of clay fractions of studied samples

Profile	Horizon	Depth(cm)	Sme	Ill	Ver	Kao	Chl	Ill-ver Ill-Sme
NPa ₁	A	0-20	x	xx	xx	x	tr	-
	Bg ₁	40-60	xx	xx	xx	tr	-	x
	BCg	60-100	x	xxx	tr	x	xx	-
Pa ₁	Ap	0-15	-	xxx	x	tr	x	-
	Bg	40-70	xxx	xx	-	tr	tr	-
	BCg	70-100	x	xxx	-	tr	xx	-
NPa ₂	A	0-10	xx	xx	x	tr	x	-
	Bkg ₁	35-70	xx	xx	xx	tr	tr	x
	Cg	100-130	xx	xxx	x	x	-	-
Pa ₂	A	0-20	-	xx	xx	x	x	-
	Bw ₁	20-50	xxx	x	x	tr	tr	-
	Cg	70-90	xxx	xx	x	x	tr	-
NPa ₃	A	0-25	x	xxx	-	tr	xx	-
	Bg	25-55	x	xx	xxx	tr	tr	-
	Ckg	55-80	x	xxx	xx	x	tr	-
Pa ₃	Apg	0-20	xxx	xx	-	tr	x	-
	Bkg	45-65	xxx	xx	tr	x	x	-
	Cg	65-90	xx	xxx	x	tr	tr	-
NPa ₄	A	0-19	x	xx	xxx	x	tr	-
	Bw ₂	45-65	x	xx	xx	x	tr	-
	C	65-100	x	xxx	xx	x	-	-
Pa ₄	A	0-18	xx	xx	x	x	tr	-
	CBg	18-45	xx	xx	x	x	tr	-
	Cg	45-90	xx	xxx	-	x	tr	-
NPa ₅	A	0-27	x	xx	xx	x	x	-
	Bk	44-66	x	x	xxx	x	tr	-
	CB	66-90	-	xxx	xxx	x	tr	-
Pa ₅	A	0-21	xx	xx	x	x	x	-
	Bg ₂	47-65	xx	xx	x	x	tr	-
	Cg	65-95	-	xxx	xxx	x	tr	-

xxx= large(25-50%)

tr= Trace (<5%)

Ill= Illite

Chl= Chlorite

xx=moderate (10-25%)

-= Not detected

Ver= Vermiculite

x=small (<10%)

Sme= Smectite

Kao= Kaolinite

Chlorite is detectable in a small amount in X-ray fluorescents in clay fraction of all profiles. No change in the peak of 14 Angstrom in magnesium glycerol and potassium with a temperature of 550 °C treatment indicates this mineral (Fig 2). The origin of this mineral in these soils is hereditary (Wilson, 1999; Khormali and Abtahi 2003). This mineral often originates from metamorphic rocks with low to moderate degrees (Grim, 1968). Barnhisel and Bertsch (1989) report that in acidic conditions (expandable minerals 2:1), first the

brucite layer (hydroxy interlayer) and then pedogenic chlorite are formed. Illite and chlorite are abundant in areas where soil formation is limited (Wilson, 1999). The abundance of these two minerals in the soil is generally due to the presence of parent materials.

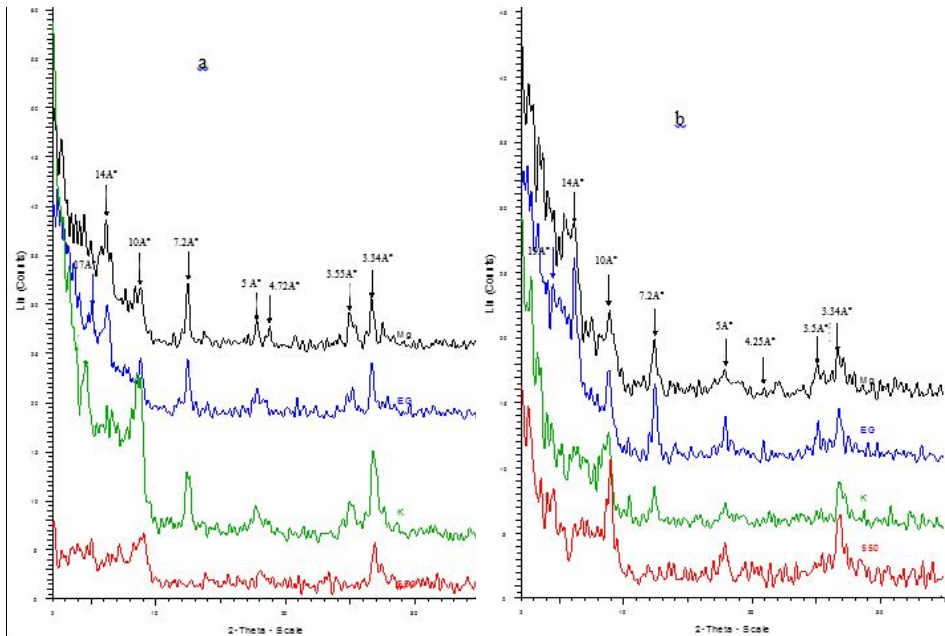


Figure 2. X-Ray diffraction patterns of clay fraction for the representative soil profiles. (a) B_g horizon of NPa₁, (b) B_g horizon of Pa₁

The presence of vermiculite has been reported in most soils of Iran (Khormali and Abtahi 2001 and 2003). Khormali and Abtahi (2003) state that vermiculite is unstable under high pH conditions with the presence of Si and Mg²⁺ and low Al solubility. An increase of Angstrom 10 peak in potassium and heat treatment is probably due to the presence of vermiculite (Figure 2a). There is a lot of vermiculite in NPa soils, mainly due to leaching conditions and the removal of potassium from mica. The probability of formation of vermiculite as an intermediate product of mica and its subsequent conversion to smectite has been confirmed (Douglas, 1989).

In this study, smectite is the dominant mineral of Pa soils (Figure 2b) because these soils are under poor drainage and submerging conditions for several months of year. Under these conditions, iron is reduced; the Si, Al, and Mg ions are dissolved from the higher regions and provide conditions for the neoformation of the smectite (Borchart, 1989). Khormali and Abtahi (2003) describe there are three main sources of smectite in soils: 1. neoformation in soil solution, 2. detrital origin or inheritance, and 3. transformation of other clay minerals. Hassannezhad et al. (2008) report that natural or human-induced flooding conditions lead to increase in smectite. Ghergherechi and Khormali

(2008) studied the effect of groundwater level and the type of land use on the origin and distribution of clay minerals. They found that in soils with poor drainage, the amount of smectite was maximum and was mostly from the neoformation process.

Kaolinite is present on all horizons in a low amount. Considering that Khormali and Abtahi (2003) expressed the acidic conditions with the average activity of Si and the low alkaline cations suitable for the neoformation of kaolinite from the soil solution, the studied soils are not suitable for the formation of kaolinite. It can be said that the reason for the presence of this mineral is its hereditary origin in these soils. Angstrom 7.2 peak in the magnesium saturation treatment is related to this mineral (Figure 2).

Illite-smectite and illite-vermiculite have been observed only in the profiles of NPa₁ and NPa₂. These types of mixed layer minerals are very common in soils where illite is formed from smectite (Moore and Reynolds 1997).

A semi-quantitative study of minerals during the toposequence shows that smectite content in lowland with higher groundwater was higher; in contrast, the vermiculite content was higher in highlands with better drainage. The changes in other clay minerals were not significant.

CONCLUSIONS

The results show that Pa soils have less evolution due to flooding and are classified in Inceptisols, whereas in the rangelands, the soils have more evolution, and except in one case, the soils were classified in Mollisols. Clay mineralogy studies show that illite is the dominated clay mineral in most of the soils. Rice cultivation and management result in flooding and hydromorphic conditions; the presence of these conditions and poor drainage can lead to an increase in the amount of smectite. The smectite is probably formed due to the neoformation process in these soils. In contrast, in NPa soils, the amount of vermiculite is higher than that of smectite. Also, the results show that in the toposequence, from the lowland to the highland, the amount of smectite is reduced while the amount of vermiculite is increased.

Rice cultivation has caused changes in the physical, chemical, and mineralogical characteristics of the studied soils. The soil BD in Pa soils has increased due to the compaction caused by soil tillage operations. The CEC is higher in this usage, which can be explained by the amount and type of clay mineral (presence of more smectite). The amount of pedogenic iron (Fe_d) has a direct correlation with the degree of soil evolution; this amount increases during toposequence from lowland areas to higher elevations and is also higher in rangeland soils than in Pa soils. However, the amount of iron extracted with oxalate is higher in the lower areas and in Pa soils. The average ratio of Fe_d/Fe_o in Pa soils is 1.36 times higher than that in NPa soils.

REFERENCES

- Banaei MH. 1998. Soil moisture and temperature regime map of Iran. Soil and Water Research Institute, Ministry of Agriculture, Iran.

- Barnhisel RI, Bertsch PM. 1989. Chlorite and hydroxy interlayered vermiculite and smectite. Pp 729-788. In: Minerals in soil Environment (J.B. Dixon & S.B Weed, editors.) Soil Sci. Soc. Am. J., Madison, Wisconsin. 729-788.
- Blake GR, Hartge KH. 1986. Bulk density. In: Klute A (Ed.) Methods of Soil Analysis. Part 1, Physical and Mineralogical Methods, 2nd ed. Agronomy. 9: 363-382.
- Borchart, G. 1989. Smectite. In: Dixon, J.B., Weed, S.B. (Eds.), Mineral in Soil Environments, 2nd ed. Soil Science Society of America, Madison, WI. pp. 635-674.
- Bouma J. 1990. Classification and Management of Wet Soils. Report of ICOMAQ. Circular 10. In: Eighth International Soil. Correlation Meeting, U.S.D.A., Soil Service, Soil Management Support Services, USDA, Washington.
- Bouyoucos GJ. 1962. Hydrometer method improved for making particle size analysis of soils. Agron. Jour. 54: 464-465.
- Chang SN. 1961. [Clay minerals of some representative paddy soils of China]. Acta Pedol Sin. 9: 81-102. (Chinese)
- Chapman HD. 1965. Cation exchange capacity. In: Black CA (Ed.), Methods of Soil Analysis. Part 2. American Society of Agronomy, Madison, WI. pp. 891-901.
- Chen LM, Zhang GL, Effland WR. 2011. Soil characteristics response times and pedogenic thresholds during the 1000-year evolution of paddy soil chronosequence. Soil Sci. Soc. Am. J. 75: 1-14.
- Costantini AC, Damiani D. 2004. Clay minerals and the development of Quaternary soils in central Italy. Revista Mexicana de Ciencias Geologicas. 21: 144-159.
- Dang VM, Anderson Dw, Farrell RE. 2002. Indicators for assessing soil quality after long-term tea cultivation in Northern Mountainous Vietnam. In: proceeding of the 17th WCSS. Thailand pp. 14-21.
- Detier DP, Birkeland PW, McCarth JA. 2012. Using the accumulation of CBD-extractable iron and clay content to estimate soil age on stable surfaces and nearby slopes, Front Range, Colorado. Geomorphology. 173-174: 17-29.
- Douglas LA. 1989. Vermiculites. Minerals in Soil Environment (J.B. Dixon & S.B Weed, editors). Soil Science Society of America, Madison, Wisconsin, USA. pp. 635 – 674.
- Egashira K, Fujii K, Yamasaki S, Virakornphanich P. 1997. Rare earth element and clay minerals of paddy soils from the central rejoin of the Mekong River, Laos. Geoderma. 78: 237-249.
- Ghergherechi S, Khormali F. 2008. [Study of the effect of groundwater level and the type of land use on the origin and distribution of clay minerals in loess derived soils in Southwest of Golestan Province]. Journal of Agriculture Sciences and Natural Resources of Gorgan. 3: 18-30. (Iranian)
- Gong ZT. 1983. Pedogenesis of paddy soils and its significance in soil classification. Soil sciences. 135 (1): 5-10.
- Gong ZT. 1986. Origin, evolution and classification of paddy soils in china. Adv. Soil Sci. 5: 174-200.
- Grim RE. 1968. Clay mineralogy. 2th edition McGraw Hill Book Company, New York, 596 p.
- Han GZ, Zhang GL. 2013. Changes in magnetic properties and their pedogenic implications for paddy soil chronosequences from different parent materials in south China. Eur. J. Soil Sci. 64 (4): 435-444.
- Hassannezhad H, Pashae A, Khormali F, Mohammadian M. 2008. Effect of soil moisture regime and rice cultivation on mineralogical characteristics of paddy soils of Mazandaran province, Northern Iran, Amol. J. Soil Sci. Madison, WI.

- Jackson ML. 1975. Soil chemical analysis. Advanced Course. Unive of Wisconsin, Collage of Agric, Dept. of soils. Madison, WI.
- Jones WD, Grime RE, Bradley F. 1954. Quantitative estimation of clay minerals by diffraction methods. *Journal of Sedimentary Petrology*. 24: 242-251.
- Khormali F, Abtahi A, Mahmoodi S, Stoops G. 2003. Argillic horizon development in calcareous soils of arid and semiarid regions of southern Iran. *Catena*, 53: 273-301.
- Khormali F, Abtahi A. 2001. [Study the relationship of physiography and the origion of fibrous mineral of palygorskite using electron microscope, Darab plain, Fars Province]. *Proceeding of 7th Iranian soil scince congress, Shahrekord University*. Pp: 171-173. (Iranian)
- Khormali F, Abtahi A. 2003. Origin and distribution of clay minerals in calcareous arid and semi-arid soils of Fars Province, southern Iran. *Clay Minerals*. 38: 511-527.
- Kittrick JA, Hope EW. 1963. A procedure for the particle size separation of soils for X-ray diffraction analysis. *Soil Science*. 96: 312-325.
- McKeague JK, Day JH. 1966. Dithionite-and oxalate-extractable Fe and Al as aids in differentiating various classes of soils. *Can. J. Soil Sci.* 46: 13-22.
- Mehra OP, Jackson ML. 1960. Iron oxide removal from soils and clays by a dithionite citrate with sodium bicarbonate. *Clays Clay Miner.* 7: 317-324.
- Moore DM, Reynolds RC. 1997. X-ray diffraction and the identification and analysis of clay minerals (2nd Ed). Oxford University Press, Oxford. 387 pages.
- Nelson DW, Sommers LE. 1982. Total carbon, organic carbon, and organic matter. In: page, A.L., Miller R H, Keeney D R. (Eds), *Methods of Soil Analysis, part 2. Chemical and Microbiological properties*. 2nd ed. *Agronomy*. 9: 539-579.
- Owliaie HR, Keshavarzi M, Adhami E. 2015. [Comparison between physicochemical properties and clay mineralogy of paddy soils of Noorabad (Fars Province) and adjacent virgin lands]. *J. of Management and Sustainable*. 4(4): 105-125. (Iranian)
- Rezapoor S, Jafarzade A, Samadi A, Oustan S. 2009. Distribution of iron oxide forms on a transect of calcareous soils, north-west of Iran. *Archives of Agronomy and Soil Science*. 56(2): 165-182.
- Salinity Laboratory Staff. 1954. *Diagnosis and Improvement of Saline and Alkali Soils*. United States Department of Agriculture Handbook No. 60 Washington, DC.
- Scarciglia F, Tuccimei P, Vacca A, Barca D, Pulice I, Salzano R, Soligo M. 2011. Soil genesis, morphodynamic processes and chronological implication in two soil transects of SE Sardina, Italy: Traditional pedological study coupled with laser ablation ICP-MS and radionuclide analyses. *Geoderma*. 162: 39-64.
- Schaetzl RJ, Anderson S. 2005. *Soils: Genesis and Geomorphology*. Cambridge University Press, U.K.
- Torabi Golsefidi H. 2001. [Genesis, classification and suitability evaluation of wetland soils for rice cultivation on different landforms in Guilan Province, Northern Iran]. *Isfahan University of Technology, Colege of Agric. Ph.D. Thesis*, 485p. (Iranian)
- Wilding NE, Smeck A, Hall GF. 1982. Pedogenesis and soil taxonomy. II. The soil orders. *Developments in soil science* 116. Elsevier Publ.
- Wilson MJ. 1999. The origin and formation of clay minerals in soils: past present and future perspectives. *Clay Mineral*. 34: 7-25.
- Zeng-Yei H, Zeng-Sang C. 2001. Quantifying soil hydromorphology of a Rice-growing Ultisol toposequence in Taiwan. *Soil. Sci. Soc. Am. J.* 65: 270-278.