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The Influence of Continuous Rice Cultivation and Different Waterlogging Periods on Morphology, Clay Mineralogy, Eh, pH and K in Paddy Soils

M.A. Bahmanyar
Sari Agriculture and Natural Resource University, P.O. Box 578, Iran

Abstract: The effect of different rice cultivation periods on the properties of selected soils in alluvial plain were studied in Mazandaran province (north of Iran) in 2004. Soils were sampled form 0, 6, 16, 26 and over 40 years rice cultivation fields. In each treatment three soil profiles and six nearby auger holes were studied. The present study results indicated that continuous rice cultivation have changed soil moisture regime from xeric to aquic, soil color from brown to grayish, surface horizons from mollic to ochric epipedon and soil structure changed from granular or blocky to massive. Therefore, the soil order has changed from Mollisols to Inceptisols. No illuviation and eluviation of clay minerals occurred as a consequence of rice cultivation. X-ray diffraction analysis showed that clay minerals in non-rice cultivated field were illite, vermiculite, montmorillonite, kaolinite and chlorite, but in rice field were illite, montmorillonite, kaolinite and chlorite, respectively. In contrast of montmorillonite, the amount of illite and vermiculite have been decreased by increasing periods of rice cultivation. The pH values of the saturated soil surface in six weeks past plantation have shifted toward neutrality. While Eh value of non-paddy soils were about +90 mv, surface horizons of paddy soils at field conditions had Eh value about +40, -12, -84, -122 mv, respectively. The amounts of organic matter and available Fe, Mn, Zn and Cu were increased whereas available K was decreased in paddy soils.

Key words: Clay minerals, Eh value, rice cultivation, soil morphology

INTRODUCTION

Rice is one of the major food crops in Iran and is mainly grown in alluvial, flood and piedmont plains of the southern coast of the Caspian Sea in the provinces of Gilan, Mazandaran and Golestan on about 450,000 ha (Anonymous, 1999).

Rice cultivation under flooded conditions can result in temporary and permanent changes in the soil. Temporary changes are limited to surface soils and are associated with puddling as practiced in many paddy fields and also with alternating chemical oxidation and reduction. Although, these temporary surficial edaphic changes are important in crop management and crop production. These changes are not large enough to warrant a change in the taxonomic classification of soils. However, the cumulative effects of these recurrent temporary changes may lead to farther permanent changes of the pedon and possibly change the taxonomic classification. As a result of flooding, paddling and the associated development of a plowpan, changes in physical properties are generally beneficial for rice growth in that they improve nutrient availability and reduce percolation losses (Neue, 1988).

Munir (1995) stated that in rice cultivated areas, soil color changed to greyish; soil structure becomes massive; soil mottles and concretions formed as strongly reduction conditions and the soil texture stayed unchanged. Changes in soil characteristics caused by rice cultivation were studied by Shishov *et al.* (1996). The changes include clay removal from the arable horizon and variation in mineralogical composition. Transformation of illite to smectite in the surface horizon of rice-supporting soils was diagnoses by Sawhney and Sehgal (1990). The layer silicate minerals of the clay fraction may also undergo some alteration during intensive gleyzation and leaching, but the extent to which this occurs is much smaller than the change in iron oxides (Zhang, 1981). Studies demonstrated that the introduction of irrigated rice-cropping practices improved soil conditions, including increased organic carbon and pH has towards to neutrality (Li, 1992).

Cultivation of paddy fields has been reported to have increased the organic matter content (Lai, 2002; Zhang and He, 2004) and phosphorus concentrations but decreased potassium content (Zhang and He, 2004). In other studies, continuous rice cultivation was to have shifted soil pH toward neutrality, whereas organic carbon, solvated phosphorus and potassium contents were increased (Kim *et al.*, 1991; Chen-Ming *et al.*, 1994) while available zinc was decreased. Waterlogging has decreased pH and Eh values in calcareous soils

(Kalbasi and Hossenpour, 1997). Meanwhile, in waterlogging conditions the amounts of available Cu and Mn has been increased (Chen-Ming *et al*., 1994). Copper and Mn ions exchanged with Mg, K and Ca that led to potassium leaching (Tian-Ren, 1981). In addition, wetting and drying cause release of K from soil (Olde *et al*., 2002). Submergence, puddling and continuous cropping (without rotation) are common practices in paddy fields in Northern Iran. The main objective of this study therefore, was to investigate changes in soil morphology, clay mineralogy, Eh, pH, K, Fe, Cu, Mn and Zn because of different waterlogging periods in rice cultivation.

MATERIALS AND METHODS

The present study has been conducted in Mazandaran province (latitude 36°, 31', 50" to 36°, 32', 40', longitude 52°, 58', 30' to 53°, 01', 15" and altitude was about 35 m above mean sea level). Average annual precipitation and temperature are about 700 mm and 16°C, respectively. Based on soil survey reports (Ministry of Agriculture and Natural Resources, 1976) in the alluvial plain, five fields (non-rice cultivated, cultivated 6, 16, 26 and over 40 years period continuous rice cultivation) located within a similar mapping unit and soils were selected. In each field with 10 ha area, three soil profiles and six nearby auger holes from rice cultivated and non-rice cultivated fields were chosen and soil samples were taken from different layers in October 2004. Morphological characteristics of each soil profile was determined in the field following the methods described in Soil Survey Manual (Soil Survey Staff, 1993) and soils were classified according to USDA, Soil Taxonomy (Soil Survey Staff, 2003).

Clay minerals were separated from soil samples after the removal of soluble salts, carbonates and organic matter as described by Jackson (1975). Clay samples were saturated with Ca^{2+} and K^{+} using 1N $CaCl_2$ and KCl, respectively. Calcium-saturated clays were also solvated by ethylene glycol and K-saturated clays heated at 550°C for five hours. The clay minerals were then identified from X-ray diffraction patterns (Jackson, 1975). The pH of the saturated paste, calcium carbonates and organic carbon were measured using a glass electrode (McLean, 1986), the titration method (Nelson, 1986) and the Walkley and Black method (Nelson and Sommers, 1986), respectively. Redox potential of the natural soil suspension of the paddy soils was determined in six weeks after planting by a redox potential electrode with Ion analyzer. Available K and Fe, Zn, Cu and Mn were measured 1 N ammonium acetate (Knudson and Peterson, 1986) and DTPA extraction methods, respectively (Olson and Ellis, 1986).

RESULTS AND DISCUSSION

The morphological characteristics of the soils studied are shown in Table 1. The alluvial materials have no development because no changes has happened in illuvial and eluvial processes and no translocation of clays and other materials has occurred in the soil profiles in both paddy and non-paddy soils. In rice field soil colors were greyish, soil structures were massive, a tendency to strongly reducing condition occurred, while the soil texture was unchanged. Present observations were in agreement with Jiang *et al*. (1993) and Reddy *et al*. (2000). Ochric and mollic epipedons were the main surface horizons of paddy and non-paddy soils, respectively, but the only subsurface diagnostic horizon identified in case was cambic horizon. Neue (1988) and Munir (1995) have reported similar observation.

X-ray diffraction analysis of different soil horizons indicated that illite was one of the major clay minerals in both paddy and non-paddy soils. Diffuse and very low intensity peaks at 1.78 nm, which has been under long and continuous rice cultivation, indicated the transformation of degraded illite into other 2:1 expansible clay minerals. Sawhney and Sehgal (1992) observed the transformation of illite in to other 2:1 expansible clay minerals. Intensities of 1.0 nm peaks, indicated that illite, increased with increasing soil depth. Vermiculite clay mineral was identified in non-paddy and paddy soils by peaks at about 1.4 nm form ethylene glycol solvated clays, which collapsed to 1.0 nm after K- saturation (Fig. 1, Chen-Ming *et al*., 1994).

However, the transformation of vermiculite into montmorillonite in the surface and subsurface horizons of paddy soils was indicated by the disappearance or weakening of the 1.4 and 1.45 nm peaks in the ethylene glycol solvated specimen (Fig. 1). Montmorillonite was one of the major clay minerals in all paddy soils studied. The proportion of montmorillonite in over forty year continuous cultivation was higher than others. This has been indicated by relatively strong peaks at 1.8 to 1.82 nm in the ethylene glycol solvated clays and 1.22 nm in the K-saturated clay samples. Peaks at 0.72 and 0.36 nm, which collapsed due to potassium saturation and heating at 550°C, indicated the small amount of kaolinite in most of the soils. However, small amounts of chlorite or hydroxy-interlayered clay minerals were also identified in some soils by the presence of stable 1.35 to 1.4 nm peaks in the K-saturated and the 550°C heated samples (Fig. 1).

Organic matter content of the soil surface horizons ranged from 3.48 to 6.32% (Table 2). However, in the paddy soils, decomposition is generally limited and organic matter accumulates. Increasing the amounts of

Table 1: Morphological characteristics of the soil profiles in different waterlogging period

Horizon	Depth (cm)	Color (Moist)	Texture	Structure	Consistence (Moist/Wet)	Boundary	Other soil characteristics
Pedon No. 1 Fine, mixed, thermic, Typic Haploxerolls (non-paddy soils)							
A_p	0-12	10YR 3/2	SiC	gr	fr	C,S	
B_{w1}	12-35	10YR 3/2	SiC	1mabk,2 fabk	fi	C,S	
B_{w2}	35-62	10YR 4/3	SiC	1msbk, 2 fsbk	fi	C,S	
C_1	62-85	10YR 4/4	SiC	M	fi	C,S	
C_2	85-125	10YR 4/4	SiC	M	fi		
Pedon No. 2 Fine, mixed, thermic, Aquandic Haploxerepts (6 years waterlogged)							
A_{pg}	0-14	10YR 3/3	SiC	M	fi	C,S	Mottling present in
B_{wg}	14-33	10YR 4/3	SiC	1msbk, 2fsbk	fi	C,S	all horizons 7.5YR 3/4
C1g	33-54	10YR 4/4	SiC	M	fi	C,S	gleyzation begins in
C_{2g}	54-76	10YR 5/4	SiC	M	fi	C,S	Apg horizon 5Y 5/1.5
C_{3g}	76-130	10YR 4/4	SiC	M	fi		in 20% matrix
Pedon No. 3 Fine, mixed, thermic, Aquandic Haploxerepts (16 years waterlogged)							
A_{pg}	0-18	10YR 5/2	SiC	M	fi	C,S	Mottling present in
B_{wg}	18-39	10YR 4/1	SiC	M	fi	C,S	all horizons 7.5YR 3/4
C_{1g}	39-68	10YR 5/2	SiC	M	fi	C,S	gleyzation begins in
C_{2g}	68-89	10YR 4/2	SiC	M	fi	C,S	Apg horizon in 20%
C_{3g}	89-125	2.5YR 5/2	SiC	M	fi	-	to 50% matrix
Pedon No. 4 Fine, mixed, thermic, Typic Epiaquepts (26 years waterlogged)							
A_{pg}	0-20	10YR 4/1	SiC	M	st.pl	C,S	Mottling present in all
B_{wg}	20-40	10YR 5/1	SiC	M	st.pl	C,S	horizon gleyzation
C_{1g}	40-70	10YR 5/2	SiC	M	st.pl	C,S	begins in Apg
C_{2g}	70-100	2.5YR 5/1	SiC	M	vst.pl	C,S	horizon and persists
C_{3g}	100-130	2.5YR 5/2	SiC	M	vst.pl	-	through the solum 5Y 5/1.5
Pedon No. 5 Fine, mixed, thermic, Typic Epiaquepts (> 40 years waterlogged)							
A_{pg}	0-20	10YR 4/2	SiC	M	st.p	C,S	Motting present in
B_{wg}	20-40	10YR 4/1	SiC	M	st.pl	C,S	all horizons, gleyzation
C_{1g}	40-70	10YR 4/1	SiC	M	st.pl	C,S	begins in Apg horizon
C_{2g}	70-100	10YR 4/2	SiC	M	vst.pl	C,S	and persists through
C_{3g}	100-130	5YR 3/1.5	SiC	M	vst.pl	-	thesolum 5Y 5/1.5

gr = granular, fr = friable, C = clear, S = smooth, 1 = few, 2 = many, m = medium, f = fine, abk = angular blocky, sbk = subangular blocky, M = massive, fi = firm, SiC = silty clay, st = sticky, pl = plasticky, vst = very sticky

organic matter in waterlogging condition have been reported by some researchers (Kim *et al.*, 1991; Chen-Ming *et al.*, 1994; Reddy *et al.*, 2000; Lai, 2002; Zhang and He, 2004). Eh values in non-paddy fields were +90 MV, but in paddy fields decreased to -122 MV (Table 2). Between waterlogging periods with continuous rice cultivation and Eh values were positive correlation, significantly (R^2 = 0.97). Torabi *et al.* (2001) determined the amounts of Eh -50 to -210 MV in rice field, Cogger *et al.* (1992) -230 MV in low lands with waterlogging and Hseu and Chen (1996) -150 MV in Alfisols with seasonal waterlogging. The soils and their parent materials were generally alkaline and pH values were mostly above 7.0 in both rice and non-rice cultivated soils. But in ricefield in six weeks after planting decreased and shifted toward neutrality (Table 2). These observations agreement with Kalbasi and Hossenpour (1997). In non-paddy fields, the amounts of available Fe were about 21 mg kg^{-1} and in waterlogging and rice cultivation condition, the available Fe raised to 117 mg kg^{-1} (Table 2). Correlation coefficient between available Fe and periods of waterlogging were significant (R^2 = 0.95). Increasing the available Fe in waterlogging condition reported by many researchers (Tian-Ren, 1981; Chen-Ming *et al.*, 1994; Kalbasi and Hossenpour, 1997). The available Mn in non-paddy fields were 5.82 mg kg^{-1} and increased to 37.2 mg kg^{-1} in paddy fields (Table 2, Yang *et al.*, 1992; Chen-Ming *et al.*, 1994).

Available K in surface horizon of non-paddy soils were 375 mg kg^{-1}, but in waterlogging condition and rice cultivation the amounts of available K decreased (Table 2). Wetting and drying in different season in ricefield released the K (Olde *et al.*, 2000). Also, due to low input of K, most irrigated rice production systems in K input was less than K removal by harvested rice grain and sometimes straw, which caused a net deficit in soil K. In addition, water saturation in the soils would increase K downward movement in soil solution or with clay. There were many studies reporting that removal of K balance was negative in rice production system (Dobermann *et al.*, 1998; Wihardjaka *et al.*, 1999; Singh *et al.*, 2002). With increasing the amounts of Fe and Mn in waterlogging condition, Fe and Mn exchanged with K and causes increase the amounts of K in soil solution. Thus, in continuous rice cultivation, the potassium in solution was either absorbed by plant or leached (Regmi *et al.*, 2002) and with increasing the period of cultivation, the amounts of available K more decreased (Table 2).

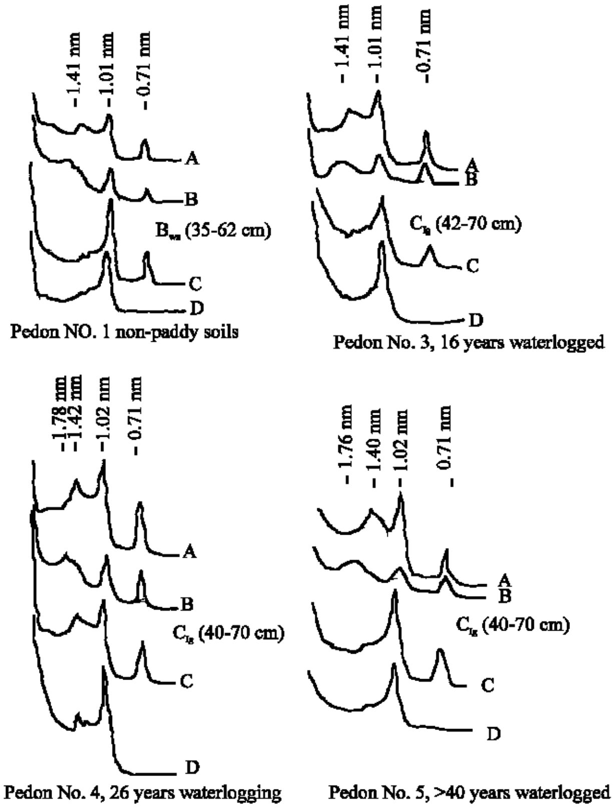

Fig. 1: X-ray diffraction patterns of clay minerals of pedon No. 1, 3, 4 and 5: (A) Ca-saturation, (B) Ethylene glycol solvated, (C) K-saturation and (D) K-saturation + 550°C heated

Table 2: Chemical properties of the soil studied

Horizon	Depth(cm)	pH	pH*	Eh*	O.M (%)	$CaCO_3$ (%)	K (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})
Pedon No. 1 (non-paddy soil)											
A_p	0-12	7.65	-	+90	3.48	16.2	375.0	21.5	0.77	2.9	5.8
B_{w1}	12-35	7.85	-	+92	1.84	14.2	268.0	13.6	0.35	2.4	4.2
B_{w2}	35-62	7.80	-	+88	0.84	15.7	222.0	9.0	0.18	1.9	5.2
C_1	62-85	7.80	-	+87	0.62	15.8	-	-	-	-	
C_2	85-125	7.70	-	+105	0.30	14.3	-	-	-	-	
Pedon No. 2 (6 years continuous rice cultivated)											
A_{pg}	0-14	7.63	6.98	+42	3.54	18.4	220.0	21.2	0.86	3.1	8.6
B_{wg}	14-33	7.87	6.85	+40	1.47	15.3	172.0	16.7	0.29	2.9	10.5
C_{1g}	33-54	7.88	6.86	+37	0.78	16.4	153.0	19.6	0.28	2.5	8.7
C_{2g}	54-76	7.91	6.87	+58	0.42	18.3	-	-	-	-	-
C_{3g}	76-130	7.90	6.90	+72	0.33	15.6	-	-	-	-	
Pedon No. 3 (16 years continuous rice cultivated)											
A_{pg}	0-18	7.65	6.83	-12	4.48	17.2	193.0	64.9	1.18	4.7	6.9
B_{wg}	18-39	7.86	6.92	-48	2.20	19.6	170.0	38.9	1.20	3.4	10.6
C_{1g}	39-68	7.88	6.95	-87	1.06	20.3	172.0	20.4	0.67	3.0	9.6
C_{2g}	68-89	7.78	6.87	-94	0.43	19.2	-	-	-	-	-
C_{3g}	89-125	7.85	6.90	-138	0.32	19.6	-	-	-	-	-
Pedon No. 4 (26 years continuous rice cultivated)											
A_{pg}	0-20	7.96	6.60	-84	4.62	18.5	190.0	75.9	1.14	6.1	18.6
B_{wg}	20-40	7.74	6.96	-112	3.30	20.8	171.0	56.2	0.50	6.1	28.1
C_{1g}	40-70	7.85	6.93	-148	2.34	19.7	185.0	40.5	0.42	8.1	20.7
C_{2g}	70-100	7.83	6.97	-187	0.78	19.3	-	-	-	-	-
C_{3g}	100-130	7.72	6.92	-224	0.31	18.7	-	-	-	-	
Pedon No. 5 (> 40 years continuous rice cultivated)											
A_{pg}	0-20	7.49	6.81	-122	6.32	14.2	175.0	129.8	1.28	8.7	37.2
B_{wg}	20-40	7.80	6.68	-154	3.36	15.8	180.0	60.7	0.88	9.6	25.9
C_{1g}	40-70	7.57	6.95	-181	1.57	14.4	180.0	45.7	0.54	9.3	21.6
C_{2g}	70-100	7.66	6.74	-217	0.79	14.9	-	-	-	-	-
C_{3g}	100-130	7.83	6.78	-243	0.34	15.4	-	-	-	-	-

* pH and Eh values has been measured simultaneously from the soil suspension taken in six weeks after planting

CONCLUSIONS

The present study has conducted that morphological variations produced grayish color, ochric epipedon and massive structure with poor drainage conditions. In waterlogging conditions under continuous rice cultivation, vermiculite clay mineral has been changed to montmorillonite. Long term rice cultivation was effected on the available P, Zn, Cu, Fe and Mn increasingly, but on Eh and K decreasingly. Also, soil pH decreased and shifted toward neutrality and organic carbon content increased.

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