Journal of Pharmacognosy and Phytochemistry 2018; 7(6): 2677-2682

Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2018; 7(6): 2677-2682
Received: 01-09-2018
Accepted: 03-10-2018

Shraddha Mohanty
Department of Soil Science,
Faculty of Agriculture Assam
Agricultural University, Jorhat,
Assam, India

RM Karmakar
Department of Soil Science,
Faculty of Agriculture Assam
Agricultural University, Jorhat,
Assam, India

Correspondence
Shraddha Mohanty
Department of Soil Science,
Faculty of Agriculture Assam
Agricultural University, Jorhat,
Assam, India

Forms of iron in clay fraction of paddy and associated non-paddy soils of Assam

Shraddha Mohanty and RM Karmakar

Abstract

Eight soil profiles collected from paddy and associated non-paddy soils of Jorhat (P1, NP1), Golaghat (P2, NP2), Sivsagar (P3, NP3) and Dibrugarh (P4, NP4) districts of Assam were studied for different forms of iron (Fe) *viz*., total (Fe_t), dithionite extractable (Fe_d), pyrophosphate extractable (Fe_p) and oxalate extractable (Fe_o) in the clay fraction using standard procedures. Total (Fe_t), dithionite extractable (Fe_d) and pyrophosphate extractable iron (Fe_p) in the clay fraction were slightly higher in non-paddy soils as compared to paddy soils whereas oxalate extractable iron (Fe_o) showed a reverse trend. Dithionite extractable iron (Fe_d) formed major portion of total iron content in the clay fraction followed by Fe_o and Fe_p in both paddy and non-paddy soils. Crystalline iron oxide (Fe_d-Fe_o) and silicate iron (Fe_t-Fe_d) was found to be higher in non-paddy soils while amorphous inorganic form of iron (Fe_o-Fe_p) showed the reverse trend. Different forms of Fe in the clay fraction were higher in illuvial B horizons due to presence of higher amount of clay. The Fe_d/Fe_t ratio was found to be higher in non-paddy soils than that of paddy soils. The active iron ratio (Fe_o/Fe_d) was higher in the surface horizon as compared to other horizons of a profile. Different fractions of soil organic carbon and the clay content had strong influence on the distribution of forms of Fe in the clay fraction of soil.

Keywords: Forms of iron, clay fraction, paddy and non- paddy soils, dithionite extractable, oxalate extractable, active iron ratio

Introduction

The pedogenesis of typical paddy growing soils is quite different from associated non-paddy growing soils which are mainly due to differences in physicochemical environments. Paddy soils are a unique anthropogenic soil type formed under long-term hydro-agric management with seasonal submergence (Gong 1999) [8]. The electrochemical changes in a submerged soil influence the solubility and transformation of Fe and Mn, which are involved in redox reactions. Artificial and seasonal water saturation in paddy soils bring about enhanced oxidation and reduction, illuviation of iron (Fe) and manganese (Mn) in the soil profiles, often leading to the formation of featured layers characterizing Fe distribution/ redistribution (Yu 1985; Zhang and Gong 1993) [32, 33]. Iron may occur in the soil as free oxides, amorphous, organic or crystalline in association with clay minerals, concretions, nodules or clay-organic complexes. Crystalline form is the predominant form of Fe in Alfisols (Onweremadu *et al.* 2007) [22]. Genesis of iron oxide was mainly influenced by pedogenic processes like eluviations, illuviation and transformation (Patil and Dasog 1997) [24]. Formation of redoximorphic features occurred as Fe and Mn concretion and depletion associated with the fluctuations of the seasonal water table (Hsue and Chen 2001) [10]. Soils with high organic carbon contain more organic acids, which may have an inhibitory effect on crystallization and lead to retardation of Fe oxide crystallization (Schwertmann *et al.* 1982) [27]. In tropical soils, free Fe oxides may be mobilized and deposited in soil profiles as Fe mottles, concretions, and hardpans (Ojanuga 1978) [21]. Translocation of clay-free iron oxides (Fed) was generally prominent in the soils with medium to coarse texture in hydromorphic soils (Gangopadhaya *et al*. 2015) [7]. Cheng *et al*. (2009) [5] reported a higher amount of clay and total Fe in paddy soil than that of the non-paddy group. More information is extremely needed for planning, uses and management of paddy and associated non-paddy soils. Thus, this work was carried out to investigate the pedogenic distribution of different forms of iron associated with clay fraction of these different but closely related soils.

Materials and methods

Four districts *viz*., Jorhat, Golaghat, Sivasagar and Dibrugarh comprises 76.6 per cent of the Upper Brahmaputra Valley Zone (UBVZ) of Assam cover an area of 12,402 km^2. The study area is part of old alluvial plain in the southern part of the Brahmaputra valley. The area is more or less flat with a gentle slope (0-1%) and slightly undulating topography. The drainage

The drainage in the area is mainly poor to imperfect due to the low lying area and/or high water table and heavy texture of soil. The climate of the study area is humid sub-tropical characterized by high rainfall and high temperature. The average annual temperature is 24.4 to 26.7 °C. The difference between mean summer and mean winter soil temperature is greater than 6 °C in the study area. Thus the soil temperature regime is "hyperthermic". The study area is characterized by mean annual rainfall of 1738.5 to 2649.4 mm. Hence, the area qualifies for "udic" moisture regime. In some paddy growing areas, the soil moisture control section remains water saturated during monsoon qualifying for aquic or oxyaquic conditions.

Table 1: Site characteristics of the study area

Profile No.	Land use	Location	Latitude	Longitude
Jorhat district				
P1	Paddy	Titabar	26^{0}34.366'N	094^{0}10.737'E
NP1	Non-paddy	Titabar	26^{0}34.383'N	094^{0}11.027'E
Golaghat district				
P2	Paddy	Maheema	26^{0}36.014'N	94^{0}03.855'E
NP2	Non-paddy	Maheema	26^{0}40.810'N	93^{0}59.157'E
Sivasagar district				
P3	Paddy	Charing	26^{0}13.426'N	091^{0}38.559'E
NP3	Non-paddy	Charing	26^{0}54.529'N	094^{0}33.937'E
Dibrugarh district				
P4	Paddy	Khowang	27^{0}14.915'N	094^{0}53.287'E
NP4	Non-paddy	Khowang	26^{0}54.530'N	094^{0}33.938'E

Eight soil profiles were collected four each from mono cropped paddy (P1, P2, P3, P4) and associated non-paddy areas (NP1, NP2, NP3, NP4). Horizon wise soil samples were collected, air dried under shade and processed. The fine earth fraction (<2 mm) was analyzed for mechanical composition (Jackson 1956; Piper 1966) [11, 25], pH (in water in 1:2.5), organic carbon, CEC (Jackson 1973) [12]. On the basis of morphological and physicochemical characteristics, the soils were classified as per "*Keys to Soil Taxonomy*" (Soil Survey Staff 2014) [29]. Further, to separate the clay fraction, 10g of undisturbed soil sample (horizon-wise) was taken in a 1000ml long beaker, 300 ml distilled water added and stirred for 30 minutes with the help of magnetic stirrer without adding any chemical. The volume was made to 1000 ml and particles of <2µ was separated by sedimentation method (Jackson 1956) [11] by siphoning. The decanted suspension was centrifuged at 1000 rpm for 15 minutes, washed three times with distilled water and dried on a water bath. Forms of Fe in the clay fraction of soil was determined by separate extractions with (i) sodium dithionite-citrate-bicarbonate (Mehra and Jackson 1960) [20], (ii) 0.2M ammonium oxalate (pH 3.2) by shaking for 4 hrs in dark (soil: extractant ratio of 1:20) (Mc Keague and Day 1966) [18], (iii) 0.1N Na-pyrophosphate (pH 10) by shaking for 16 hrs (soil: extractant ratio of 1:20) (Kononova *et al*. 1966) [14]. Among the extractants used dithionite-citrate-bicarbonate reagent was used to extract both crystalline and non-crystalline Fe oxides, small amount of organically bound Fe along with limited amount of Fe bearing silicates (Borggard 1988) [1]. This was followed by acid ammonium oxalate, which dissolved both "amorphous" and "organically bound" forms of Fe, but not the crystalline forms (Parfitt and Child 1988) [23]. In comparison, pyrophosphate extractant dissolved only the fraction of Fe that is bound with organic matter (Loveland and Didby 1984) [15]. Fe in the extract was determined using atomic absorption spectrophotometer (Model: Pelican- AA 203D). Total Fe content in clay fraction of soil was carried out following the procedure of Jackson (1973) [12].

Results and Discussion

Physicochemical Properties of the Soils

Physicochemical properties of the paddy and associated non-paddy soils are represented in Table 2. Sand, silt and clay contents ranged 17.9-55.7, 21.5-50.8 and 26.2-56.9 per cent respectively in paddy soils and 23.3-65.4, 11.4-42.9 and 14.4-44.4 per cent respectively in non-paddy soils. Presence of relative higher clay content indicates heavier texture of the paddy soils as compared to non-paddy soils may be due to lower topographic position of these soils and/or more pedogenic development of paddy soils. The pH values determined in distilled water (soil: water = 1: 2.5) were found to be in the acidic range in all profiles may be due to leaching of the bases under high rainfall, acidic nature of the parent material, Kaolinitic type of clay (Chakravarty *et al*. 1992; Karmakar and Rao 1998) [4, 13] and organic carbon content. The low EC (0.15-0.20 dSm^{-1}) observed indicates that the soils contain very low amount of soluble salts and there is no salinity problem in these soils. The amount of organic carbon was higher (7.9 to 12.0 g kg^{-1}) in the surface horizon of paddy soils as compared to that in the non-paddy soils (5.8 to 10.0 g kg^{-1}). The profile weighted means of organic carbon content also indicates that paddy soils contained higher amount of organic C as compared to non-paddy counterparts (Wu 2011; Zhang *et al*. 2015) [31, 34]. The cation exchange capacity (CEC) of soils varied from 7.50 to 14.10 cmol (p$^+$) kg^{-1} in paddy soils and from 5.10 to 12.70 cmol (p$^+$) kg^{-1} in non-paddy soils. Low CEC of alluvium-derived soils of Assam is related to dominance of low activity clay like kaolinite (Chakravarty and Barua 1983; Karmakar and Rao 1998; Dutta and Shanwal 2006) [3, 13, 6]. The value of per cent base saturation was lower (32.3 to 51.6) in paddy soils as compared to that in non-paddy soils (34.4 to 57.5) which may be due to more clay content in these horizons. In general, lower base saturation of soils reflects dystric or ultic nature of the soils.

Table 2: Physicochemical properties of soil

Horizon	Depth (cm)	Sand	Silt	Clay	pH (1:2.5)	E.C. (1:2.5) (dSm^1)	OC (g kg^{-1})	CEC cmol (p$^+$) kg^{-1}	BS (%)
		< ------ (%) ------ >							
P1 (Titabar - Paddy soil): *Typic Epiaqualfs*									
Ap	0-25	27.3	29.9	42.8	4.4	0.20	12.0	12.1	36.7
BA	25-35	18.3	30.6	51.1	4.5	0.16	8.7	12.7	41.6
Bt1	35-90	12.2	32.6	55.2	4.7	0.14	7.2	13.5	51.2
Bt2	90-125	11.9	31.2	56.9	4.6	0.13	2.9	14.1	51.6
Bt3	125-145	17.3	30.6	52.1	4.5	0.13	2.4	13.3	45.2
BC	145-165+	27.8	30.9	41.3	4.5	0.12	2.0	13.5	38.0
Wt. mean		17.3	31.3	51.4	4.6	0.14	5.9	11.5	42.4
NP1 (Titabar – Non-paddy soil): *Aeric Epiaqualfs*									
Ap	0-15	55.7	13.2	31.1	4.8	0.16	10.0	10.2	37.5

Horizon	Depth (cm)	Sand	Silt	Clay	pH (1:2.5)	E.C. (1:2.5) (dSm^{1})	OC (g kg^{-1})	CEC cmol (p^{+}) kg^{-1}	BS (%)
		< ------	(%)	------ >					
AB	15-35	49.5	17.7	32.8	5.0	0.13	8.5	11.3	35.8
Bt1	35-80	39.0	16.6	44.4	5.4	0.12	2.4	12.7	45.3
Bt2	80-130	46.1	12.6	41.3	5.4	0.11	1.9	11.2	44.4
BC	130-160+	53.8	11.4	34.8	5.3	0.14	0.7	10.9	41.4
Wt. mean		46.9	14.2	38.9	5.3	0.13	3.4	11.8	41.8
P2 (Maheema - Paddy soil): ***Aeric Epiaqualfs***									
Ap	0-15	23.7	34.8	41.5	4.9	0.15	10.8	11.3	32.3
B	15-45	16.2	35.6	48.2	5.1	0.17	6.7	12.2	32.6
Bt1	45-80	12.4	34.9	52.7	5.3	0.18	6.2	12.8	40.2
Bt2	80-110	18.6	32.8	48.6	5.2	0.18	5.1	11.8	48.3
BC	110-165	36.3	30.1	33.6	5.1	0.16	3.2	11.6	32.3
Wt. mean		23.2	33.0	43.8	5.1	0.17	5.5	11.97	37.0
NP2 (Maheema – Non-paddy soil): ***Ultic Hapludalfs***									
Ap	0-10	33.3	39.1	27.6	4.8	0.17	9.3	8.1	37.2
AB	10-25	35.8	33.8	30.4	4.9	0.13	4.6	8.7	40.9
Bt1	25-60	24.2	40.2	35.6	4.8	0.15	2.5	8.9	50.1
Bt2	60-85	27.1	36.2	36.7	5.2	0.16	2.1	9.2	53.2
Bt3	85-125	29.2	33.9	36.9	5.2	0.18	1.7	9.0	47.3
BC	125-160	44.2	32.9	22.9	4.9	0.13	0.5	7.8	46.4
Wt. mean		31.9	35.7	32.3	5.0	0.15	2.4	8.7	47.4
P3 (Charing - Paddy soil): ***Aeric Epiaqualfs***									
Ap	0-15	17.9	48.9	33.2	4.8	0.19	9.8	8.7	44.1
AB	15-30	11.3	50.8	37.9	5.1	0.13	6.7	9.4	41.6
Bt1	30-65	12.1	41.1	46.8	5.2	0.16	4.1	11.9	39.5
Bt2	65-100	15.1	39.2	45.7	5.2	0.16	3.6	11.5	43.0
Bt3	100-140	18.1	37.8	44.1	5.3	0.15	2.6	9.5	48.5
C	140-170	32.4	36.3	31.3	5.1	0.15	2.5	9.7	43.5
Wt. mean		18.2	40.6	41.2	5.2	0.16	4.1	10.4	43.7
NP3 (Charing – Non-paddy soil): ***Aeric Epiaqualfs***									
Ap	0-15	32.9	41.6	25.5	4.9	0.17	7.4	7.8	41.3
AB	15-30	28.2	42.9	28.9	5.4	0.18	4.8	8.5	47.1
Bt1	30-65	23.3	39.8	36.9	5.8	0.15	1.8	8.9	48.7
Bt2	65-100	31.9	32.9	35.2	5.7	0.13	1.5	8.9	41.3
BC	100-145	37.7	34.2	28.1	5.7	0.12	1.3	8.5	47.2
C	145-165	39.8	37.8	22.4	5.2	0.12	0.5	8.7	34.4
Wt. mean		32.4	37.0	30.6	5.6	0.14	2.2	8.6	44.2
P4 (Khowang - Paddy soil: ***Aeric Epiaqualfs***									
Ap	0-10	36.5	34.8	28.7	5.3	0.17	7.9	7.5	40.8
BA	10-35	38.0	29.2	32.8	5.7	0.20	4.8	8.9	39.8
Bt1	35-65	30.2	33.6	36.2	5.8	0.18	4.6	9.4	40.1
Bt2	65-105	38.3	21.5	40.2	6.0	0.18	4.6	9.1	44.7
BC	105-135	45.6	22.2	32.2	5.9	0.20	4.1	8.6	40.9
C	135-195	49.0	24.8	26.2	5.9	0.19	2.5	8.2	42.2
Wt. mean		41.3	26.2	32.5	5.8	0.19	4.1	8.7	41.8
NP4 (Khowang – Non-paddy soil): ***Typic Dystrudepts***									
Ap	0-15	50.3	27.5	22.2	5.6	0.15	5.8	5.5	44.5
Bw1	15-35	49.0	26.2	24.8	5.8	0.13	4.0	5.9	47.1
Bw2	35-50	53.0	21.8	25.2	5.9	0.12	3.0	5.6	57.5
Bw3	50-110	51.4	22.4	26.2	6.0	0.12	2.1	6.2	56.8
BC	110-150	62.5	18.8	18.7	5.7	0.13	1.1	5.1	48.6
C	150-195	65.4	20.2	14.4	5.7	0.13	0.8	5.7	51.6
Wt. mean		56.7	21.9	21.4	5.8	0.13	2.1	5.7	52.0

Distribution of different forms of Fe in clay fraction of soil

The data on distribution of different forms of iron in the clay fraction is presented in Table 3. Total iron content in the clay fraction (Fe$_t$) varied from 8.06 to 13.70 per cent in paddy soils and 9.21 to14.42 per cent in non-paddy soils. Irrespective of land use, total iron content in clay (Fe$_t$) increased with soil depth reached a maximum and decreased thereafter. Lower amount Fe$_t$ in paddy soil attributed by solubilization and leaching of Fe in response to drop in redox potential during puddling and submergence (Gotoh 1976) [9].

In dithionite extraction procedure (Mehra and Jackson 1960) [20], dithionite is a powerful reductant, bicarbonate buffers the system at pH 7–9 and sodium citrate prevents the reprecipitation of dissolved Fe (Borggard 1988) [1]. The procedure extracts both non-crystalline and crystalline Fe oxides and may also include small amount of water soluble, exchangeable, and organically bound Fe along with limited amount of Fe bearing silicates (Borggard 1988) [1]. The amount of dithionite extractable iron in the clay fraction (Fe$_d$) varied from 1.30 to 3.22 per cent in paddy soils and 1.66 to3.58 per cent in non-paddy soils (Table 3). Dithionite extractable iron in clay fraction (Fe$_d$) increased with soil depth and reached a maximum value in B$_t$ horizon and decreased thereafter except in P3, NP3 (Charing, paddy and non-paddy) and NP4 (Khowang, non-paddy). Fe_d formed major portion of total iron (Fe_t) content in the clay fraction constituting 14.54 to 25.75 per cent in paddy soils and 16.03 to 26.67 per cent in non-paddy soils. The result indicates that slightly lesser amount of Fe_d is associated with clay fraction in paddy soils. The paddy management led to a decreased crystallinity of soil Fe oxides, because crystalline Fe oxides can be transformed to poorly crystalline forms when artificially submerged (Hsue and Chen 2001; Zhang *et al.* 2003) [10, 35]. Oxalate dissolved both “amorphous” and “organically bound” forms of Fe, but not the crystalline forms (Parfitt and Childs 1988) [23]. The amount of oxalate extractable iron in the clay fraction (Fe_o) varied from 0.47 to 1.11 per cent in paddy soils and 0.41 to 0.98 per cent in non-paddy soils (Table 3). Distribution of oxalate extractable iron in the clay fraction (Fe_o) was more or less irregular throughout the profile except in the paddy soils of Charing (P3) and Khowang (P4) where, Fe_o content decreased with soil depth. The Fe_o constituted 2.95 to 10.99 per cent of total iron content in the clay fraction (Fe_t) in paddy soils and 2.89 to 8.87.

Table 3: Distribution of different forms of Fe in clay fraction of soil

Horizon Designation	**Depth (cm)**	**Fe_t**	**Fe_d**	**Fe_o**	**Fe_p**	**% of total Fe in clay fraction**			**crystalline (Fe_d-Fe_o)**	**Amorphous inorganic (Fe_o-Fe_p)**	**Silicate (Fe_t-Fe_d)**	**Fe_d/Fe_t**	**Fe_o/Fe_d**
		<------------(%)--------->				**Fe_d**	**Fe_o**	**Fe_p**	<------------(%)--------->				
P1 (Titabar - Paddy soil): *Typic Epiaqualfs*													
Ap	0-25	11.52	2.22	1.00	0.19	19.29	8.67	1.68	1.22	0.80	9.30	0.19	0.45
BA	25-35	9.63	2.48	0.78	0.24	25.75	8.11	2.49	1.70	0.54	7.15	0.26	0.31
Bt1	35-90	11.98	2.66	0.69	0.23	22.18	5.77	1.93	1.97	0.46	9.33	0.22	0.26
Bt2	90-125	13.11	3.22	1.01	0.04	24.57	7.73	0.34	2.21	0.97	9.89	0.25	0.31
Bt3	125-145	13.70	3.08	1.11	0.07	22.46	8.08	0.50	1.97	1.04	10.63	0.22	0.36
BC	145-165+	11.63	2.37	0.92	0.05	20.41	7.89	0.45	1.46	0.87	9.26	0.20	0.39
Wt. mean		12.18	2.72	0.89	0.15	22.28	7.30	1.24	1.83	0.74	9.46	0.22	0.33
NP1 (Titabar – Non-paddy soil): *Aeric Epiaqualfs*													
Ap	0-15	12.56	2.48	0.72	0.26	19.72	5.72	2.10	1.76	0.46	10.08	0.20	0.29
AB	15-35	11.11	2.67	0.81	0.32	24.00	7.26	2.83	1.86	0.49	8.45	0.24	0.30
Bt1	35-80	13.44	3.58	0.59	0.09	26.67	4.40	0.67	2.99	0.50	9.86	0.27	0.16
Bt2	80-130	14.42	3.53	0.50	0.05	24.46	3.49	0.36	3.02	0.45	10.89	0.24	0.14
BC	130-160+	11.05	1.94	0.41	0.04	17.55	3.67	0.33	1.53	0.37	9.11	0.18	0.21
Wt. mean		12.93	3.04	0.57	0.11	23.28	4.46	0.91	2.47	0.46	9.89	0.23	0.20
P2 (Maheema - Paddy soil): Aeric Epiaqualfs													
Ap	0-15	8.17	1.30	0.83	0.17	15.87	10.13	2.10	0.47	0.66	6.88	0.16	0.64
B	15-45	8.65	1.65	0.95	0.12	19.11	10.99	1.44	0.70	0.83	7.00	0.19	0.58
Bt1	45-80	9.53	2.11	0.67	0.04	22.14	7.06	0.42	1.44	0.63	7.42	0.22	0.32
Bt2	80-110	10.02	1.53	0.73	0.04	15.31	7.27	0.38	0.80	0.69	8.49	0.15	0.48
BC	110-165	13.05	1.90	0.85	0.03	14.54	6.49	0.20	1.05	0.82	11.15	0.15	0.45
Wt. mean		10.51	1.78	0.81	0.06	17.24	7.90	0.68	0.97	0.74	8.73	0.17	0.47
NP2 (Maheema – Non-paddy soil): Ultic Hapludalfs													
Ap	0-10	9.21	1.72	0.68	0.37	18.63	7.40	3.98	1.03	0.32	7.49	0.19	0.40
AB	10-25	10.83	2.19	0.76	0.38	20.20	7.04	3.53	1.42	0.38	8.64	0.20	0.35
Bt1	25-60	10.56	2.67	0.62	0.18	25.24	5.83	1.73	2.05	0.43	7.89	0.25	0.23
Bt2	60-85	12.66	2.46	0.69	0.11	19.46	5.47	0.84	1.77	0.59	10.20	0.19	0.28
Bt3	85-125	11.68	1.94	0.74	0.08	16.65	6.32	0.72	1.21	0.65	9.73	0.17	0.38
BC	125-160	10.38	1.66	0.68	0.04	16.03	6.59	0.39	0.98	0.64	8.72	0.16	0.41
Wt. mean		11.07	2.13	0.69	0.15	19.29	6.28	1.35	1.44	0.55	8.94	0.19	0.34

Horizon Designation	**Depth (cm)**	**Fe_t**	**Fe_d**	**Fe_o**	**Fe_p**	**% of total Fe in clay fraction**			**crystalline (Fe_d-Fe_o)**	**amorphous inorganic (Fe_o-Fe_p)**	**Silicate (Fe_t-Fe_d)**	**Fe_d/Fe_t**	**Fe_o/Fe_d**
		<------------(%)--------->				**Fe_d**	**Fe_o**	**Fe_p**	<------------(%)--------->				
P3 (Charing - Paddy soil): Aeric Epiaqualfs													
Ap	0-15	9.32	2.04	0.91	0.21	21.86	9.74	2.28	1.13	0.70	7.28	0.22	0.45
AB	15-30	10.56	2.38	0.68	0.23	22.52	6.48	2.22	1.69	0.45	8.18	0.23	0.29
Bt1	30-65	8.06	2.04	0.61	0.14	25.24	7.55	1.79	1.43	0.46	6.03	0.25	0.30
Bt2	65-100	11.18	2.55	0.59	0.08	22.82	5.29	0.71	1.96	0.51	8.63	0.23	0.23
Bt3	100-140	11.23	1.83	0.53	0.04	16.33	4.74	0.38	1.30	0.49	9.39	0.16	0.29
C	140-170	8.26	1.52	0.47	0.04	18.37	5.70	0.50	1.05	0.43	6.74	0.18	0.31
Wt. mean		9.81	2.03	0.60	0.10	**20.89**	**6.20**	**1.09**	**1.44**	**0.49**	**7.78**	**0.21**	**0.30**
NP3 (Charing – Non-paddy soil): Aeric Epiaqualfs													
Ap	0-15	9.50	2.23	0.80	0.27	23.52	8.43	2.83	1.43	0.53	7.26	0.24	0.36
AB	15-30	9.43	1.85	0.84	0.24	19.63	8.87	2.50	1.01	0.60	7.58	0.20	0.45
Bt1	30-65	10.62	2.28	0.69	0.20	21.45	6.48	1.90	1.59	0.49	8.34	0.21	0.30
Bt2	65-100	12.91	2.93	0.62	0.16	22.72	4.80	1.25	2.31	0.46	9.97	0.23	0.21
BC	100-145	13.14	2.72	0.68	0.14	20.71	5.21	1.09	2.04	0.54	10.42	0.21	0.25
C	145-165	10.39	2.13	0.48	0.10	20.47	4.66	1.00	1.64	0.38	8.26	0.20	0.23
Wt. mean		11.55	2.48	0.67	0.17	21.42	5.95	1.57	1.80	0.50	9.08	0.21	0.28
P4 (Khowang - Paddy soil): Aeric Epiaqualfs													
Ap	0-10	10.20	2.12	0.88	0.22	20.77	8.61	2.18	1.24	0.66	8.08	0.21	0.41
BA	10-35	11.45	2.14	0.83	0.24	18.69	7.27	2.06	1.31	0.60	9.31	0.19	0.39

Bt1	35-65	11.18	2.27	0.69	0.08	20.34	6.19	0.69	1.58	0.62	8.91	0.20	0.30
Bt2	65-105	11.43	2.65	0.49	0.07	23.21	4.32	0.60	2.16	0.43	8.77	0.23	0.19
BC	105-135	12.46	2.41	0.48	0.06	19.34	3.81	0.44	1.93	0.42	10.05	0.19	0.20
C	135-195	12.60	2.22	0.37	0.04	17.63	2.95	0.29	1.85	0.33	10.38	0.18	0.17
Wt. mean		11.85	2.33	0.55	0.09	19.75	4.71	0.76	1.78	0.46	9.52	0.20	0.24
NP4 (Khowang – Non-paddy soil): Typic Dystrudepts													
Ap	0-15	10.53	2.27	0.81	0.36	21.57	7.72	3.37	1.46	0.46	8.26	0.22	0.36
Bw1	15-35	12.35	2.37	0.98	0.38	19.15	7.97	3.10	1.38	0.60	9.99	0.19	0.42
Bw2	35-50	10.13	2.03	0.75	0.19	19.99	7.42	1.83	1.27	0.57	8.11	0.20	0.37
Bw3	50-110	11.76	2.71	0.71	0.10	23.04	6.01	0.82	2.00	0.61	9.05	0.23	0.26
BC	110-150	12.66	2.52	0.48	0.06	19.89	3.83	0.49	2.03	0.42	10.14	0.20	0.19
C	150-195	9.99	1.94	0.29	0.04	19.45	2.89	0.41	1.66	0.25	8.05	0.19	0.15
Wt. mean		11.38	2.37	0.60	0.13	20.82	5.28	1.17	1.77	0.47	9.01	0.21	0.25

per cent in the non-paddy soils. This suggests that rice cultivation increases the amorphous iron. At initial stage of soil development, alternate wetting and drying during rice cultivation results in partial decomposition of silicate clays by a process called ‘ferro lysis’ (Brinkman 1970) [2], which releases amorphous iron. As soil development proceeds, this amorphous iron is converted to crystalline form. The reason for occurrence of more Fe_o in paddy soils is the inhibitory effect of high organic carbon on crystallization of Fe oxide associated with clay fraction (Schwertmann *et al.* 1982) [27].

Pyrophosphate extractant dissolves the fraction of iron bound with organic matter (Loveland and Digby 1984; McKeague *et al.* 1971; Tan 1978) [15, 19, 30]. The amount of pyrophosphate extractable iron in the clay fraction (Fe_p) varied from 0.03 to 0.24 per cent in paddy soils and 0.04 to 0.38 per cent in non-paddy soils (Table 4.10). The Fe_p constituted 0.20 to 2.49 per cent of total iron content in the clay fraction (Fe_t) in paddy soils and 0.33 to 3.98 per cent in non-paddy soils. All pedon had lower amount of Fe_p than Fe_o. This indicates that only a portion of amorphous iron was complexed with organic matter. Higher Fe_p in the plow-sole suggests that iron forms complexes with humified materials and bound to clay fraction in the surface horizon and is migrated to the plow-sole.

In general, different forms of iron in the clay fraction were found to be in descending order as $Fe_d > Fe_o > Fe_p$. This finding is in corroboration with that of Seal *et al.* (2010) [28].

The amount of crystalline iron oxide (Fe_d-Fe_o) in the clay fraction varied from 0.47 to 2.21 per cent in paddy soils and 0.98 to 3.02 per cent in non-paddy soils (Table 3). This form of iron tended to increase with soil depth. In general, paddy soils contained lower amount of crystalline iron oxide (Fe_d-Fe_o) as compared to non-paddy soils both in surface (0-25 cm) and series control section (25-100 cm) as a result of higher organic carbon content in the paddy soils which inhibits crystallization of iron bound to clay fraction. Higher concentration of hydroxyl-carbonic acids are particularly effective in inhibiting the transformation of ferrihydrite to well-crystallized oxides (Schwertmann and Taylor 1977) [26].

The amount of amorphous inorganic iron (Fe_o-Fe_p) in the clay fraction varied from 0.33 to 1.04 per cent in paddy soils and 0.25 to 0.65 per cent in non-paddy soils (Table 3). Distribution of this form of iron was irregular with soil depth. The result suggests that amorphous inorganic iron is also present in the clay fraction and its amount is higher in paddy soils due to less crystallization. The amount of silicate iron (Fe_t-Fe_d) in the clay fraction varied from 6.03 to 11.15 per cent in paddy soils and 7.26 to 10.89 per cent in non-paddy soils. Distribution of this form of iron was irregular with soil depth. On the weighted mean basis, paddy soils contained lower amount of silicate iron (Fe_t-Fe_d) in clay fraction as compared to non-paddy soils both in surface (0-25 cm) except in Chirang (NP4) and series control section (25-100 cm).

Fe_d/Fe_t ratio in the clay fraction varied from 0.15 to 0.26 in paddy soils and 0.16 to 0.37 in non-paddy soils. The active iron ratio (Fe_o/Fe_d) in clay fraction varied from 0.17 to 0.64 in paddy soils and 0.14 to 0.45 in non-paddy soils. The crystalline Fe oxides increases at the expense of the poorly crystalline forms with increasing soil age as indicated by the ratios of Fe_o/Fe_d (Mahaney and Fahey 1988) [17]. The ratios of Fe_o/Fe_d in all the soil solums were less than one. This supports the view that free Fe oxides in most of the soils were at an advanced stage of crystallinity or aging (Mahaney *et al.* 1991) [16]. On the weighted mean basis, paddy soils had higher active iron ratio than the associated non-paddy soils.

Interrelationship among different forms of Fe and with soil properties

Correlation between different forms of Fe with various physicochemical properties of the soils is presented in Table 4. Organic carbon was significantly correlated with oxalate (0.460**) and pyrophosphate (0. 563 **) extractable Fe in clay fraction. Generally, there was significant negative relationship between pH with Fe_o (-0.485**) and Fe_o/Fe_d (0.386**). pH did not show any significant correlation with Fe_t, Fe_d, Fe_p and requires further work to establish any relationship. Fe_p was positively and significantly correlated with Fe_o (0.399**). A similar result was obtained between Fe_d/Fe_t and Fe_d (0.737**). There was significant negative relationship between the active iron ratio (Fe_o/Fe_d) with Fe_t (-0.489**), Fe_d (-0.615**) and Fe_d/Fe_t (-0.439**) while, Fe_o/Fe_d positively and significantly correlated with Fe_o (0.730**).

Table 4: Correlation coefficients (r) among forms of Fe and other parameters of soil

	Fe_t	**Fe_d**	**Fe_o**	**Fe_p**	**Fe_d/Fe_t**	**Fe_o/Fe_d**
OC_{soil}	-0.388**	-0.222	0.460**	0.563**	0.079	0.525**
pH	0.168	0.050	-0.485**	-0.141	-0.087	-0.386**
Fe_d	0.748**	1.000				
Fe_o	-0.014	0.016	1.000			
Fe_p	-0.231	-0.038	0.399**	1.000		
Fe_d/Fe_t	0.122	0.737**	0.052	0.221	1.000	
Fe_o/Fe_d	-0.489**	-0.615**	0.730**	0.292	-0.439**	1.000

Conclusion

More intense weathering in paddy soils as compared to non-paddy soils was due to anthropogenic factors and agro-hydrological regimes. Most of the paddy soils exhibited aquic characteristics leading to process of gleization. Fe is the major soil constituent occurring in several mineralogical forms as discrete particles or as associated with surfaces of other minerals or clay fraction in soil. Hence, the amount and distribution of extractable Fe oxides in soil profiles may serve as indicators of the stage and degree of soil development. Less amount of Fe_d and more amount of Fe_o were associated with clay in the paddy soils than its non-paddy counterpart. In general, different forms of iron in the clay fraction were found to be in descending order of dithionite extractable > oxalate extractable > pyrophosphate extractable. It is concluded that the results of the study may help to understand pedogenesis in extended areas of this region and also provide insight for better management of these contrasting but closely associated soils.

References

1. Borggard OK. Phase identification by selective dissolution technique. Iron in soils and clay minerals Boston, MA, 1988, 93-98.
2. Brinkman R. Ferrolysis, a hydromorphic soil forming process. Geoderma. 1970; 3:199-206.
3. Chakravarty DN, Barua JP. Characterization and classification of the soils of citrus growing belts of hill districts of Assam. Journal of the Indian Society of Soil Science. 1983; 31:287-295.
4. Chakravarty DN, Sehgal JL, Pal DK, Dev G. Clay mineralogy of Assam soils developed in alluvium. Agropedology. 1992; 2:45-49.
5. Cheng YQ, Yang LZ, Zhi-Hong Cao ZH, Ci E, Yin S. Chronosequential changes of selected pedogenic properties in paddy soils as compared with non-paddy soils. Geoderma. 2009; 151:31-41.
6. Dutta S, Shanwal AV. Potassium bearing minerals in some soils of semi-arid (Haryana) and humid (Assam) regions of India. Agropedology. 2006; 16:86-91.
7. Gangopadhyay SK, Bhattacharyya T, Sarkar D. Hydromorphic soils of Tripura: their pedogenesis and characteristics. Current Science. 2015; 108:984-992.
8. Gong ZT. Soil Taxonomic classification of China: Theory, Methodology and Applications, Science Press, Beijing Science, 1999, 109-164.
9. Gotoh S. Distribution of total and extractable forms of iron, manganese and aluminium in development of rice soils of Saga Polder lands. Soil Science and Plant Nutrition. 1976; 22:335-344.
10. Hsue ZY, Chen ZS. Quantifying soil hydro morphology of rice growing Ultisol top osequences in Taiwan. Soil Science Society American Journal. 2001; 65:270-278.
11. Jackson ML. Soil Chemical Analysis-Advanced course. Department of Soil Science, University of Wisconsin, Madison, WI, 1956.
12. Jackson ML. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi, 1973.
13. Karmakar RM, Rao AEV. Clay mineralogy of soils developed on different physiographic units in lower Brahmaputra valley zone of Assam. Journal of Agricultural Science Society for NE India. 1998; 11:20-25.
14. Kononova MM. In: Soil Organic Matter, 2nd ed., Pergamom Press, Oxford, 1966, 377-426.
15. Loveland PJ, Digby P. The extraction of Fe and Al by 0.1 M pyrophosphate solutions: A comparison of some techniques. Journal of Soil Science. 1984; 35:243-250.
16. Mahaney WC, Hancock RGV, Sanmugadas K. Extractable Fe-Al and geochemistry of late Pleistocene Paleosol in the Dalijia Shan, Western China. J Southeast Asian Earth Sci. 1991; 6:75-82.
17. Mahaney WC, Fabey BD. Extractable Fe and Al in late Pleistocene and Holocene paleosols on Niwot Ridge, Colorado Front Range. Catena. 1988; 15:17-26.
18. McKeague JA, Day JH. Dithionite and oxalate extractable Fe and Al as aids in differentiating various Classes soils. Canadian Journal of Soil Science. 1966; 46:13-22.
19. Mc Keague JA, Brydon JE, Miles NM. Differentiation of forms of extractable iron and aluminium in soils. Soil Science Society of America Proceedings. 1971; 35:33-38.
20. Mehra OP, Jackson ML. Iron oxide removal from soils and clays by a dithionite – citrate system buffered with sodium bicarbonate. In‘ Clays and Clay Mineral Proc.’ 7th Nat. Conf. Monograph.5 Cart Science Series. Pergamon Press, New York, 1960, 283-323.
21. Ojanuga AG. Genesis of Soils in the Metamorphic Forest Region of South-Western Nigeria. Pedolomorphic Pedologie xxviii. 1978; 1:105-117.
22. Onweremadu EU, Omeke J, Onyia VN, Aguand CM, Onwubiko NC. Inter-Horizon Variability in Phosphorus-Sorption Capability of Sesquioxide-Rich Soils Southeastern Nigeria. Journal of American Science. 2007; 3:43-48.
23. Parfitt RL, Childs CW. Estimation of forms of Fe and Al-A review, and analysis of contrasting soils by dissolution and Mossbauer methods. Australian Journal of Soil Research. 1988; 26:121-144.
24. Patil PL, Dasog GS. Genesis of iron oxide concretions in Oxisols, Ultisols and Alfisols of North Karnataka. Journal of Indian Society of Soil Science. 1997; 45:778-781.
25. Piper CS. Soil and Plant Analysis. University of Adelaide, Australia, 1966.
26. Schwertmann U, Taylor RM. Transformation to hematite to goethite in soils. Nature. 1977; 232:624-625.
27. Schwertmann U, Schulze DG, Murad E. Identification of ferrihydrite in soils by dissolution kinetics, differential X-ray diffraction, and Mossbauer Spectroscopy. Soil Science Society of America Journal. 1982; 46:869-875.
28. Seal A, Bera R, Bhattacharyya P, Mukhopadhyay K, Giri R. Degree of soil development in some alfisols of subtropical India with special reference to the nature and distribution of Fe and Al. International Journal of Agricultural Research. 2010; 5:720-726.
29. Soil Survey Staff ‘Keys to Soil Taxonomy’, Twelfth Edition. USDA, Washington, DC, 2014.
30. Tan KH. Variations in soil humic compounds as related to regional and analytical differences. Soil Science. 1978; 125:351-357.
31. Wu J. Carbon accumulation in paddy ecosystems in subtropical China: evidence from landscape studies. European Journal of Soil Science. 2011; 62:29-34.
32. Yu TR. Physical Chemistry of Paddy Soils. Science Press and Springer-Verlag, Beijing and Berlin, 1985, 217.
33. Zhang GL, Gong ZT. Geochemical features of element migration under artificial submergence. Acta Paedologia Sinica. 1993; 30:355-365.
34. Zhang J, Wang M, Wu S, Muller K, Cao Y, Liang P, *et al*. Land use affects soil organic carbon of paddy soils: empirical evidence from 6280 years BP to present. Journal of Soils and Sediments, 2015.
35. Zhang Y, Lin X, Werner W. The effect of soil flooding on the transformation of Fe oxides and the adsorption /desorption behaviour of phosphate. Journal of Plant Nutrition and Soil Science. 2003; 166:68-75.