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Distribution of Different Forms of Aluminium in Clay Fraction of Paddy and Associated Non-Paddy Soils of Assam

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A B S T R A C T

Profiles of paddy and associated non-paddy soils of Jorhat (P1, NP1), Golaghat (P2, NP2), Sivasagar (P3, NP3) and Dibrugarh (P4, NP4) districts of Assam were investigated for different forms of aluminium (Al): total (Al_t), dithionite extractable (Al_d), pyrophosphate extractable (Al_p) and oxalate extractable (Al_o) in the clay fraction. Total Al (Al_t), dithionite extractable Al (Al_d) and oxalate extractable Al (Al_o) in clay fraction was slightly higher in paddy soils as compared to non-paddy soils whereas pyrophosphate extractable Al (Al_p) showed a reverse trend. Al_d formed major portion of total aluminium content in clay fraction (Al_t) followed by Al_p and Al_o in both paddy and non-paddy soils. Crystalline aluminium oxide (Al_d-Al_o), amorphous inorganic (Al_o-Al_p) and silicate aluminium (Al_t-Al_d) in clay fraction was found to be higher in paddy soils than non-paddy soils. Also, irrespective of the land use, the content of different forms of Al in the clay fraction was irregular with depth. Al_d/Al_t was found to be slightly higher in non paddy soil than that of paddy soil. Different fraction of organic carbon and the content of clay had a strong influence on the distribution of forms of Al in the clay fraction of soil. The results also revealed that there was equilibrium in different fractions of this element.

Introduction

Paddy is cultivated under wet conditions. Specific practices (submergence, puddling *etc.*) involved rice cultivation bring about changes in the morphological and physico-chemical characteristics of the original profile to a variable extent. The degree to which such changes are superimposed on the original material depends on the soil material, pedogenic processes active in the area, the degree of evolution of the soil and certain management practices (Moormann, 1981). Some studies suggest that periodic irrigation, drainage, fertilization and tillage during the processes of rice production have resulted in rapid changes in soil characteristics. Paddy soils had lower pH and higher organic matter content than their non-rice growing counterparts (Jondhale and Prasad, 2006). Hydromorphic condition developed in paddy soils may result in formation of an E (eluvial) horizon below the upper A (alluvial) horizon due to clay mineral structural change and leaching of Fe, Al, Mn (Brinkman, 1970; Kyuma, 2004), as well as the concentration of clay, silt and the formation of anomalous clay pedofeatures on microscopic form down the profile (He *et al.,* 2010; Miura *et al.,* 1992).

During soil development and weathering iron and aluminium are released and re-precipitated as amorphous or crystalline oxides, hydroxides or oxhydroxides (Guertal, 1994). Pedological study usually deals with the contents of crystalline and amorphous Al oxides. So, the aim of this study was to determine the content and relations of different forms of Al in clay fraction of paddy and associated non-paddy soils considering their significance both in pedological research and in the context of soil chemistry and environmental studies.

Materials and Methods

Mono cropped paddy growing areas and associated non-paddy growing areas were selected in the Upper Brahmaputra Valley Zone (UBVZ) of Assam. The climate of the study area is humid sub-tropical characterized by high rainfall (1738.5 to 2649.4 mm) and high temperature (24.4 to 26.7°C). Representative soil profiles were collected from Jorhat, Golaghat, Sivasagar, Dibrugarh districts (Table 1). Soil samples were collected horizon wise, dried under shade and processed. Based on morphological and physicochemical characteristics, the soils were classified as per "*Keys to Soil Taxonomy*" (Soil Survey Staff, 2014). To separate 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 $<2\mu$ was separated by sedimentation method (Jackson, 1956) by siphoning. The decanted suspension was centrifuged at 1000 rpm for 15 minutes, washed thrice with distilled water and dried on a water bath. Forms of Al in the clay fraction of soil was determined by individual extractions with (i) sodium dithionite-citrate-bicarbonate (Mehra and Jackson, 1960), (ii) 0.2M ammonium oxalate (pH 3.2) by shaking for 4 hrs in dark (soil: extractant ratio of 1:20) (McKeague and Day, 1966), (iii) 0.1N Na-pyrophosphate (pH 10) by shaking for 16 hrs (soil: extractant ratio of 1:20) (Kononova *et al.,* 1966). Al in the extract was determined colorimetrically using 'Aluminon' reagent (Krishna Murti *et al.,* 1974). Total Al content in clay fraction of soil was carried out following the procedure of Jackson (1973). Simple correlation analysis was followed for some selected variables following the approaches of Snedecor and Cochran (1967).

Results and Discussion

Distribution of different forms of Al in clay fraction of soil

The data on distribution of different forms of aluminium in the clay fraction are presented in table 2. Total aluminium content in the clay fraction (Al_t) varied from 2.23 to 4.80 % in paddy soils and 1.99 to 3.84 %in non-paddy soils. Irrespective of land use, total aluminium content in the clay fraction (Al_t) increased with soil depth. The depth of maximum accumulation of Al_t in soil profiles varied from soil to soil. The Al_t was significantly negatively correlated with bulk density (r= -0.466**) and soil pH (r= -0.535**) (Table 3).

Citrate-Bicarbonate-Dithionite extracts both non-crystalline and crystalline Al oxides. The amount of dithionite extractable aluminium in the clay fraction (Al_d) varied from 0.06 to 0.43 % in paddy soils and 0.04 to 0.39 % in non-paddy soils (Table 2). Irrespective of land use, distribution of Al_d in the clay fraction was irregular throughout the profiles. The Al_d formed major portion of total aluminium (Al_t) content in the clay fraction constituting 1.54 to 10.15 % in paddy soils and 1.52 to 11.25 % in non-paddy soils. The Al_d was negatively correlated with soil pH (r= -0.291*) (Table 3).

Oxalate dissolved both “amorphous” and “organically bound” forms of Al, but not the crystalline forms (Parfitt and Childs, 1988). The amount of oxalate extractable aluminium in the clay fraction (Al_o) varied from 0.03 to 0.30 % in paddy soils and 0.02 to 0.27 % in non-paddy soils (Table 2). The amount of Al_o in the clay fraction was found to be maximum in surface and plow-sole than in other horizons. In general, the surface horizons of paddy soils contained higher amount of oxalate extractable aluminium (Al_o) in the clay fraction as compared to surface horizons of non-paddy soils. The Al_o constituted 1.07 to 6.75 % of total aluminium (Al_t) content in the clay fraction in paddy soils and 0.81 to 7.15 % in non-paddy soils. The Al_o was significantly and positively correlated with OC_{soil} (r= 0.554**) and negatively significantly correlated with bulk density (r= -0.443**) and soil pH (r= -0.370*) (Table 3). Pyrophosphate extractant dissolve Al bound with organic matter (Driscoll *et al.*, 1985). The amount of pyrophosphate extractable aluminium in the clay fraction (Al_p) varied from 0.02 to 0.23 % in paddy soils and 0.01 to 0.31 % in non-paddy soils (Table 2). The vertical distribution of pyrophosphate extractable aluminium in the clay fraction (Al_p) decreased with depth. The Al_p constituted 0.35 to 5.98 % of total aluminium (Al_t) content in the clay fraction in paddy soils and 0.57 to 9.78 % in non-paddy soils. The Al_p was significantly and positively correlated with OC (r= 0.750**) and negatively and significantly correlated with bulk density (r= -0.438*) and soil pH (r= -0.370*) (Table 3).

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

Table.2 Different forms of aluminium in clay fraction of soil

Horizon Designation	Depth (cm)	Al_t (%)	Al_d (%)	Al_o (%)	Al_p (%)	% of total Al in clay fraction			crystalline (Al_d-Al_o) (%)	amorphous inorganic(Al_o-Al_p) (%)	Silicate (Al_t-Al_d) (%)	Al_d/Al_t	Al_o/Al_d
						Al_d	Al_o	Al_p					
P1 (Titabar - Paddy soil): *Typic Epiaqualfs*													
Ap	0-25	3.96	0.31	0.21	0.23	7.89	5.28	5.91	0.10	-0.02	3.65	0.08	0.67
BA	25-35	4.45	0.35	0.30	0.19	7.91	6.75	4.25	0.05	0.11	4.10	0.08	0.85
Bt1	35-90	4.77	0.08	0.18	0.06	1.78	3.75	1.21	-0.09	0.12	4.69	0.02	2.11
Bt2	90-125	4.80	0.07	0.13	0.04	1.54	2.64	0.84	-0.05	0.09	4.73	0.02	1.71
Bt3	125-145	4.15	0.12	0.07	0.04	2.94	1.57	0.95	0.06	0.03	4.03	0.03	0.53
BC	145-165+	4.43	0.13	0.07	0.05	2.87	1.48	1.02	0.06	0.02	4.30	0.03	0.52
Wt. mean		4.52	0.14	0.15	0.08	3.30	3.39	1.97	-0.01	0.07	4.38	0.03	1.35
NP1 (Titabar – Non-paddy soil): *Aeric Epiaqualfs*													
Ap	0-15	3.15	0.28	0.15	0.31	8.95	4.81	9.78	0.13	-0.16	2.87	0.09	0.54
AB	15-35	3.84	0.39	0.27	0.21	10.11	7.15	5.56	0.11	0.06	3.45	0.10	0.71
Bt1	35-80	3.51	0.09	0.10	0.06	2.55	2.92	1.61	-0.01	0.05	3.42	0.03	1.14
Bt2	80-130	3.04	0.05	0.07	0.03	1.52	2.34	0.86	-0.02	0.04	2.99	0.02	1.54
BC	130-160+	3.00	0.11	0.05	0.02	3.53	1.54	0.57	0.06	0.03	2.89	0.04	0.44
Wt. mean		3.28	0.13	0.11	0.08	3.96	3.19	2.44	0.03	0.03	3.14	0.04	1.02
P2 (Maheema - Paddy soil): *Aeric Epiaqualfs*													
Ap	0-15	3.64	0.28	0.20	0.22	7.61	5.45	5.98	0.08	-0.02	3.36	0.08	0.72
B	15-45	3.71	0.37	0.17	0.16	9.85	4.56	4.29	0.20	0.01	3.34	0.10	0.46
Bt1	45-80	4.21	0.10	0.26	0.06	2.34	6.29	1.36	-0.17	0.21	4.11	0.02	2.69
Bt2	80-110	3.85	0.11	0.16	0.05	2.81	4.12	1.21	-0.05	0.11	3.74	0.03	1.47
BC	110-165	3.75	0.06	0.10	0.05	1.47	2.55	1.28	-0.04	0.05	3.69	0.02	1.74
Wt. mean		3.85	0.15	0.17	0.09	3.98	4.26	2.26	-0.02	0.08	3.70	0.04	1.56
NP2 (Maheema – Non-paddy soil): *Ultic Hapludalfs*													
Ap	0-10	2.20	0.18	0.07	0.13	8.11	3.12	5.77	0.11	-0.06	2.02	0.08	0.39
AB	10-25	2.80	0.21	0.11	0.10	7.36	3.95	3.64	0.10	0.01	2.59	0.07	0.54
Bt1	25-60	3.22	0.09	0.10	0.09	2.74	3.05	2.67	-0.01	0.01	3.13	0.03	1.11
Bt2	60-85	3.05	0.08	0.05	0.05	2.55	1.80	1.55	0.02	0.01	2.97	0.03	0.71
Bt3	85-125	2.74	0.06	0.05	0.04	2.35	1.66	1.39	0.02	0.01	2.68	0.02	0.71
BC	125-160	2.96	0.06	0.02	0.03	2.16	0.81	1.06	0.04	-0.01	2.90	0.02	0.38
Wt. mean		2.91	0.09	0.06	0.06	3.25	2.11	2.11	0.03	0.00	2.82	0.03	0.69

Horizon Designation	Depth (cm)	Al_t (%)	Al_d (%)	Al_o (%)	Al_p (%)	% of total Al in clay fraction			crystalline (Al_d-Al_o) (%)	amorphous inorganic(Al_o-Al_p) (%)	Silicate (Al_t-Al_d) (%)	Al_d/Al_t	Al_o/Al_d
						Al_d	Al_o	Al_p					
P3 (Charing - Paddy soil): *Aeric Epiaqualfs*													
Ap	0-15	3.87	0.38	0.04	0.08	9.77	1.07	2.10	0.34	-0.04	3.49	0.10	0.11
AB	15-30	4.22	0.43	0.22	0.07	10.15	5.21	1.77	0.21	0.15	3.79	0.10	0.51
Bt1	30-65	4.75	0.41	0.17	0.08	8.69	3.66	1.58	0.24	0.10	4.34	0.09	0.42
Bt2	65-100	4.27	0.09	0.08	0.04	2.15	1.85	0.96	0.01	0.04	4.18	0.02	0.86
Bt3	100-140	4.68	0.17	0.15	0.02	3.57	3.21	0.51	0.02	0.13	4.51	0.04	0.90
C	140-170	4.71	0.16	0.11	0.02	3.48	2.33	0.35	0.05	0.09	4.55	0.04	0.67
Wt. mean		4.50	0.24	0.13	0.05	5.44	2.86	1.05	0.11	0.08	4.26	0.05	0.65
NP3 (Charing – Non-paddy soil): *Aeric Epiaqualfs*													
Ap	0-15	2.84	0.32	0.03	0.04	11.25	1.01	1.33	0.29	-0.01	2.52	0.11	0.09
AB	15-30	2.96	0.36	0.16	0.10	12.33	5.31	3.28	0.21	0.06	2.60	0.12	0.43
Bt1	30-65	2.98	0.26	0.07	0.10	8.56	2.51	3.26	0.18	-0.02	2.72	0.09	0.29
Bt2	65-100	2.75	0.20	0.05	0.05	7.34	1.71	1.88	0.15	0.00	2.55	0.07	0.23
BC	100-145	1.99	0.07	0.06	0.03	3.28	2.87	1.54	0.01	0.03	1.92	0.03	0.88
C	145-165	2.13	0.07	0.05	0.01	3.34	2.55	0.67	0.02	0.04	2.06	0.03	0.76
Wt. mean		2.54	0.19	0.06	0.05	6.82	2.56	2.01	0.12	0.01	2.36	0.07	0.49
P4 (Khowang - Paddy soil): *Aeric Epiaqualfs*													
Ap	0-10	2.23	0.13	0.03	0.06	6.02	1.56	2.82	0.10	-0.03	2.10	0.06	0.26
BA	10-35	3.56	0.32	0.15	0.13	8.97	4.22	3.55	0.17	0.02	3.24	0.09	0.47
Bt1	35-65	3.14	0.11	0.10	0.05	3.66	3.16	1.58	0.02	0.05	3.03	0.04	0.86
Bt2	65-105	2.91	0.08	0.14	0.04	2.64	4.75	1.39	-0.06	0.10	2.83	0.03	1.80
BC	105-135	3.28	0.09	0.04	0.04	2.81	1.18	1.13	0.05	0.00	3.19	0.03	0.42
C	135-195	3.24	0.10	0.07	0.04	3.14	2.28	1.28	0.03	0.03	3.14	0.03	0.73
Wt. mean		3.15	0.13	0.09	0.05	3.96	2.96	1.70	0.03	0.04	3.03	0.04	0.86
NP4 (Khowang – Non-paddy soil): *Typic Dystrudepts*													
Ap	0-15	1.99	0.17	0.03	0.07	8.44	1.32	3.62	0.14	-0.05	1.82	0.08	0.16
Bw1	15-35	2.12	0.18	0.06	0.09	8.67	2.88	4.18	0.12	-0.03	1.94	0.09	0.33
Bw2	35-50	2.55	0.11	0.05	0.05	4.44	1.98	1.94	0.06	0.00	2.44	0.04	0.45
Bw3	50-110	2.44	0.04	0.04	0.05	1.78	1.56	2.06	0.01	-0.01	2.40	0.02	0.88
BC	110-150	2.28	0.07	0.03	0.05	2.89	1.38	2.19	0.03	-0.02	2.21	0.03	0.48
C	150-195	2.41	0.06	0.05	0.05	2.54	2.01	1.96	0.01	0.00	2.35	0.03	0.79
Wt. mean		2.34	0.08	0.04	0.06	3.61	1.78	2.39	0.04	-0.01	2.26	0.04	0.63

Table.3 Correlation coefficients (r) among forms of Al in clay fraction and other parameters of soil

	Al_t	Al_d	Al_o	Al_p	Al_d/Al_t	Al_o/Al_d
OC_{soil}	0.224	0.633**	0.554**	0.750**	0.606**	-0.052
Bulk density	-0.466**	-0.125	-0.443**	-0.438**	0.022	-0.333*
pH	-0.535**	-0.291*	-0.370*	-0.370*	-0.138	-0.059
Al_d	0.290	1.000				
Al_o	0.619**	0.534**	1.000			
Al_p	0.110	0.620**	0.573**	1.000		
Al_d/Al_t	-0.061	0.914**	0.300*	0.596**	1.000	
Al_o/Al_d	0.367*	-0.435	0.414**	-0.162	-0.580**	1.000

r-value for 44 df = 0.291 at $P_{0.05}$ and 0.376 at $P_{0.01}$

The amount of crystalline aluminium oxide (Al_d-Al_o) in the clay fraction varied from -0.17 to 0.34 % in paddy soils and -0.02 to 0.29 % in non-paddy soils. This may be due to higher organic C in paddy soils which inhibits crystallization. The amount of amorphous inorganic aluminium (Al_o-Al_p) in the clay fraction varied from -0.04 to 0.21 % in paddy soils and -0.16 to 0.06 % in non-paddy soils (Table 2). Negative values in some of the soils indicate that whole of the amorphous Al is complexed with organic matter in these soils. Distribution of both crystalline and amorphous form of aluminium was irregular with soil depth. In general, the surface horizons of paddy soils contained higher amount of amorphous inorganic aluminium (Al_o-Al_p) in the clay fraction as compared to surface horizons of non-paddy soils.

The amount of silicate aluminium (Al_t-Al_d) in the clay fraction varied from 2.10 to 4.73 % in paddy soils and 1.92 to 3.45 % in non-paddy soils (Table 2). Distribution of this form of aluminium increased with depth and then decreased.

In general, the surface horizons of paddy soils contained higher amount of silicate aluminium (Al_t-Al_d) in the clay fraction as compared to surface horizons of non-paddy soils.

The results indicate that irrespective land use, various forms of Al in the clay fraction followed the descending order of Al_d>Al_p>Al_o. With increasing soil acidity, all the forms of aluminium (Al_t, Al_d, Al_o, Al_p) in the clay fraction increased as evident from significant negative correlation between forms of aluminium and soil pH (Table 3).

On the other hand, amount of all the forms of aluminium in clay fraction increased with soil organic C as evident from the significant positive correlations of forms of Al and organic C (Table3). The crystalline Al oxides increased at the expense of the poorly crystalline forms with increasing soil age as indicated by the ratios of Al_o/Al_d (Mahaney and Fahey, 1988).

Slightly higher amount of all forms of Al has been observed in the clay fraction of paddy soils as compared to non-paddy soils. This may be attributed to relative variation in total Al (Al_t) in these soils due to differential quantitative existence of alumino-silicates in the parent material and occurrence of more amount of soil organic C in paddy soils.

Aluminium in relation to pedogenesis

The behaviour of pedogenic aluminium in paddy soils is different from that of Fe and

Mn. Aluminium shows relative persistence to redox changes (Lantimer, 1952) while at the same time, pH governs its sensitivity and mobility in soils (Table 3).

A little movement of Al in soils under paddy cultivation has been observed in the present study (Table 2). Within a profile, Al_d/Al_t ratio showed higher values for the upper horizons than the lower horizons irrespective of land use. This clearly showed the influence of organic C in soil and clay fractions and pH of the soil (Table 3).

The Al_o/Al_d ratio in clay fraction varied from 0.11 to 2.69 in paddy soils and 0.16 to 1.54 in non-paddy soils. On the profile weighted mean basis, paddy soils had higher Al_o/Al_d ratio in clay fraction than the associated non-paddy soils.

Distribution of Al in clay fraction is greatly influenced by the soil genesis and nature and degree of pedogenic processes. Such processes vary among paddy and non-paddy soils due to specific practices undertaken during paddy cultivation. Higher amount of Al_d and Al_o were associated with clay in the paddy soils than its non-paddy counterpart. Dominance of crystalline form of Al in the clay fraction over amorphous and silicate form indicate structural distortion due to intense weathering in paddy soil. Crystalline Al oxide, amorphous inorganic Al and silicate Al in clay fraction was found to be higher in paddy soils than non-paddy soils. This information can be necessary for better management of these contrasting but closely associated soils.

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