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Pedogenic distribution of iron and aluminium under different land uses in Golaghat district of Assam

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Abstract
Iron and aluminium are the two most essential elements for understanding various soil forming processes. Profile distribution of different forms of Fe and Al oxides, particularly dithionite and oxalate extractable Fe and Al, serves as useful indicators to identify the horizon for accumulation of secondary oxides and the depth of argillic horizon. The investigation was carried out in Golaghat district of Assam taking five soil profiles from different land uses *viz*., forest, paddy, tea, bamboo and vegetable. Different extractants were used to determine various forms of Fe and Al viz., CBD, ammonium oxalate and sodium pyrophosphate. It was found that among the pedogenic iron and aluminium oxides, dithionite extractable iron (Fe_d) and aluminium (Al_d) content was highest in all the pedons irrespective of land uses. On the weighted mean basis, paddy soil recorded the highest Fe_d and Al_d. The depth distribution was irregular for oxalate extractable iron (Fe_o) and aluminium (Al_o), amorphous inorganic iron ($Fe_o – Fe_p$) and aluminium ($Al_o – Al_p$) and crystalline form of aluminium ($Al_d – Al_o$) within a profile. On the weighted mean basis, vegetable soil recorded highest Fe_o, paddy soil recorded highest ($Fe_o – Fe_p$) and forest soil recorded the highest ($Fe_d – Fe_o$). Also bamboo soil recorded the highest Al_o and ($Al_o – Al_p$) and forest soil recorded highest ($Al_d – Al_o$). The surface horizons recorded comparatively higher amount of Fe_p and Al_p than the subsurface horizons in all the pedons. The activation ratios, Fe_o/Fe_d and Al_o/Al_d were highest for vegetable soil and bamboo soils respectively, which indicates that these two are relatively young soil. The increasing trend of clay/Fe_d and clay/Al_d ratios within a profile in forest, paddy and tea soils is indicative that these are relatively weathered soils. These ratios follows inconsistent trend in bamboo and vegetable soils. Correlation studies among different forms of Fe and Al and selected soil properties were also examined.

Keywords: land use, dithionite extractable, oxalate extractable, pyrophosphate extractable

Introduction
The pedogenic oxides in soil primarily refer to the Fe and Al fraction bound in organic matter, amorphous and crystalline form of oxides. The oxides and hydroxides of iron and aluminium are important constituent of highly weathered soils of tropical and sub-tropical soils. The Fe and Al released during the weathering of Fe and Al bearing parent materials are reprecipitated in the soils as oxides or hydroxide and oxyhydroxide of iron and aluminium. The quantities of these alternation products generally increase with soil age (Dolui and Bera, 2001) [6] and their distribution in soil profiles indicate the stage and degree of soil development (Mahaney and Fahey, 1988) [21]. However, very meager information is available on the degree of soil development and the direction of pedogenic processes of Fe and Al in the soils under different land uses of Golaghat district. Hence, the present study was intended to investigate the different forms of Fe and Al and the interrelationship among themselves as well as with some important soil characteristics in relation to pedogenic processes in different land uses of Golaghat district, Assam.

Materials and Methods
The study area is situated in Upper Brahmaputra valley zone of Assam and lies between 25^{O}49’N and 26^{O}54’N latitudes and 93^{O}16’E and 94^{O}13’E longitudes. The district covers an area of 3502 km² out of which 1036.27 sq.km is covered by forest and it lies at an elevation of 326 ft. The climate of Golaghat district is humid subtropical. It is mainly influenced by south west monsoon from Bay of Bengal and determined by surrounding hills of Assam. The district experiences a mean annual rainfall of 1738.51 mm and a mean annual temperature of 24.21^{O}C. The soil moisture and temperature regimes in the study area are udic and hyperthermic respectively. The location of the study area is depicted in fig 1.

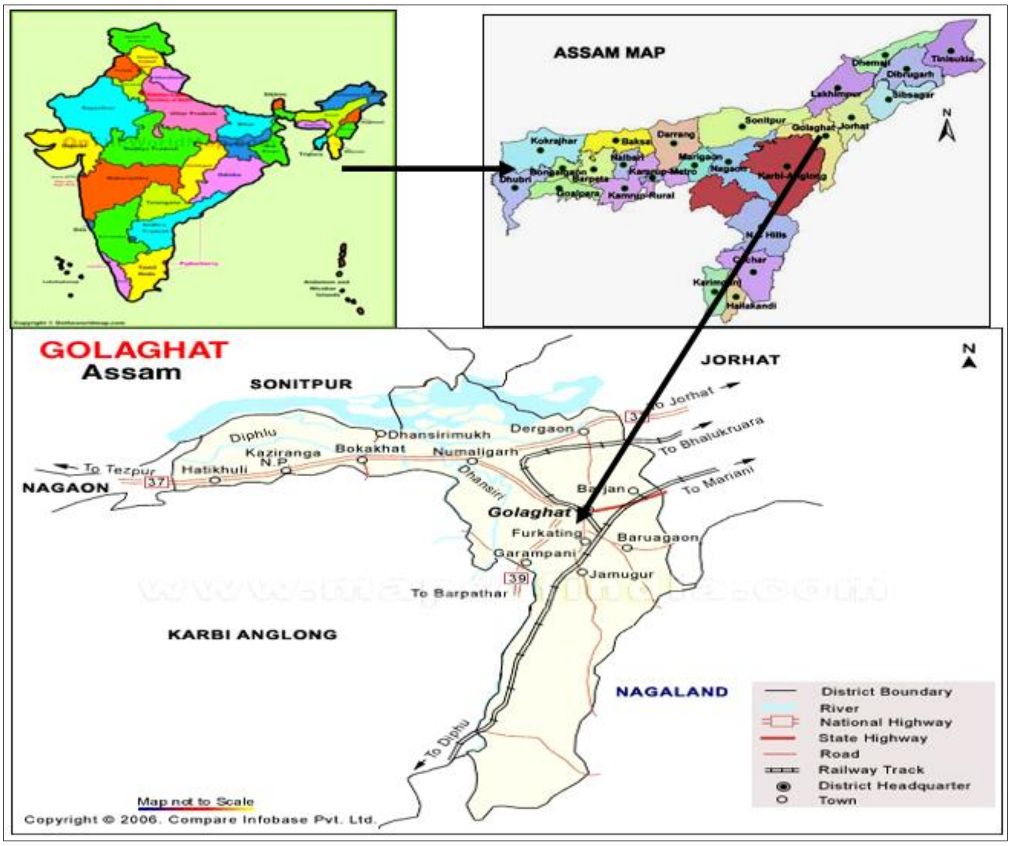


Fig 1: Map showing location of the study area

Horizon wise soil samples were collected from selected profiles under different land uses *viz*., forest cover (P1), rice cultivation (P2), tea cultivation (P3), bamboo plantation (P4) and vegetable cultivation (P5). The details of the five location sites are given in table 1. Horizon wise soil samples were collected, air dried under shade and processed. The fine earth fraction (<2mm) from each horizon were analyzed for physical and chemical characteristics using standard procedures *viz*., mechanical composition (Piper, 1966) [27], pH (In water and 1N KCl in 1:2.5 ratio) by glass electrode pH meter method (Jackson, 1973) [14], electrical conductivity by digital conductivity meter (Jackson, 1973) [14], organic carbon, CEC and per cent base saturation following standard procedures (Jackson, 1973) [14].

Table 1: Location and site characteristics of the studied profiles

Pedon No.	Location	Latitude	Longitude	Land use	Physiography
P1	Nambor	26° 24′ 697″N	93° 53′ 775″ E	Forest cover	Alluvial plain
P2	Borjan	26° 34′ 322″N	94° 04′ 078″ E	Rice cultivation	Alluvial plain
P3	Doria	26° 37′ 898″N	93° 56′ 622″ E	Tea cultivation	Alluvial plain
P4	Dergaon	26° 40′ 812″N	93° 59′ 139″ E	Bamboo plantation	Alluvial plain
P5	Danichapori	26° 40′ 810″N	93° 59′ 157″ E	Vegetable cultivation	Alluvial plain

Fractions of Fe and Al were determined in the soil by separate extractions (i) citrate- bicarbonate- dithionite (Mehra and Jackson, 1960) [25] (ii) acid ammonium oxalate (0.2M), four hour extraction at pH 3.2 (McKeague and Day, 1966) [23] (iii) sodium pyrophosphate (0.1M), sixteen hour extraction at pH 10 (Loveland and Digby, 1984) [20]. Fe and Al in the extract was determined colorimetrically using the 'Ortho-phenanthroline' reagent (Krishna Murti *et al*., 1970) [18] and 'Aluminon' reagent (Krishna Murti *et al*., 1974) [19] respectively.

Results and Discussion

Soil characteristics

Profile weighted mean (PWM) values of some relevant physical and chemical characteristics of soils are presented in table 2. The pH values determined in distilled water (soil: water = 1: 2.5) were found to be in acidic range in all the pedons. The acidic soil reaction in general, may be attributed to acidic parent materials and high rainfall in the stud**y** area. The cultivated soils recorded comparatively lesser pH_{H20} values in comparison to forest soil (P1) and it might be due to less exchangeable Al^{3+} and H^{+} ions content under forest ecosystem. This is in conformity with the findings of Amenla *et al*., (2010) [1]. The soil pH determined in 1M KCl solution was lower compared to water i.e all the soils contained considerable amount of reserve acidity. The electrical conductivity of the pedons was low which might be due to loss of soluble salts under high rainfall condition in the study area. The low EC observed in the studied soils also indicates that the soils contain very small amount of soluble salts and hence there is no hazard of salinity problems in these soils. The highest value of organic carbon was recorded in A horizon of forest soil (P1) with 2.20 per cent and this might be due to the incorporation of huge amount of forest litter to the soil as compared to cultivated land. This corroborates with the findings of Sangtam *et al*., (2017) [28]. On the weighted mean basis, forest soil (P1) recorded the highest sand content (47.1 per cent) and vegetable soil (P5) recorded the highest silt content (48.9 per cent). It might be due to the influence of topography in the development of these soils. Rice soil (P2) recorded the highest clay content (41.7 per cent) and this may be attributed to more weathering induced by specific agronomic practices and alternate oxidation-reduction in paddy soils. Correlation analysis showed that sand was negatively and significantly correlated with silt (r = -0.617**) and clay (r = -0.530**) which suggests in-situ weathering of sand to form silt and clay in these soils. This corroborates with the findings of Dutta *et al*., (2017) [12]. On the weighted mean basis forest soil recorded the highest CEC (13.7 cmol (p^+) kg^{-1}) and the CEC was found to be significantly and positively correlated with clay content (0.441*). This indicates that the CEC of soils was mainly contributed by the clay content rather than organic carbon content. The percent base saturation (PBS) of the soils was found to be higher in vegetable soil (P5) which is an Entisol. The PBS is apparently related to soil development stage.

Table 2: Profile weighted mean (PWM) values of some physicochemical properties under different land uses

Physico-chemical properties (PWM)	P1(Forest)	P2(Rice)	P3(Tea)	P4(Bamboo)	P5(Vegetable)
pH_{H20} (1 : 2.5)	5.4	5.4	4.2	5.2	5.3
pH_{KCl} (1 : 2.5)	4.3	4.2	3.7	4.0	4.5
EC (dSm^{-1})	0.04	0.04	0.07	0.01	0.09
Organic carbon (%)	0.63	0.38	0.50	0.70	0.32
Sand (%)	47.1	30.0	29.9	24.6	31.2
Silt (%)	24.6	28.3	32.3	42.1	48.9
Clay (%)	28.4	41.7	37.8	33.4	19.9
CEC [cmol(p^+) kg^{-1}]	13.7	12.4	9.7	7.9	8.0
Base saturation (%)	38.70	36.38	28.03	32.01	60.86

Distribution of different forms of iron and aluminium in soil profiles

Data on different forms of Fe and Al are presented in table 3 and comparison of different forms of iron and aluminium and their ratios are presented in table 4.

Pyrophosphate extractable Fe and Al

Pyrophosphate extractant dissolved the fraction of Fe (Loveland and Digby, 1984) [20] and Al (Driscoll *et al*., 1985) [9] bound with organic matter. This fraction of Fe varied from 0.04 to 0.14 per cent and Al varied from 0.01 to 0.17 per cent (Table 3). All the pedons had lower amount of Fe_p than Fe_o and the content of this fraction is very much low in all the soils. This suggests that amount of organic matter in these soils was not sufficient to form complex with higher amount of amorphous iron (Karmakar, 1985) [16]. It may also be due to state of organic matter which is in a less colloidal state than it is necessary for complexing the iron compounds (Sutton *et al*., 1989) [29]. The Fe_p showed highest concentration in surface horizon and decreased with depth as shown by organic carbon which suggests the close relationship between these two parameters. Thus, the surface soil (0-25cm) recorded comparatively higher Fe_p and Al_p than the series control section (25-100cm) in all the pedons (Fig 2). On the weighted mean basis, forest (P1), tea (P3) and bamboo (P4) soil recorded highest amount of Fe_p and bamboo (P4) and vegetable (P5) soil recorded higher Al_p. Dutta (2014) [11] reported higher Fe_p in forest ecosystem of alluvial soils of Assam.

Table 3: Fe and Al (%) extracted by different extractants

Horizon	Depth(cm)	Pyrophosphate extractable (%)		Oxalate extractable (%)		Dithionite extractable (%)	
		Fe_p	Al_p	Fe_o	Al_o	Fe_d	Al_d
P1- Nambor, forest							
A	0-15	0.14	0.04	1.87	0.39	4.17	1.83
AB	15-35	0.10	0.03	1.11	0.03	3.86	2.32
Bw1	35-55	0.09	0.02	1.19	0.03	3.66	1.83
Bw2	55-80	0.09	0.03	1.54	0.06	3.55	1.62
Bw3	80-100	0.08	0.01	1.70	0.07	3.35	2.25
Bw4	100-155	0.09	0.02	2.27	0.03	3.46	1.72
Weighted mean		0.09	0.02	1.75	0.08	3.61	1.87
P2- Borjan, rice							
Ap	0-20	0.13	0.14	2.04	0.33	4.05	1.96
BA	20-60	0.08	0.07	2.17	1.06	3.45	1.78
Bt1	60-90	0.08	0.04	1.47	0.30	3.19	1.55
Bt2	90-130	0.07	0.03	2.51	1.68	3.07	2.02
Bt3	130-175	0.07	0.01	2.99	1.25	4.45	2.52
Weighted mean		0.08	0.05	2.24	1.03	3.64	2.01
P3- Doria, tea							
Ap	0-15	0.10	0.04	2.31	1.09	2.54	1.70
BA	15-45	0.10	0.04	2.01	0.32	2.57	1.69
Bw1	45-75	0.10	0.01	2.28	0.41	2.66	1.55
Bw2	75-115	0.09	0.06	2.51	1.15	2.67	1.71
Bw3	115-155	0.08	0.04	0.66	1.01	2.69	1.80
Weighted mean		0.09	0.04	1.87	0.80	2.64	1.69
P4- Dergaon, bamboo							
A	0-15	0.14	0.17	1.64	0.52	2.76	2.00
BA	15-45	0.10	0.07	2.02	1.44	2.76	1.65

Bw1	45-75	0.08	0.05	2.46	1.71	2.76	1.97
Bw2	75-110	0.09	0.05	1.82	1.09	2.76	1.52
Bw3	110-135	0.08	0.05	1.33	1.26	2.78	1.75
Bw4	135-150	0.09	0.04	1.86	0.92	2.79	1.67
Weighted mean		0.09	0.06	1.89	1.24	2.77	1.74
P5- Danichapori, vegetables							
Ap	0-20	0.10	0.16	2.25	1.01	2.88	1.81
AC	20-35	0.09	0.05	1.60	0.76	2.75	1.51
C1	35-50	0.09	0.04	2.23	0.82	2.65	1.58
C2	50-90	0.07	0.04	2.28	1.03	2.55	1.68
C3	90-115	0.04	0.05	2.53	1.71	3.98	2.10
C4	115-150	0.09	0.04	2.52	1.37	2.59	1.82
Weighted mean		0.08	0.06	2.30	1.17	2.87	1.77

Acid ammonium oxalate extractable Fe and Al

Oxalate dissolved both "amorphous" and "organically bound" forms of Fe and Al, but not the crystalline forms (Parfitt and Childs, 1988) [26]. Amorphous forms of Fe and Al like hydroxides and oxyhydroxides were dissolved from soil using this extractant (Mckeague *et al.*, 1971) [24]. Al compounds associated with organic matter were also extracted as amorphous alumino-silicates including allophone and imogolite (Kodama and Ross, 1991) [17]. This fraction of Fe varied from 0.66 to 2.99 per cent and Al varied from 0.03 to 1.71 per cent (Table 3). On the weighted mean basis, the Fe_o content was recorded highest in vegetable soil (P5) and Al_o content was recorded highest in bamboo soil (P4). The surface soil recorded comparatively higher Fe_o in forest (P1) and rice (P2) soil whereas the series control section recorded higher Fe_o in tea (P3), bamboo (P4) and vegetable (P5) soils respectively (Fig 2). While, the surface soil recorded comparatively higher amount of Al_o in forest (P1) and tea (P3) soil whereas the series control section recorded higher Al_o content in rice (P2), bamboo (P4) and vegetable (P5) soils (Fig 2). Fe_o was more in the illuvial horizons of all the pedons except P5 which might be due to translocation of Fe (Bera *et al*., 2015) [3]. The depth distribution of Fe_o and Al_o was irregular in all the pedons.

The difference between oxalate and pyrophosphate extractable Fe and Al gave a measure of amorphous inorganic Fe and Al (Dolui and Bera, 2001; Dolui and Chakravarty, 1998) [6, 5] in soils. Data (Table 4) revealed that amorphous Fe ($Fe_o – Fe_p$) in the soil ranged between 0.57 to 2.92 per cent and amorphous Al ($Al_o – Al_p$) of the soils varied from 0 to 1.66 per cent. The data presented provided evidence that an approximate differentiation can be made between organically complexed Fe and Al and amorphous inorganic Fe and Al by selective extraction of soils with pyrophosphate and oxalate. The large apparent increase in the quantities of ($Fe_o – Fe_p$) forms and ($Fe_o – Fe_p$) forms suggested a shift towards inorganic pedogenic phases at the expense of organically bound phase (Bera *et al.*, 2015 and Jersak *et al*., 1992) [3, 15]. On the weighted mean basis, the ($Fe_o – Fe_p$) was recorded highest in rice soil (P2) and ($Al_o – Al_p$) was recorded highest in bamboo soil (P4). The series control section (25-100cm) recorded comparatively higher amount of amorphous inorganic iron ($Fe_o – Fe_p$) than the surface soil (0-25cm) in all the pedons except forest (P1) and rice (P2) soil. In P1 and P2 the surface soil recorded higher amount of amorphous inorganic iron (Fig 3). The surface soil recorded comparatively higher ($Al_o – Al_p$) in forest (P1) and tea (P3) soil whereas the series control section recorded higher amount of ($Al_o – Al_p$) in rice (P2), bamboo (P4) and vegetable (P5) soils (Fig 3). The amorphous inorganic iron ($Fe_o – Fe_p$) and aluminium ($Al_o – Al_p$) was irregularly distributed in all the pedons.

Dithionite citrate bicarbonate extractable Fe and Al (Fe_d and Al_d)

A perusal of data on various forms of iron and aluminium revealed that dithionite extractable iron (Fe_d) and aluminium (Al_d) constituted the highest amount among the pedogenic forms of iron and aluminium irrespective of land uses. The Fe_d and Al_d indicates the crystalline form of iron and aluminium present in the primary and secondary minerals (Mehra and Jackson, 1960) [25]. The amount of Fe_d and Al_d in soil was found to vary from 2.54 to 4.45 percent and 1.51 to 2.52 per cent under different land uses (Table 3). On the weighted mean basis, the Fe_d and Al_d content was recorded highest in paddy soil (P1). This indicated higher degree of soil development in paddy soil which is an Alfisol. This corroborates with the findings of Dutta (2001) [10] for some alluvium derived paddy soils of Assam. The surface soil (0-25cm) recorded comparatively higher Fe_d in forest soil (P1), rice soil (P2) and vegetable soil (P5) pedons whereas the series control section (25-100cm) recorded higher Fe_d in tea soil (P3) (Fig 2). In bamboo soil (P4) the amount of Fe_d in surface was similar with series control section. The surface soil (0-25cm) recorded comparatively higher Al_d than the series control section (25-100cm) in all the pedons (Fig 2). The Fe_d in tea soil (P3) and bamboo soil (P4) regularly increased with soil depth.

Table 4: Comparison of different forms of Fe and Al and their ratio

Depth(cm)	Amorphous (%)		Crystalline (%)		Degree of activation (%)		Co-migration of clay	
	$Fe_o – Fe_p$	$Al_o – Al_p$	$Fe_d – Fe_o$	$Al_d – Al_o$	Fe_o / Fe_d	Al_o / Al_d	Clay/ Fe_d	Clay/Al_d
P1- Nambor, forest								
0-15	1.73	0.35	2.29	1.44	0.45	0.21	4.73	4.72
15-35	1.01	-	2.75	2.29	0.29	0.01	5.18	5.18
35-55	1.10	0.01	2.47	1.80	0.33	0.02	7.27	7.27
55-80	1.45	0.03	2.01	1.55	0.43	0.04	7.97	7.97
80-100	1.62	0.06	1.65	2.18	0.51	0.03	9.69	9.67
100-155	2.18	0.01	1.19	1.68	0.66	0.02	9.53	9.54
	1.66	0.05	1.86	1.79	0.49	0.04	7.98	7.98
P2- Borjan, rice								

0-20	1.91	0.19	2.00	1.63	0.50	0.17	7.00	6.99
20-60	2.09	0.99	1.27	0.72	0.63	0.59	9.58	9.57
60-90	1.39	0.26	1.73	1.25	0.46	0.19	15.07	15.08
90-130	2.44	1.65	0.56	0.34	0.82	0.83	15.56	15.54
130-175	2.92	1.24	1.46	1.27	0.67	0.50	10.28	10.27
	2.24	0.99	1.32	0.97	0.64	0.51	11.77	11.76
P3- Doria, tea								
0-15	2.21	1.05	0.23	0.61	0.91	0.64	10.44	10.43
15-45	1.91	0.28	0.56	1.37	0.78	0.19	11.88	11.87
45-75	2.18	0.40	0.38	1.14	0.86	0.26	12.79	12.78
75-115	2.42	1.09	0.16	0.56	0.94	0.67	16.51	16.48
115-155	0.57	0.97	2.03	0.79	0.24	0.56	16.41	16.39
	1.78	0.76	0.77	0.89	0.71	0.47	14.28	14.26
P4- Dergaon, bamboo								
0-15	1.51	0.35	1.12	1.47	0.59	0.26	11.91	11.92
15-45	1.92	1.37	0.74	0.20	0.73	0.88	13.44	13.44
45-75	2.37	1.66	0.30	0.26	0.89	0.87	14.29	14.28
75-110	1.74	1.04	0.94	0.43	0.66	0.72	11.04	11.05
110-135	1.24	1.21	1.45	0.49	0.48	0.72	10.07	10.07
135-150	1.77	0.88	0.92	0.75	0.67	0.55	10.74	10.72
	1.80	1.17	0.87	0.50	0.68	0.72	12.07	12.06
P5- Danichapori, vegetables								
0-20	2.15	0.85	0.64	0.80	0.78	0.56	7.46	7.47
20-35	1.51	0.71	1.14	0.74	0.58	0.51	7.10	7.09
35-50	2.14	0.78	0.42	0.75	0.84	0.52	5.07	5.06
50-90	2.21	0.99	0.27	0.65	0.89	0.61	8.03	8.04
90-115	2.49	1.66	1.45	0.39	0.63	0.81	6.18	6.18
115-150	2.43	1.33	0.07	0.45	0.97	0.75	6.95	6.95
	2.22	1.11	0.57	0.60	0.82	0.65	7.01	7.01

The increasing trend of Fe_d was similar to the findings of Dutta *et al*., (2017) [12] and Gangopadhyay *et al.*, (2016) [13] where they found increasing trend of Fe_d for some alluvium derived soils under different land uses of Assam. This might be due to fluctuating ground water table which causes seasonal reduction of iron and enhances its downward movement with recession of ground water or due to co-migration of Fe with clay (Blume and Schwertmann, 1969) [4]. Citrate– bicarbonate – dithionite removes mainly crystalline iron oxide. But a portion of amorphous iron is also removed by this extractant. So (Fe_d – Fe_o) represents more or less crystalline form of iron. Crystalline Fe (Fe_d – Fe_o) in the soils ranged between 0.07 to 2.75 per cent while crystalline Al (Al_d – Al_o) in the soils varied from 0.20 to 2.29 per cent. In all the soils CBD extracted Fe and Al values were higher than the acid ammonium oxalate extracted values indicating that a considerable fraction was present in crystalline form. The high temperature condition and the prolonged dry season (4 to 5 months annually) may be responsible for the high amount of crystalline Fe and Al fraction in these soils. On the weighted mean basis, forest soil (P1) recorded highest amount of crystalline form of iron. This suggests that the crystallization of amorphous iron is highest in forest soil. The surface soil (0-25cm) recorded comparatively higher amount of (Fe_d – Fe_o) than the series control section in all the pedons irrespective of land uses (Fig 3). While, the surface soil recorded comparatively higher (Al_d – Al_o) in rice soil (P2), bamboo soil (P4) and vegetable soil (P5) whereas, the series control section recorded higher (Al_d – Al_o) in forest soil (P1) and tea soil (P3) (Fig 3).

Degree of activation

The crystalline Fe and Al oxides increased at the expense of the poorly crystalline forms with increasing soil age as indicated by the ratios of Fe_o/Fe_d and Al_o/Al_d (Mahaney and Fahey, 1988) [21]. According to Mahaney *et al*., (1991) [22] soils with high ratio were younger soils, whereas low ratios indicated older soils. The ratios of (Fe_o/Fe_d) and (Al_o/Al_d) in all the pedons were less than one (Table 4). This supports the view that free Fe and Al oxides in most of the soils were at an advanced stage of crystallinity or ageing (Bera *et al*., 2005 and Mahaney *et al*., 1991) [22]. The highest weighted mean active Fe and Al ratio value (0.82) was recorded for vegetable soil (P5) which is an Entisol and bamboo soil (P4) which is an Inceptisol. It suggests that these soils are relatively young. The lowest value was recorded for forest soil (P1). This suggests that the soils might be older or weathering might have progressed relatively well and to a more advanced stage.

Co-migration of clay

The co-migration of Fe and Al with clay in the different soil profiles is evidenced by the ratios of clay/Fe_d and clay/Al_d. The ratios (Table 4) followed an increasing trend with few exceptions in case of forest (P1), rice (P2) and tea (P3) soils, which can be corroborated with the observations of Bera *et al*., (2015) [3]. According to Dolui and Bera (2001) [6] these ratios increased with depth within the profile where horizon formation was well expressed and established. In bamboo (P4) and vegetable (P5) soils the ratios did not follow any consistent pattern with relevance to the different horizons at different depths. It might indicate that the horizon formation was still in progress (Bera *et al*., 2015) [3].

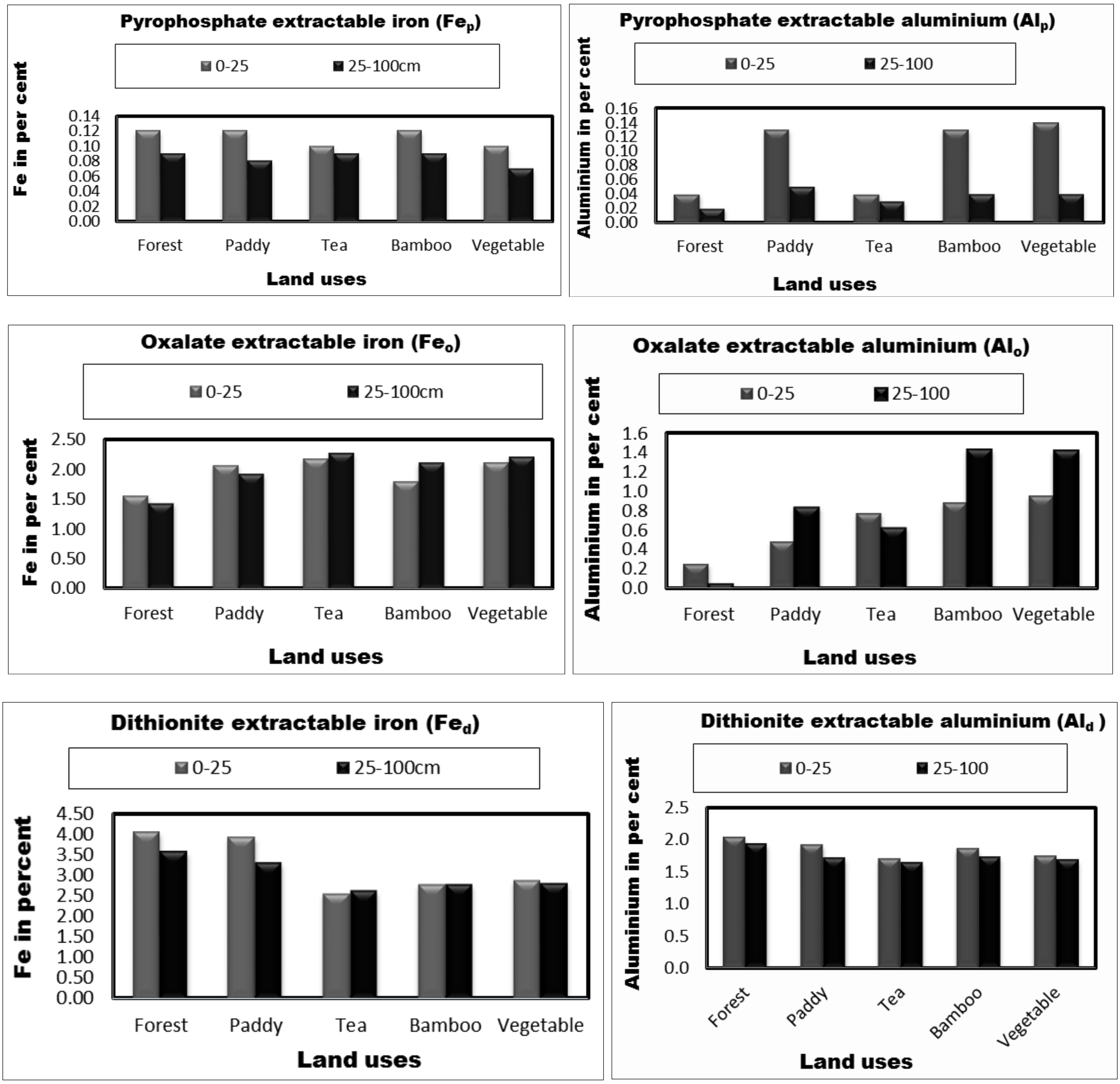
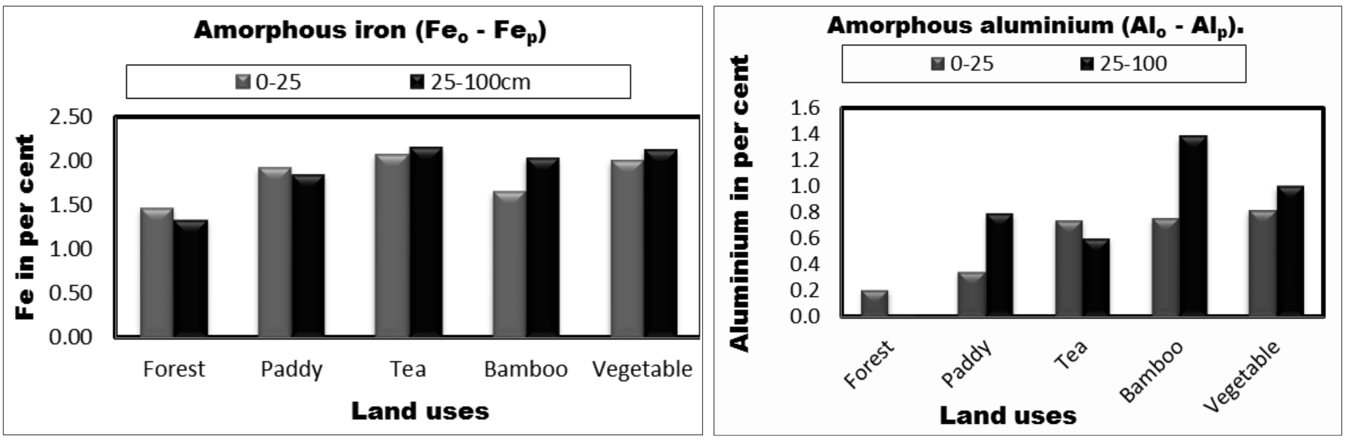


Fig 2: Distribution of Fe_p, Al_p, Fe_o, Al_o, Fe_d and Al_d in surface (0-25 cm) and series control sections (25-100 cm) under different land uses of Golaghat district



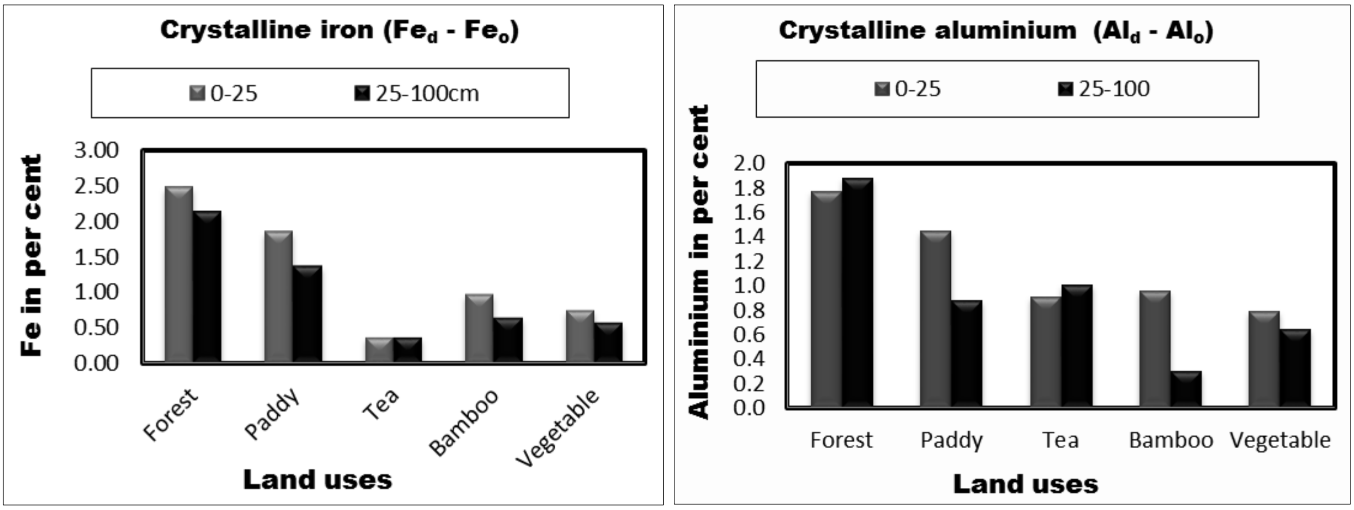


Fig 3: Distribution of (Fe_o - Fe_p), (Al_o - Al_p), (Fe_d – Fe_o) and (Al_d – Al_o) in surface (0-25 cm) and series control sections (25-100 cm) under different land uses of Golaghat district

Table 5: Correlation matrix for different forms of iron and aluminium and physicochemical properties of soils under different land uses of Golaghat district

Y/X	pH(H$_2$0)	Org. C	Clay	CEC	Fe$_d$	Al$_d$	Fe$_p$	Al$_p$	Fe$_o$
Fe$_d$	0.416*	0.202	0.023	0.515**					
Al$_d$	0.248	0.058	0.164	0.354	0.617*				
Fe$_p$	-0.259	0.832**	-0.207	-0.038	0.052	-0.080			
Al$_p$	-0.126	0.483**	-0.118	-0.173	-0.096	-0.011	0.518**		
Fe$_o$	0.034	-0.135	0.068	-0.056	0.033	0.165	-0.218	0.001	
Al$_o$	0.031	-0.247	0.197	-0.411*	-0.289	0.066	-0.433*	0.090	0.500**

Relationship with soil properties

Relationship of pedogenic Fe and Al with soil properties are presented in Table 5. pH of the soil was found to have significant positive correlation with dithionite extractable fraction of Fe (0.416*). This might be due to the fact that increase in soil pH increased the adsorptive affinity of clay and iron oxides, thus reducing the concentration of iron in labile pool. Organic carbon was positively and significantly correlated with Fe_p (0.832**) and Al_p (0.438**). Positive correlation of Fe_p with organic carbon (r = 0.832**) is indicative of the fact that organic carbon influenced the solubility and availability of Fe which protects itself from oxidation and precipitation of available Fe into unavailable form thus increasing its availability in these soils. This corroborates with the findings of Dolui *et al.*, (1988) [8] who found similar relationship in different soil series of West Bengal. Positive correlation of Al_p with organic carbon (r = 0.483**) indicates Al-organic carbon complexes in these soils. The results are in good conformity with the findings of Dutta (2001) [10] and Dolui and Maity (2004) [7]. Cation exchange capacity also showed significant positive correlation with Fe_d. Cation exchange capacity indicated the total negative charge of the colloid and in soil may be correlated to the availability of iron and aluminium from charge sites (Bera *et al*., 2015) [3].

Interrelationship among different forms of Fe and Al

Interrelationship among different forms of Fe and Al are presented in Table 5. Fe_p was positively and significantly correlated with Al_p (0.518**), Fe_d was positively and significantly correlated with Al_d (0.617**) and Fe_o was positively and significantly correlated with Al_o (0.500**). Similar relationships were reported by Bera *et al*., (2015) [3].

Conclusion

Fractionation of soil Fe and Al by sequential extraction is useful in determining various forms of Fe and Al in soils. Availability of Fe and Al in soils is related to the amount of different solid forms of Fe and Al in equilibrium with the soil solution. Fe and Al are the major soil constituents occurring in several mineralogical forms: as discrete particles or as associated with surfaces of other minerals. Hence, the amount and distribution of extractable Fe and Al oxides in soil profiles may serve as indicators of the stage and degree of soil development.

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