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Forms of iron and weathering index of some typical pedons of Bundelkhand region in relation to physiography and parent material

C.S. Walia[1] *and Y.S. Rao*[2]

1. National Bureau of Soil Survey and Land Use Planning, Regional Centre, New Delhi 110 012
2. Division of Soil Science and Agricultural Chemistry, Indian Agricultural Research Institute, New Delhi 110 012

Abstract
Weathering index (WI) and distribution of two forms of iron in ten typical pedons of various landforms of Bundelkhand region were used for pedogenic evaluation. Dithionite iron (Fe_d) content varied from 13 to 55 per cent of total iron (Fe_t) and these variations were caused by the interaction of parent material, physiography and pedogenic development of soils. Fe_d/Fe_t ratio either slightly increased or decreased with depth irrespective of physiographic location in Inceptisols and Vertisols because of low weathering index. This ratio sharply increased in the Bt horizon of relatively more weathered Alfisols. Oxalate iron (Fe_o) content of soils accounted for only 3.5 to 13 per cent of Fe_t and declined with depth in majority of soils due to crystallization. Fe_o/Fe_d followed a similar pattern in these pedons except in Alfisols where it showed an increase in the Bt horizon probably due to the association of illuvial clay with amorphous Fe as coatings. WI increased sharply in sedentary Inceptisols with depth and differences between the B and C horizons were very narrow. However, in Alfisols the increase in WI was relatively gradual due to more uniform weathering but varied with the parent material and physiography. In alluvium derived Inceptisols and Vertisols the depthwise increase in WI was more abrupt and varied from horizon to horizon without any specific trend indicating their younger stages of development. WI was found to be negatively correlated with Fe_d/Fe_t and Fe_o/Fe_t ratios.

Additional keywords: Ratios of iron forms, pedogenesis.

Introduction

Weathering index calculated from the total composition of soils has direct bearing on the age of soils and also provides basis to understand profile development in relation to parent material (Evans and Cameron 1979). Profile distribution of different forms of iron oxides particularly dithionite and oxalate extractable iron serve as a useful indicator to identify the horizon of accumulation of secondary oxides (McKeague and Day 1966), depth of weathering and argillic horizon (Chatterjee and Raghumohan 1982). These two approaches have been used for pedogenic evaluation and intensity of weathering in the soils occurring under different physiographic positions and developed from different parent materials in Banda district of Uttar Pradesh in Bundelkhand region, where such information is almost lacking.

Materials and methods

The study area is located between 24°55' and 25°35'N latitudes and 80°03' and 81°04'E longitudes covering part of Banda district. This region represents a transitional zone of tropical dry subhumid type of climate with mean annual temperature of 25°C and mean annual rainfall of 1032 mm. The area thus, exhibits 'hyperthermic' temperature regime and ustic moisture regime.

Based on reconnaissance soil survey ten typical pedons representing various landforms (Table 1) delineated through aerial photo-interpretations were exposed and sampled horizonwise. The details of morphological, physical and chemical characteristics are reported elsewhere (Walia and Rao 1996, 1997). Total elemental composition of soil samples was carried out following the procedure of Jackson (1974) and weathering index of each horizon was calculated by the formula given by Evans and Cameron (1979).

$$CaO + MgO + K_2O + Na_2O \text{ to } CaO + MgO + K_2O + Na_2O + SiO_2 + Al_2O_3 + Fe_2O_3$$

Dithionite iron (Fe_d) and oxalate iron (Fe_o) were extracted from soils as per methods by Mehra and Jackson (1960) and Mckeague and Day (1966), respectively and their contents were estimated by atomic absorption spectrophotometer.

Table 1. Soil site characteristics

Pedon	Classification	Parent material	Physiography	Slope (%)	Erosion
Markundi (P1)	Typic Ustochrepts	Shale	Hill	30-50	Severe
Tikria (P2)	Dystic Ustochrepts	Kaimur sand stone	Subdued plateau	1-3	Moderate
Devagan (P3)	Ultic Haplustalfs	Feldspathic sand stone	Flat topped hill	0-1	Slight
Bahilpurwa (P4)	Udic Ustochrepts	Vindhyan sand stone	Gently sloping plateau	1-5	Moderate
Gonda (P5)	Ultic Haplustalfs	Granite	Monadnock	1-3	Slight to moderate
Mariahu (P6)	Udic Ustochrepts	Colluvium	Foot hill slopes	3-5	Moderate
Khraund (P7)	Fluventic Ustochrepts	Alluvium	Piedmont plain	1-3	Slight to moderate
Bharatkup (P8)	Typic Ustochrepts	Alluvium	Recent dissected flood plain	3-8	Moderate to severe
Badausa (P9)	Udic Haplusterts	Alluvium	Slightly undulating flood plain	1-3	Slight
Anuwan (P10)	Vertic Epiaquepts	Alluvium	Level flood plain	0-1	Slight

Results and discussion

Forms of iron and their ratios

The data on various forms of iron and their ratios are presented in table 2. Dithionite iron (Fe_d) constituted about 13-55 per cent of total iron (Fe_t) in red soils. Markundi soils of steep hill slopes showed lowest Fe_d (13-19%) though these are formed from iron rich shale due to minimum pedochemical weathering and erosion on steep slopes. Devagan, Tikria and Bahilpurwa soils developed on a variety of sand stones contained 16.9 to 55 per cent Fe_d of Fe_t but the content of Devagan soils was found to be highest formed on relatively more stable surface. Gonda soils derived from granite though more developed than Bahilpurwa soils on sand stone but contained less Fe_d due to its low Fe_t content. Among the alluvium derived soils Mariahu and Khraund soils of foot hill slopes and piedmont plain contained more Fe_d (11-20%) because of origin of new sediments from adjoining hills and it declined further in the flood plain soils (Anuwan, Badausa and Bharatkup) of Yamuna river and its tributaries. The data, thus, strongly indicated that variations in Fe_d were mostly associated with parent material, physiography and pedogenic development.

Table 2. Different iron forms, their ratios and weathering index

Horizon	Depth (cm)	CBD-Fe (%)	Oxalate-Fe (%)	Total-Fe (%)	Fe_o/Fe_d	Fe_d/Fe_t	Weathering index
			HILLY UPLANDS				
			Markundi – P1 – Typic Ustochrepts				
Ah	0-13	0.98 (13.3)	0.18 (2.4)	7.35	0.18	0.13	4.78
Bw1	13-31	1.44 (18.9)	0.15 (2.0)	7.63	0.10	0.19	6.20
Bw2	31-50	1.47 (18.6)	0.14 (1.7)	7.92	0.10	0.18	6.08
C	50-70	1.01 (14.3)	0.10 (1.4)	7.07	0.10	0.10	6.77
			Tikria – P2 – Dystric Ustochrepts				
Ap	0-12	0.76 (43.0)	0.14 (7.9)	1.77	0.18	0.43	1.62
Bw1	12-25	1.04 (37.1)	0.13 (4.6)	2.80	0.12	0.37	1.74
Bw2	25-45	1.05 (31.2)	0.12 (3.6)	3.36	0.11	0.31	1.80
C	45-60	0.87 (32.2)	0.20 (7.4)	2.70	0.23	0.32	1.86
			Devagan – P3 – Ultic Haplustalfs				
Ah	0-15	1.26 (36.6)	0.12 (3.5)	3.44	0.10	0.37	1.99
Bw	15-30	1.96 (39.8)	0.65 (13.2)	4.92	0.33	0.40	2.06
Bt1	30-55	2.51 (53.4)	0.61 (13.0)	4.70	0.24	0.53	2.19
Bt2	55-80	2.81 (55.1)	0.61 (12.0)	5.10	0.22	0.56	2.29
Bc	80-100	2.57 (45.1)	0.31 (3.9)	5.70	0.12	0.43	2.27
			Bahilpurwa – P4 – Udic Ustochrepts				
Ap	0-14	1.42 (40.8)	0.14 (4.0)	3.48	0.10	0.41	1.44
Bw1	14-38	1.72 (45.5)	0.12 (3.2)	3.78	0.07	0.45	2.10
Bw2	38-60	1.80 (44.5)	0.13 (3.2)	4.04	0.07	0.44	2.25
C	60-100	0.83 (16.9)	0.17 (3.5)	4.90	0.20	0.17	2.30
			Gonda – P5 – Ultic Haplustalfs				
Ap	0-12	0.43 (19.8)	0.08 (5.7)	2.17	0.18	0.20	4.10
Bt1	12-34	0.83 (32.6)	0.20 (7.9)	2.54	0.24	0.33	4.52
Bt2	34-50	1.06 (34.2)	0.23 (7.4)	3.10	0.22	0.34	4.62
C	50-65	0.47 (19.6)	0.11 (6.0)	2.40	0.23	0.19	5.01
			PIEDMONT PLAIN				
			Mariahu – P6 – Udic Ustochrepts				
Ap	0-13	0.30 (11.7)	0.27 (10.5)	2.56	0.90	0.12	1.01
Bw1	13-29	1.04 (28.8)	0.23 (6.5)	3.61	0.22	0.22	1.84
Bw2	29-50	1.30 (29.2)	0.28 (6.3)	4.45	0.21	0.29	2.16
Bw3	50-73	1.06 (23.2)	0.26 (5.7)	4.56	0.24	0.23	2.21
Bw4	73-100	0.75 (14.9)	0.22 (4.4)	5.02	0.29	0.15	2.47
			Khraund – P7 – Fluventic Ustochrepts				
Ap	0-10	0.44 (16.0)	0.07 (2.7)	2.74	0.16	0.16	1.46
Bw1	10-28	1.15 (23.0)	0.11 (2.2)	4.96	0.10	0.23	2.33
Bw2	28-52	1.04 (22.7)	0.16 (3.4)	4.58	0.15	0.23	2.31
Bw3	52-75	1.09 (24.5)	0.13 (2.9)	4.45	0.12	0.24	2.12
Bw4	75-106	1.20 (25.5)	0.14 (3.0)	4.70	0.12	0.25	2.12
BC	106-150	0.87 (17.1)	0.10 (2.0)	5.07	0.11	0.17	2.66

Horizon	Depth (cm)	CBD-Fe (%)	Oxalate-Fe (%)	Total-Fe (%)	Fe_o/Fe_d	Fe_d/Fe_t	Weathering index
			FLOOD PLAIN				
			Bharatkup – P8 – Typic Ustochrepts				
Ap	0-14	0.91 (25.8)	0.12 (3.4)	3.53	0.13	0.26	5.82
BwCa	14-30	0.57 (11.8)	0.04 (0.8)	4.84	0.07	0.12	5.38
Bw	30-47	0.57 (11.4)	0.04 (0.8)	4.98	0.07	0.11	5.80
BC	47-75	0.57 (12.3)	0.04 (0.8)	4.62	0.07	0.12	6.07
1C	75-100	0.60 (11.6)	0.06 (1.1)	5.19	0.01	0.11	6.77
2C	100-150	0.71 (13.4)	0.08 (1.5)	5.30	0.11	0.13	6.52
			Badausa – P9 – Udic Haplusterts				
Ap	0-13	0.57 (11.3)	0.10 (1.9)	5.06	0.17	0.11	4.70
A1	13-30	0.64 (12.3)	0.08 (1.6)	5.19	0.12	0.12	5.49
A2ss	30-53	0.74 (14.0)	0.07 (1.3)	5.30	0.09	0.14	5.05
A3ss	53-80	0.79 (15.4)	0.07 (1.5)	5.30	0.09	0.14	5.05
A4ss	80-100	0.77 (14.8)	0.07 (1.3)	5.21	0.09	0.15	5.19
A5	110-160	0.60 (110)	0.06 (1.2)	5.47	0.10	0.11	4.71
			Anuwan – P10 – Vertic Epiaquepts				
Ap	0-13	1.50 (3.08)	0.08 (1.7)	4.87	0.05	0.31	3.77
Bw1	13-30	0.97 (20.6)	0.02 (0.3)	4.70	0.02	0.21	4.21
Bw2	30-60	0.90 (19.3)	0.02 (0.4)	4.67	0.02	0.19	3.89
Bw3	60-81	0.90 (21.6)	0.03 (0.7)	4.17	0.03	0.21	3.96
Bw4	81-110	0.94 (20.2)	0.06 (1.3)	4.64	0.06	0.20	4.06
Bw5	110-160	1.14 (23.1)	0.04 (0.8)	4.93	0.03	0.26	4.66

CBD-Fe=Fe_d; Oxalate-Fe=Fe_o; Total-Fe=Fe_t
Figures in parentheses indicate per cent of total iron.

Fe_d content in general tend to increase with depth except alluvium derived Bharatkup calcareous soils. However, the distribution of Fe_d in proportion to its Fe_t (Fe_d/Fe_t) with depth provided important indication of weathering intensity (Torrent *et al.* 1980). In Markundi and Bahilpurwa soils Fe_d/Fe_t ratio was slightly increased in the B horizon however it slightly decreased in Tikria soils indicated relatively very low to low weathering intensity in these soils. Sharp increase in Fe_d/Fe_t ratio was noticed in the Bt horizon of Gonda and Devagan soils and followed by a decline in the BC horizons suggesting the translocation of free Fe_2O_3 to lower horizons under relatively more intense weathering conditions. In Mariahu and Khraund soils, Fe_d/Fe_t ratio presented a increasing trend with depth but the distribution was found to be irregular possibly due to lithological variations as confirmed by the authors (Walia and Rao 1996, 1997). Bharatkup and Anuwan soils which represented dissected and level flood plain the Fe_d/Fe_t ratio decreased with depth though irregularly but it has slightly increased in Badausa soils indicating the young stage of their pedogenic development and it corroborated the earlier findings reported by the authors (Walia and Rao 1997). Thus, the data indicated that the Fe_d/Fe_t ratio increased with the development of soils and such an observation was also obtained by Rao (1985), Karmakar (1985) and Torrent *et al.* (1980) but this ratio was related with the age of soil by Ardunio *et al.* (1986).

Oxalate iron (Fe_o) content of soils varied from 0.07 to 0.65 per cent accounting for 3.5 to 13% of Fe_t. Red soils in general contained more Fe_o than alluvium derived flood plain soils (P8 to P10). Fe_o values were invariably lower corresponding to that of Fe_d indicating the dominance of crystalline form of Fe_2O_3 (Rao 1985). Surface content of Fe_o (0.08 to 0.27%) in majority of pedons was higher due to its complexity with organic matter (McKeague and Day 1966) and decreased thereafter. The depthwise distribution of

Fe_o presented various trends. The Fe_o content decreased regularly in Markundi soils whereas in Tikria and Bahilpurwa soils Fe_o decreased in the Bw horizon followed by increase in the C horizon. A reverse trend was observed in Devagan and Gonda soils having the Bt horizon. Alluvium derived soils (P7 to P10) have not shown any specific pattern of Fe_o distribution. The pattern of Fe_o distribution in profile seemed to follow dominantly clay and organic matter distribution in profile which are ultimately related to physiography, parent material and age of soils (Walia and Rao 1996, 1997) and influenced the rate of crystallization (Karmakar 1985).

Fe_o/Fe_d ratio followed a similar pattern in the profile, it is higher in surface and decreased in the Bw horizons apparently due to crystallization of amorphous Fe_2O_3. Fe_o/Fe_d ratio in alluvium derived soils (P6 to P10) followed an irregular trend below the A horizon on account of lithological discontinuity. In Badausa soils, however, the variations in Fe_o/Fe_d ratios was minimum below surface possibly due to pedoturbation. The Fe_o/Fe_d ratio increased markedly in the Bt horizon of Devagan and Gonda soils suggesting the association of amorphous Fe_2O_3 with alluvial clay as coatings.

Weathering Index (WI)

The average WI was highest (6.0) in Markundi soils developed on shales followed by Gonda soils (4.10) on granite. The mean WI varied from 1.75 to 2.17 in soils developed on sand stone and its alluvium (Tikria, Devagan, Bahilpurwa and Khraund). Among the recent flood plain soils, Bhartkup soils derived from calcareous alluvium showed maximum WI (6.06) followed by Badausa and Anuwan soils. Thus, the data strongly suggested that WI varied depending upon nature and composition of parent rock and source of alluvium. The depthwise pattern of WI provided some important clues regarding weathering intensity. WI increased with the depth in majority of the soils, which indicated the fall in weathering intensity with depth (Evans and Cameron 1979). In sedentary and relatively younger soils (Bahilpurwa, Tikria and Markundi) WI increased sharply in the Bw horizon and differences between the Bw and C horizons became narrower indicating weathering was still active in these soils. However, in Devagan which are relatively older soils formed on stable surfaces were characterized by deeper solum and fine texture, the increase in WI was gradual with depth indicating more intense and uniform weathering in these soils. The Gonda soils which were relatively shallower and coarse textured, the difference in subjacent horizons (A-Bt-C) are relatively more sharp than Devagan soils. Hence, the data suggested that two Alfisols formed from two parent materials on two geomorphic surfaces displayed different trend of WI.

In alluvium derived soils (P6 to P10) the increase in WI was noticed to be erratic in most of the pedons with no specific trend of profile development which manifested their juvenile stages of pedogenesis. This was expected because their source of materials were mostly transported sediments which were deposited in different cycles. Similar observation was also reported by Raghu Mohan *et al.* (1981) in alluvial soils of Goa.

The correlation coefficient between WI and Fe_d/Fe_t was negative (R= -0.62) and significant. The active iron ratio (Fe_o/Fe_d) was also negatively correlated with WI (r= -0.32) which is significant at 5% level. Similar relationship was also reported by Rao (1985) in soils of Telangana region of Andhra Pradesh.

Thus, the two parameters indicated that the soils of Banda district of Bundelkhand region are slight to moderately weathered with a juvenile to intermediate stages of profile development.

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