Journal of the Indian Society of Soil Science, Vol. 67, No. 2, pp 228-235 (2019)
DOI: 10.5958/0974-0228.2019.00025.2

Short Communication

Characterization and Classification of Soils under Rice-based Cropping Systems in Balod District of Chhattisgarh

Uttam Kumar, V.N. Mishra, Nirmal Kumar[1*], R.K. Jena[2], L.K. Srivastava and R.K. Bajpai

Department of Soil Science and Agricultural Chemistry, Indira Gandhi Krishi Vishwavidyalaya, Raipur, 492012, Chhattisgarh

Several authors have tried to classify soils at block/ district level for providing suitable land use options which include various land use/land cover classes (Jena *et al.* 2016). But information on arable soils, particularly under different cropping systems is meagre for Chhattisgarh state. Although soils under different cropping systems (rice–lathyrus, rice–chickpea, rice–wheat and rice–fallow, *etc*.) of Chhattisgarh have been reported as Typic Haplusterts, Chromic Haplusterts, Vertic Haplustepts and Typic Haplustepts at subgroup level (Tamgadge *et al.* 2002), detailed information is still lacking to identify their suitability, and at the same time limitations to increase the productivity of these rice-based cropping systems. Keeping this in view, an attempt was made to characterize and classify the soils under rice-based cropping systems in Balod district, Chhattisgarh.

Balod district lies in between 20°24′ to 21°03′ N latitudes and 80°47′ to 81°31′ E longitudes at an elevation of 324 m above the mean sea level, and occupies an area of 3527 sq. km. The study area falls under Chhattisgarh Plain agro-climatic zone where 50% of the total geographical area is under cultivation. Predominately rice-based cropping systems such as rice–lathyrus, rice–chickpea, rice–wheat and rice–fallow are practiced under rainfed ecosystem. The study region is characterized by the hot-humid tropical climate, with an average annual rainfall of 1028 mm. Maximum rainfall is received between June and October. The maximum temperature in summer may exceed up to 42 °C and varies between 30 to 42 °C, whereas the minimum temperature often falls below 10 °C during the winter season and varies between 0 to 25 °C. The hottest and coolest months are May and December, respectively. The soil moisture regime of the district is characterized as ustic, whereas the soil temperature regime is isohyperthermic (Soil Survey Staff 2014). Soil observations were made in different rice-based cropping systems *i.e.,* rice–lathyrus, rice–chickpea and rice–fallow across the district covering an area of 1768 sq. km. From each cropping system, five pedons were studied and after soil correlation three master pedons were identified (Fig. 1). Horizon-wise morphological properties including depth, colour, structure, texture, graveliness, consistency, occurrence

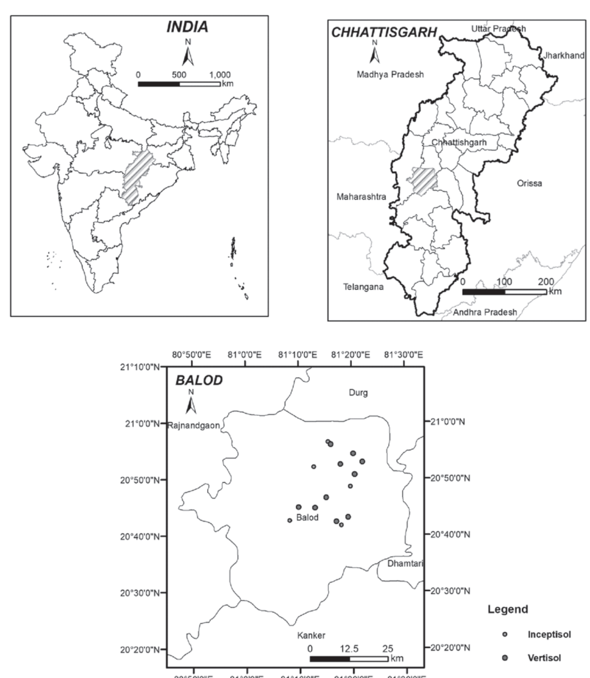

Fig. 1. Study area and location of pedons

*Corresponding author (Email: urwithnirmal@gmail.com)
Present address
[1]ICAR-National Bureau of Soil Survey and Land Use Planning, Nagpur, 440033, Maharashtra
[2]ICAR- National Bureau of Soil Survey and Land Use Planning, Regional Centre, Jorhat, 785004, Assam

Table 1. Soil morphological characters of representative pedons of Balod district, Chhattisgarh

Horizon	Depth (cm)	Matrix color (Moist)	Structure			Consistency			Nodules		Root		Efferv	Others
			Grade	Size	Type	D	M	W	Conca S- Q	Conir S – Q	S	Q		
Pedon 1 (Rice–lathyrus): Very fine, smectitic, isohyperthermic, Typic Haplustert														
Ap	0-12	10 YR 4/3	2	m	sbk	h	fi	vs vp	m, f	f, f	Vf	m	es	-
Bw	12-31	10 YR 3/2	2	m	sbk	h	fi	vs vp	c, f	f, f	Vf	m	es	-
Bss_1	31-57	10 YR 3/2	2	m	abk	h	fi	vs vp	c, m	f, f	Vf	c	ev	ss
Bss_2	57-90	10 YR 3/2	2	m	abk	h	fi	vs vp	c, m	f, f	-	-	ev	ss
Bss_3	90-158	10 YR 4/4	2	m	abk	h	fi	vs vp	c, m	f, f	-	-	ev	ss
Pedon 2 (Rice–chickpea): Very fine, smectitic, isohyperthermic, Typic Haplustert														
Ap	0-18	10 YR 4/4	2	m	sbk	h	fi	vs vp	c, f	f, f	F	m	es	-
Bw	18-40	10 YR 3/2	2	m	sbk	h	fi	vs vp	c, f	f, f	F	m	es	-
Bss_1	40-80	10 YR 3/2	2	m	abk	h	fi	vs vp	c, m	f, f	-	-	ev	ss
Bss_2	80-122	10 YR 3/2	2	m	abk	h	fi	vs vp	c, m	f, f	-	-	ev	ss
Bss_3	122-154	10 YR 3/2	2	m	abk	h	fi	vs vp	c, m	f, f	-	-	ev	ss
Pedon 3 (Rice–fallow): Fine loamy, smectitic, isohyperthermic, Vertic Haplustept														
Ap	0-10	10 YR 3/2	2	m	sbk	s	fr	ss sp	f, f	f, f	F	m	e	-
Bw_1	10-30	10 YR 4/6	2	m	sbk	s	fr	ss sp	f, f	f, f	F	f	e	-
Bw_2	30-50	10 YR 4/6	2	m	sbk	s	fr	ss sp	f, c	f, f	F	f	es	-
Bw_3	50-88	10 YR 4/6	2	m	sbk	s	fr	ss sp	f, c	f, c	-	-	ev	-
Bw_4	88-150	10YR 4/6	2	m	sbk	s	fr	ss sp	-	-	-	-	ev	

Note: Structure: 2 – moderate, m – massive, m – medium, sbk – sub angular blocky, abk – angular blocky
Consistency: D – dry, M – moist, W – wet, h- hard, s –soft, fi – firm, fr – friable, vs –very sticky, vp – very plastic, ss – slightly sticky, sp –slightly plastic
Nodule: S- size: f-fine, m- medium, c-coarse, Q - quantity: f – few, c – common.
Root: S – size: vf – very fine, f-fine, Q - quantity: f – few, c – common, m – many.
Efferv. : – Effervescence, e – slight effervescence, es – strong effervescence, ev – violent effervescence.
Other: ss – slickensides, pf – pressure faces.

of nodules *etc.* were described following USDA soil survey manual (Soil Survey Division Staff 2005). The soils were classified as per Soil taxonomy (Soil Survey Staff 2014). Horizon-wise soil samples were collected, air-dried and sieved under shade. The fine earth (<2 mm) was analyzed following standard procedures. Physicochemical properties soils were analyzed following Jackson (1973).

Morphological characteristics of the soils are presented in table 1. The soils were very deep (> 150 cm) and well-drained. The colour varied from very dark greyish brown (10 YR 3/2) to dark yellowish brown (10 YR 4/6), with the dominant hue of 10 YR with value ranging from 3 to 4 and chroma varying between 2 and 6. There was not much variation in soil colour with depth. The dark colour in these soils may partly be due to the high content of dark-coloured ferromagnesian minerals. Moreover, the dark matrix colour was due to the presence of high organic carbon (OC) content in the surface horizons. The surface structure of these rice growing soils was massive and structureless due to different agricultural operations such as ploughing and puddling. The sub-surface soil structure varied from medium, moderate and sub-angular blocky (2 m sbk) to medium, moderate and angular blocky (2 m abk) with dominance of medium moderate sub-angular blocky (2 m sbk) in pedon 3, whereas pedons 1 and 2 were predominantly medium, moderate and angular blocky (2 m abk). This type of soil structure may be attributed to higher clay content and low organic carbon content (Priya *et al.* 2017). Slickensides, wedge-shaped aggregates with cracks were observed in pedons 1 and 2. Consistency of the soils was hard (dry), firm (moist), very sticky and very plastic (wet). Increase in stickiness and plasticity may be due to high clay content down the profile, which was observed in case of pedons 1 and 2. In pedon 3, the consistency was soft, friable, slightly sticky and slightly plastic due to relatively lower clay content than pedons 1 and 2.

Physical characteristics of the soils are presented in table 2. The sand content in soils varied from 12.2 to 61.5% that decreased with depth, whereas it was irregular with depth in pedon 3 with higher sand content throughout the profile. The silt content varied from 10.4 to 25.3%. The depth distribution of silt content followed similar trends as in case of sand with reverse in distribution. The clay content ranged from 25.1 to 69.5% that increased with depth in pedons 1 and 2, whereas its distribution did not follow any specific trend in pedon 3. The studied soils showed wide textural variation from sandy clay loam to clay (Fig. 2). The enrichment of clay content in the lower horizon might be due to illuviation or vertical migration of clay. There was no textural class variation in pedon 3.

Bulk density (BD) of soils varied from 1.27 to1.62 Mg m^{-3} and showed an increase with depth.

Table 2. Soil physical characteristics of representative pedons of Balod district, Chhattisgarh

Horizon	Depth (cm)	Particle size				BD (Mg m^{-3})	PD (Mg m^{-3})	Porosity (%)
		Sand (%)	Silt (%)	Clay (%)	Class			
Pedon 1 (Rice–lathyrus): Very fine, smectitic, isohyperthermic, Typic Haplustert								
Ap	0-12	15.2	25.3	59.5	c	1.31	2.55	48.6
Bw	12-31	14.8	24.8	60.3	c	1.35	2.58	47.7
Bss_1	31-57	13.1	24.2	62.7	c	1.39	2.61	46.7
Bss_2	57-90	13.5	23.6	62.9	c	1.44	2.63	45.3
Bss_3	90-158	13.7	22.5	63.8	c	1.49	2.67	44.2
Pedon 2 (Rice–chickpea): Very fine, smectitic, isohyperthermic, Typic Haplustert								
Ap	0-18	14.6	24.8	60.5	c	1.27	2.52	49.6
Bw	18-40	14.6	24.1	61.3	c	1.30	2.54	48.8
Bss_1	40-80	13.0	23.4	63.5	c	1.35	2.59	47.9
Bss_2	80-122	12.1	21.1	66.7	c	1.37	2.64	48.1
Bss_3	122-154	12.2	18.3	69.5	c	1.42	2.68	47.0
Pedon 3 (Rice–fallow): Fine loamy, smectitic, isohyperthermic, Vertic Haplustept								
Ap	0-10	56.2	12.2	31.6	scl	1.36	2.61	47.9
Bw_1	10-30	61.5	13.4	25.1	scl	1.45	2.63	44.9
Bw_2	30-50	57.3	10.4	32.3	scl	1.49	2.66	44.0
Bw_3	50-88	60.5	11.1	28.4	scl	1.56	2.69	42.0
Bw_4	88-150	53.4	16.9	29.7	scl	1.62	2.72	40.4

Note: Texture: c –clay, scl – sandy clay loam.

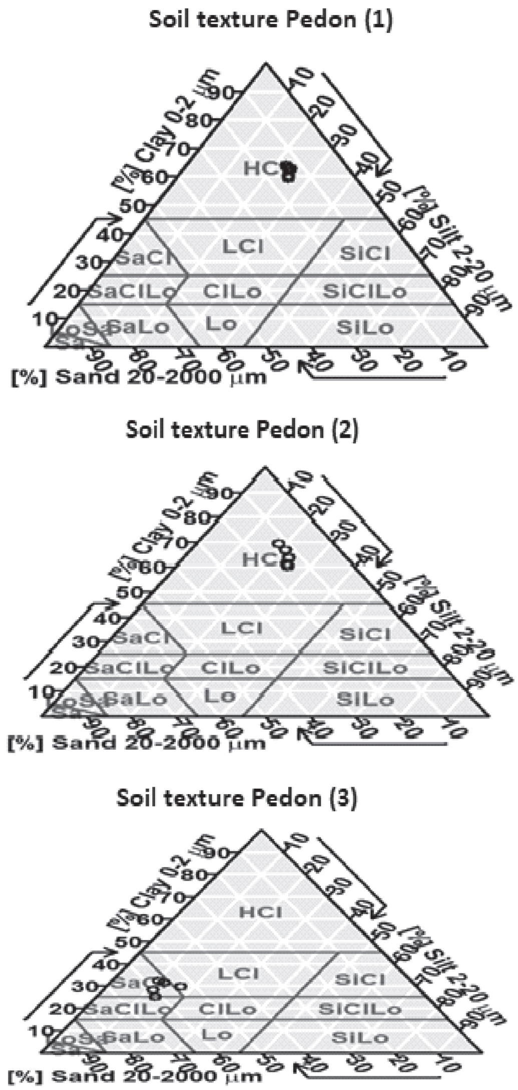

Fig. 2. Textural triangle of pedons

This could be attributed to clogging of pores by dispersed clay in sub-soil layers and reduction of OC resulting in greater compaction and less aggregation (Khan and Kamalakar 2012). The BD showed highly significant and negative correlation with OC (r = -0.862**) and porosity (r = -0.988**) (Table 5). The particle density (PD) of soils ranged from 2.52 to 2.72 Mg m^{-3} and increased with depth. Lower PD of surface soils could be attributed to higher OC content, as evident from significantly negative correlation between PD and OC (r = -0.978**). However, higher particle density in sub-surface horizons might be due to greater soil compaction (Pulakeshi *et al.* 2014). This is supported by a significant positive correlation between PD and BD (r = 0.924**) (Table 5). The porosity of soils varied from 40.4 to 49.6%. The porosity of surface soil was higher than sub-soil, which might be attributed to higher OC content in surface soils as indicated by a highly significant positive correlation between these parameters (r = 0.776**). A decrease in OC with depth increased BD and soil compaction in deeper horizons (Leelavathi *et al.* 2009). This observation was supported by a significant negative correlation between porosity and BD (r = -0.988**) (Table 5). Soil moisture content (SMC) ranged from 10.5 to 23.5%, and decreased progressively with depth (Fig. 3). The difference in SMC might be due to variation in clay and OC content and heterogeneity of parent material. Progressive decrease in SMC with depth could be ascribed to increase in BD, decrease in total pore space and reduction of macropores with depth. This was supported by a significant and positive correlation of SMC with OC (r = 0.823**) and porosity (r = 0.834**) and significant and negative correlation with BD (r = -0.877**) (Table 5). The water holding capacity (WHC) of soils ranged from 21.8 to 44.3%, which decreased gradually with depth (Fig. 4). This could be attributed to the increased BD and decreased OC in the sub-surface horizons (Khan and Kamalakar 2012). This is supported by a significant negative correlation between WHC and BD (r = -0.905**), and significant positive correlation with OC content (r = 0.724**) (Table 5).

Chemical characteristics of the soils are presented in table 3. Soil pH varied from slightly acidic to slightly alkaline, and ranged from 6.2 to 7.8. Soil reaction in pedons 1 and 2 was neutral to slightly alkaline, whereas it was slightly acidic to neutral in pedon 3. Lower pH value in surface horizons is mainly attributed to leaching of bases. The pH of all pedons increased with depth, which could be attributed to an increase in bases with depth and their incomplete downward leaching. This is supported by a significant positive correlation of pH with base saturation (r = 0.897**) (Table 5). The EC of soils varied from 0.08 to 0.19 dS m^{-1} indicating that the soils are non-saline. The depth-wise distribution of EC did not follow any particular pattern in either pedons. Nonetheless, the upper horizon was relatively low in salts than the lower horizons, obviously due to leaching of salts from the surface and their accumulation in the lower depths (Pulakeshi *et al.* 2014). The OC content varied from 2.1 to 6.3 g kg^{-1}, as the soils were under low to the medium category of OC. The surface horizons were higher in OC than sub-surface horizons, which might be attributed to addition of greater biomass and *vice versa.*

Table 3. Soil chemical characteristics of representative pedons of Balod district, Chhattisgarh

Horizon	Depth	pH	EC	OC	Available nutrients (kg ha^{-1})			Exchangeable cations [cmol(p$^+$)kg^{-1}]				CEC	CEC/	CaCO$_3$	Base
	(cm)	(dS m^{-1})	(g kg^{-1})		N	P	S	Ca^{2+}	Mg^{2+}	Na$^+$	K$^+$	[cmol(p$^+$) kg^{-1}]	Clay	(%)	saturation (%)
Pedon 1 (Rice – lathyrus): Very fine, smectitic, isohyperthermic, Typic Haplustert															
Ap	0-12	7.1	0.15	5.8	242	27.7	21.7	25.5	15.0	0.95	0.67	46.2	0.78	5.27	91
Bw	12-31	7.4	0.12	5.3	227	19.8	19.5	24.2	16.0	0.87	0.74	45.4	0.75	7.51	92
Bss$_1$	31-57	7.4	0.14	4.6	202	15.2	17.3	27.4	14.2	0.79	0.43	45.7	0.73	8.45	94
Bss$_2$	57-90	7.6	0.18	3.6	139	12.6	14.4	28.0	14.5	0.82	0.57	48.2	0.77	9.89	91
Bss$_3$	90-158	7.8	0.17	2.5	91	10.4	12.2	24.8	15.5	0.76	0.35	47.7	0.75	10.47	87
Pedon 2 (Rice – chickpea): Very fine, smectitic, isohyperthermic, Typic Haplustert															
Ap	0-18	7.3	0.16	6.3	279	30.5	19.2	24.5	10.5	0.82	0.24	40.2	0.66	5.62	90
Bw	18-40	7.5	0.17	5.9	243	28.6	17.5	22.3	12.6	1.25	0.26	39.3	0.64	6.54	93
Bss$_1$	40-80	7.6	0.14	4.6	221	17.8	14.4	21.8	15.4	2.34	0.35	43.2	0.68	9.28	92
Bss$_2$	80-122	7.8	0.15	3.4	157	14.1	11.9	20.6	14.8	2.87	0.37	42.4	0.64	9.87	91
Bss$_3$	122-154	7.8	0.19	2.3	104	11.4	10.1	19.5	16	3.51	0.39	45.3	0.65	12.42	87
Pedon 3 (Rice – fallow): Fine loamy, smectitic, isohyperthermic, Vertic Haplustept															
Ap	0-10	6.2	0.09	4.5	210	17.4	14.5	7.5	2.4	0.65	0.73	19.2	0.61	1.85	59
Bw$_1$	10-30	6.3	0.08	4.1	187	14.5	12.7	8.4	3.1	0.46	0.62	18.1	0.72	2.47	70
Bw$_2$	30-50	6.3	0.10	3.6	145	12.2	11.9	6.3	3.3	0.77	0.66	17.6	0.54	2.78	63
Bw$_3$	50-88	6.5	0.12	2.7	123	10.4	9.5	8.4	4.7	0.82	0.78	20.1	0.71	3.89	73
Bw$_4$	88-150	6.7	0.11	2.1	87	9.7	8.6	9.7	4.2	0.91	0.91	22.2	0.75	4.41	71

Available N varied from 87 to 279 kg ha^{-1}, which was maximum in surface horizons and decreased regularly with depth. Available P ranged from 9.7 to 30.5 kg ha^{-1}, and decreased gradually with depth. Highest available P was observed in the surface horizon due to high OC content and/or an external supply of P. Available S varied from 8.6 to 21.7 kg ha^{-1}, and decreased progressively with depth. Higher available S in surface soils could be attributed to higher OC content as approximately 95% of the total amount of S in soils is found in the organic matter. Available N, P and S contents were higher in pedon 1 and 2, may be due to prevalance of rice-legume cropping systems involving chickpea and lathyrus, which build-up OC content and stimulate microbial activity in soil. However, as per nutrient index, available N, P and S were in the low, medium and medium category, respectively.

Exchangeable Ca^{2+} was the dominant cation in soils ranging from 7.5 to 28.0 cmol(p$^+$) kg^{-1}, followed by exchangeable Mg^{2+} [2.4 to 16.0 cmol(p$^+$)kg^{-1}], Na^+ [0.46 to 3.51 cmol(p$^+$)kg^{-1}] and K^+ [0.24 to 0.91 cmol(p$^+$)kg^{-1}]. Exchangeable bases did not follow any particular trend in the pedons. From the distribution of Ca^{2+} and Mg^{2+}, it is evident that Ca^{2+} showed the strongest relationship with all the species. Lower amount of exchangeable monovalent cations compared to the divalent ones may be attributed to preferential leaching of the former over the later (Thangasamy *et al.* 2005). The CEC of soils ranged from 17.6 to 48.2 cmol(p$^+$)kg^{-1} and its depth distribution was irregular in all pedons. The CEC of these soils was mainly contributed by the silt and clay fractions rather than OC as evident from significant positive correlation of CEC with silt ($r = 0.908^{**}$) and clay ($r = 0.966^{**}$) (Table 5). A significant positive correlation between CEC and silt fraction was also reported by Karmakar (2014). Results suggested that the silt fraction also carried sufficient negative charge, may be due to weathering and /or finer silt fraction nearer to 0.002 mm size. The CEC: clay ratio of soils ranged from 0.54 to 0.78, and its depth distribution did not follow any particular trend in the pedons. The higher value of CEC: clay indicated mixed mineralogy and dominance of smectitic clay. The $CaCO_3$ content of soils varied from 1.85 to 12.42%, and its depth distribution was also irregular in the pedons. Presence of $CaCO_3$ in the soil horizons might be due to

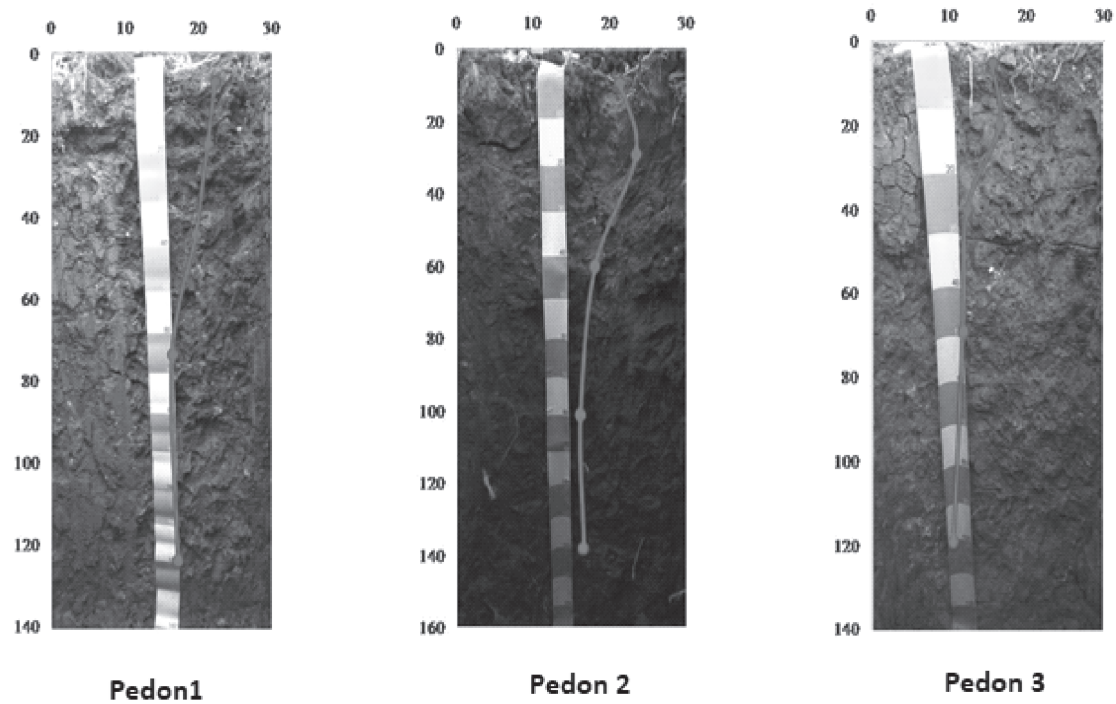

Fig. 3. Depth distribution of soil moisture content (%) in representative pedons

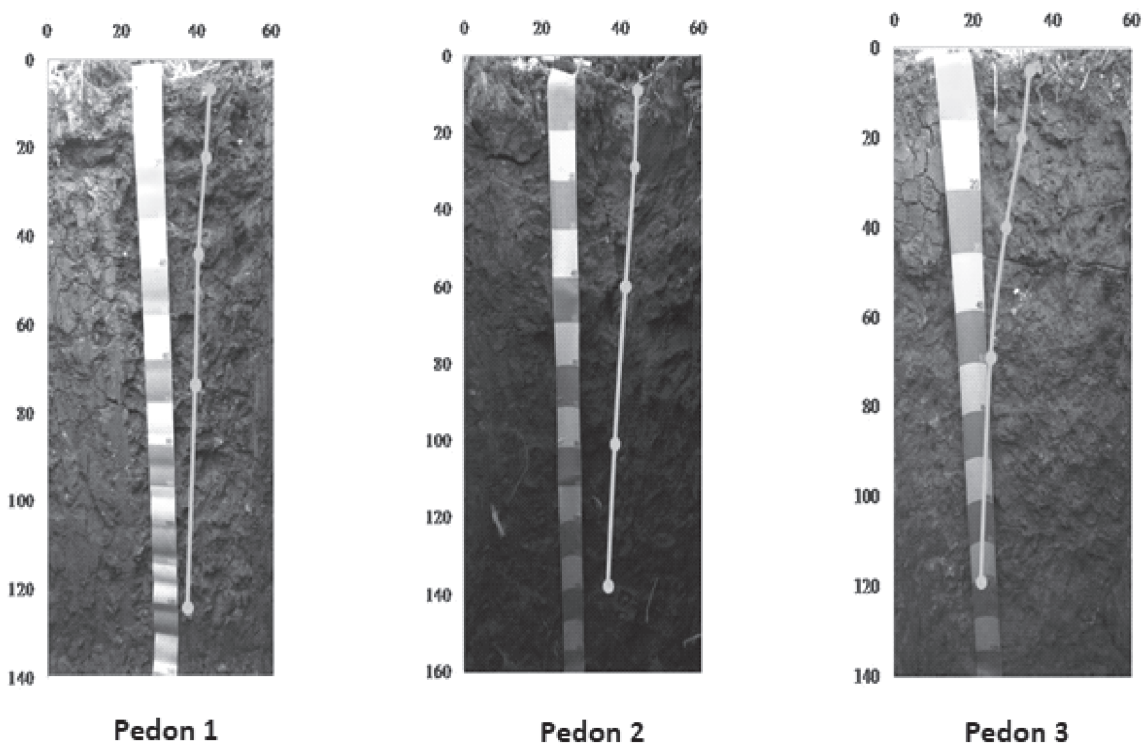

Fig. 4. Depth distribution of water holding capacity (%) in representative pedons

calcification and inheritance from parent material (Khan and Kamalakar 2012). Base saturation of soils varied from 59 to 94% in different pedons, which revealed greater saturation of exchange complexes with basic cations (Pulakeshi *et al.* 2014). The base saturation was positively correlated with pH ($r = 0.897^{**}$), EC ($r = 0.773^{**}$) and CEC ($r = 0.932^{**}$) (Table 5).

Table 4. Soil profile classification in the pedons of Balod district, Chhattisgarh

Pedons	Classification	Soil orders
Pedon 1 (Rice – lathyrus)	Very fine, smectitic, isohyperthermic, Typic Haplustert	Vertisol
Pedon 2 (Rice – chickpea)	Very fine, smectitic, isohyperthermic, Typic Haplustert	Vertisol
Pedon 3 (Rice – fallow)	Fine loamy, smectitic, isohyperthermic, Vertic Haplustept	Inceptisol

Table 5. Pearson's correlation coefficients among soil properties

Parameters	Silt	Clay	BD	PD	Porosity	SMC	WHC	pH	EC	OC	CEC	Base Saturation
Silt	1											
Clay	0.854**	1										
BD	-0.605*	-0.582**	1									
PD	-0.608*	-0.413	0.924**	1								
Porosity	0.580*	0.627*	-0.988**	-0.854**	1							
SMC	0.791**	0.660**	-0.877**	-0.886**	0.834**	1						
WHC	0.837**	0.818**	-0.905**	-0.830**	0.895**	0.930**	1					
pH	0.805**	0.954**	-0.370	-0.208	0.422	0.502	0.661**	1				
EC	0.673**	0.857**	-0.314	-0.192	0.354	0.443	0.569*	0.873**	1			
OC	0.507	0.260	-0.862**	-0.978**	0.776**	0.823**	0.724**	0.044	0.021	1		
CEC	0.908**	0.966**	-0.506	-0.391	0.531**	0.666**	0.798**	0.930**	0.828**	0.249	1	
Base saturation	0.929**	0.910**	-0.531*	-0.479	0.530*	0.717**	0.784**	0.897**	0.773**	0.361	0.932**	1

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

Based on morphological and physicochemical characteristics, the soils were classified into Vertisol and Inceptisol (Table 4). The presence of more than 25 cm thick layer associated with slickensides close enough to intersect in sub-horizons (Bss diagnostic horizons), more than 30% clay in the fine earth fraction and 1-3 cm wide cracks up to 1 m qualified pedons 1 (rice–lathyrus) and 2 (rice–chickpea) for Vertisol (Table 4). At the same time, pedon 3 (rice–fallow) showed no argillic or kandic horizons whereas changes in soil colour, structure and irregular distribution of soil particle size were observed, exhibiting cambic sub-surface diagnostic horizons, thus classified as Inceptisols (Table 4). The soils had ustic soil moisture regime as these were wet for more than 180 consecutive days in a year. So pedons 1, 2 and 3 were classified as Ustert and Ustept at sub-order level. Due to absence of salic or gypsic or calcic epipedon or duripan in all pedons, soils were classified as Haplustert (P1 and P2) and Haplustept (P3) at great group level. Further, pedons were classified as Typic at sub-group level since these represented the central concept of great group. Hence, at sub-group level, pedons 1 and 2 were classified as Typic Haplustert and pedon 3 as Typic Haplustept. Similar kinds of soils in Chhattisgarh were also reported by Tamgadge *et al.* (2002). The soils of study area were placed under isohyperthermic temperature regime because the mean annual temperature is more than 22 °C and the difference between mean summer and winter temperature is less than 6 °C (Tamgadge *et al.* 2002). Pedon 1 with CEC: clay ratio more than 0.7 (0.75) was classified as smectitic mineralogy. The CEC: clay ratio for pedons 2 and 3 was 0.65 and 0.69, respectively. Hence, the mineralogy class for pedons 2 and 3 was also smectitic as the ratio came in the range of 0.5-0.7. Pedons 1 and 2 containing more than 60% clay (weighted average) were classified as very fine particle size class, whereas pedon 3 was classified as fine loamy. At family level, pedon 1 and 2 were classified as very fine, smectitic, isohyperthermic, Typic Haplustert, and pedon 3 as fine loamy, smectitic, isohyperthermic, Vertic Haplustept.

The soils developed on uniform parent material and under same overhead climatic conditions showed considerable variation in morphological and physicochemical properties due to variation in land use, particularly cropping systems and management practices. Remarkable changes in soil properties, both in terms of morphological and physicochemical parameters, were observed in intensively-cultivated soils under rice-based cropping systems. Available N, P and S were higher in rice–legume systems compared with rice-fallow. However, as per nutrient index, the status of available N was low whereas that of available P and S was medium. Presence of clay-skins, reduction in sand content with a corresponding increase in clay, WHC and CEC were observed in rice–legume systems. The study showed that the soils under rice–legume systems were qualified for Typic Haplustert and those under rice–fallow system qualified for Vertic Haplustept.

References

Jackson, M.L. (1973) *Soil Chemical Analysis.* Prentice Hall of India (Pvt.) Ltd., New Delhi.

Jena, R.K., Duraisami, V.P., Sivasamy, R., Shanmugasundaram, R., Krishnan, R., Padua, S., Bandyopadhyay, S., Ramachandran, S., Ray, P., Deb Roy, P., Singh, S.K. and Ray, S.K. (2016) Characterization and classification of soils of Jirang block in Meghalaya plateau. *Agropedology* **26**, 47-57.

Karmakar, R.M. (2014) Soil developed in different land forms in north bank plain zone of Assam. II. Sand mineralogy. *Agropedology* **24**, 52-63.

Khan, M.A.A. and Kamalakar, J. (2012) Physical, physicochemical and chemical properties of soils of newly established agro-biodiversity park of Acharya NG Ranga Agricultural University, Hyderabad, Andhra Pradesh. *International Journal of Farm Sciences* **2**, 102-116.

Leelavathi, G. P., Naidu, M.V.S., Ramavatharam, N. and Karunsagar, G. (2009) Genetics, classification and evaluation of soils for sustainable land use planning in Yepedu Mandal of Chittoor district, Andhra Pradesh. *Journal of the Indian Society of Soil Science* **57**, 109-120.

Priya, P.G., Ray, S.K., Choudhary, P.L., Bhattacharya, T., Chandran, P., Kharche, V.K., Tiwary, P. and Biswas, A.K. (2017) Characterization of some Vertisols of different Agro-ecological regions of India. *Agropedology* **27**, 84-92.

Pulakeshi, H.B.P., Patil, P.L. and Dasog, G.S. (2014) Characterization and classification of soil resources derived from chlorite schist in northern transition zone of Karnataka. *Karnataka Journal of Agricultural Sciences* **27**, 14-21.

Soil Survey Division Staff (2005) *Soil Survey Manual* (Indian print), USDA Hand Book 18 US Government Printing office, Washington DC.

Soil Survey Staff. (2014) *Keys to Soil Taxonomy*, Twelfth Edition. USDA: Natural Resources Conservation Service, Washington, DC.

Tamgadge, D.B., Gahbhiya, K.S. and Pandey, G.P. (2002) *Soil Series of Chhattisgarh*, Technical Bulletin. NBSS Publ. No. 85. National bureau of Soil Survey and Land Use Planning, Nagpur, 183p.

Thangasamy, A., Naidu, M.V.S., Ramavatharam, N. and Raghava Reddy, C., (2005) Characterization, classification and evaluation of soil resources in Sivagiri micro-watershed of Chittoor district in Andhra Pradesh for sustainable land use planning. *Journal of the Indian Society of Soil Science* **53**, 11-21.

Received 23 May 2018; Accepted 24 May 2019