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Characterization and Taxonomic Classification of Soils under a Toposequence Located in Eastern India

Prava Kiran Dash, Antaryami Mishra, Subhashis Saren

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ABSTRACT

Toposequence or catena is a term used to describe variations in soil physico-chemical properties observed in a particular geographical area caused only due to variations in topographic positions, having all other factors of soil formation as common. Taking this concept into cognizance, three representative soil profiles were exposed in three different topographic positions namely upland, medium land and low land in the selected study area of Eastern India. The exposed pedons were evaluated with a broad objective to identify the potential soil related crop production constraints in different land types. Results revealed that soils developed in different topographic positions differed greatly with respect to their physico-chemical properties and degree of soil profile development. Upland soils were detected with A-C soil profile (*Typic ustorthents*), which lacked B horizon; that of medium and low land soils with well-formed soil profiles being taxonomically classified as A-Bt-BC-C (*Udichaplustalfs*) and A-B_t-C (*Aeric ochraqualfs*) respectively at subgroup level. Upland soils were found to be the sites of soil erosion with less clay fraction, low organic carbon status, low base (cation) saturation and more acidic soils; that of low land soils were mostly characterized by impeded drainage condition augmented with high water table. Proper soil management practices, crop diversification and proper land use planning can decline the risks of crop failures caused by different soil limitations in different topographic positions.

Keywords Catena, Crop production constraints, Land use planning, Soil profile.

Prava Kiran Dash*
PhD Research Scholar
e-mail : dashpraval11@gmail.com

Dr. Antaryami Mishra
Professor and OIC, AICRP on STCR
e-mail : antar199@yahoo.co.in

Dr. Subhashis Saren
Assistant Professor,
Department of Soil Science and Agricultural Chemistry,
Odisha University of Agriculture and Technology,
Bhubaneswar, Odisha 751003, India
e-mail : saren.bckv@gmail.com
*Corresponding author

INTRODUCTION

Soil is the resultant product of 5 interacting soil forming factors namely parent material, biosphere, climate, topography and time (Milne 1935). Toposequence or catena is a term used to describe variations observed in a particular geographical area due to variations in topography (relief), remaining all other factors of soil formation same. At present, there is more demand for agricultural produce to meet the widening requirements of burgeoning population. This is particularly true for countries like India where population growth rate is high. Standard soil survey helps in gathering information about soils in a systematic matter regarding their genesis, extent and characteristics to assess their potentials and limitations for specific purpose (Vedadri and Naidu 2018). To achieve soil resource management in toposequences, knowledge on physical and chemical characteristics and classification is an essential requirement (Rehman et al. 2017).

RRTTS and KVK farm, Dhenkanal (having 23.6 ha of agricultural land) located in the Mid-Central Table Land Agro Climatic Zone of Odisha has great significance with respect to advanced agricultural research trials in Eastern Indian soils. Since, the prevailing land types of this farm are widely variable, specific land management practices must be suggested for every land type. But, any systematic soil survey of this area had not been done yet and very few soil survey information about the arable soils of this area was available. Therefore,an attempt has been made in the present investigation to characterize and classify the study area, which can be further extended to other Eastern Indian soils.

MATERIALS AND METHODS

Experimental site

Geographically, the study area lies in 20^{o}37' N latitude and 85^{o}36' E longitude with a mean elevation of 308 feet above mean sea level (MSL). The study area is situated in the feet of Charakhola hills which comes under Dhenkanal forest range. Based on slope and elevation, the study area has been divided into three major physiographic units such as gently sloping upland (332 feet above MSL, slope of 3-5%), very gently sloping medium land (308 feet above MSL, slope of 1-3%) and nearly levelled low land (295 feet above MSL, slope of 0-1%) . The study area is characterized by hot, dry and sub-humid climate with dry summer and mild winter. Mean annual rainfall is 1432.3 mm out of which 75.5% is received during monsoon (June to September). The mean maximum temperature and mean minimum temperature of the region are 33.1^{0}C and 21.7^{o}C, respectively as recorded at the local observatory. An agro forestry model based orchard is designed in the upland of the study area. The medium and low lands are mostly used for research trials and foundation seed production. Some portions of the low land are not under cultivation due to severe water logging condition prevailing in that area.

Soil sampling and analysis

The land form of the study area was determined through traversing the area and elevations above MSL of different points were recorded using GPS instrument (Garmin make; model : 76MAPCSx). After a general traversing of the study area three representative soil profiles located in three different topographic positions were selected and exposed. The soil samples collected from different horizons were air dried and ground with wooden hammer. Ambient soil was passed through 2 mm sieve and then subjected to various physical and chemical analyses. Soils were analyzed for textural class by Bouyoucos Hydrometer method (Bouyoucos 1962), pH (1 : 2) (Jackson 1973), EC (1 : 2) (Jackson 1973), Organic Carbon (Walkley and Black 1934), Bulk density (Klute 1986), Particle density (Chopra and Kanwar 1986), Water Holding Capacity (Piper 1950), Cation Exchange Capacity (Chapman 1965), Exchangeable cations (Page et al. 1982) and Exchangeable acidity (Thomas 1996). The soils were classified taxonomically up to family level following Keys to Soil Taxonomy (Soil Survey Staff 2014). Statistical correlation analyses were done following Statistical procedure for agricultural research (Gomez and Gomez 1983).

RESULTS AND DISCUSSION

Physical characteristics

Particle size distribution

In pedon 1, the percentage of sand , silt and clay content ranged between 78.0–83.6, 10.8 to 11.8 and

Table 1a. Physical characteristics of pedon 1 (Upland).

Horizon	Depth (cm)	Sand	Silt (%)	Clay	Bulk density	Particle density (Mg m^{-3})	Porosity	WHC (%)
Al	0-18	78.0	10.8	11.2	1.58	2.40	34.1	34,8
Cl	18-66	79.0	11.4	9.6	1.62	2.50	35.2	34.1
C2	67-91	83.6	11.8	4.6	1.88	2.60	27.7	32.9
C3	91-130		Partially weathered parent material					

4.6 to 11.2 percentage respectively (Table 1 a) ; that in pedon 2, ranged between 58.4 to 66.4, 8.6 to 23.4 and 14.0 to 31.0% respectively (Table 2a); that in pedon 3, ranged between 52.2 to 66.4, 6.6 to 19.0 and 14.6 to 38.2 respectively (Table 3a). In case of pedon%1, a gradual increase in sand content was observed from surface to the depth of 91 cm. Large coarse fragments were found throughout the soil profile which might be attributed to the process of soil erosion with runoff water from the sloped foot hills towards the level topography and also due to absence of eluviation process in the soils of upland. On the other hand clay content gradually decreased with increasing depth up to 91cm depth (Fig.1a). In case of pedon 2, a gradual decrease in sand content was observed from surface to the depth of 150 cm. On the other hand, clay content gradually increased with increasing depth up to 81 cm depth and then decreased up to a depth of 150 cm (Fig. 1a). In case of pedon 3, a gradual decrease in sand content was observed from surface to the depth of 129 cm. On the other hand, clay content gradually increased up to a depth of 129 cm and then decreased up to a depth of 160 cm (Fig.1a). Increase in percentage clay in pedon 2 and 3 might be attributed to the process of eluviation and illuviation in medium land and low land Mishra (1981).

Table 2a. Physical characteristics of Pedon 2 (Medium land).

Horizon	Depth (cm)	Sand	Silt (%)	Clay	Bulk density	Particle density (Mg m^{-3})	Porosity	WHC (%)
AP	0-15	66.4	19.6	14.0	1.52	2.35	35.3	35.2
Bt 1	15-27	64.4	18.2	17.4	1.58	2.46	35.7	37.0
Bt 21	27-45	62.4	16.6	21.0	1.59	2.48	35.8	38.4
Bt 22	45-57	61.4	13.2	25.4	1.63	2.54	35.8	38.8
Bt 23	57-81	60.4	8.6	31.0	1.64	2.58	36.4	39.5
BC	81-103	58.8	23.4	17.8	1.88	2.61	27.9	36.8
C	103-150	58.4	17.2	14.0	1.90	2.62	27.4	32.9

Table 3a. Physical characteristics of pedon 3 (Low land).

Horizon	Depth (cm)	Sand	Silt (%)	Clay	Bulk density	Particle density (Mg m^{-3})	Porosity	Water Holding Capacity (%)
Ap	0-9	66.4	19.0	14.6	1.30	2.32	43.9	36.1
A2	9-21	64.4	18.6	17.0	1.32	2.38	44.5	37.8
Bt1	21-54	62.2	10.6	27.2	1.34	2.42	44.6	39.2
Bt2	54-93	58.8	6.6	34.6	1.38	2.50	44.8	40.2
Bt3	93-129	52.2	9.6	38.2	1.40	2.56	45.3	41.5
C	129-160	60.8	17.0	22.2	1.50	2.65	43.3	37.9

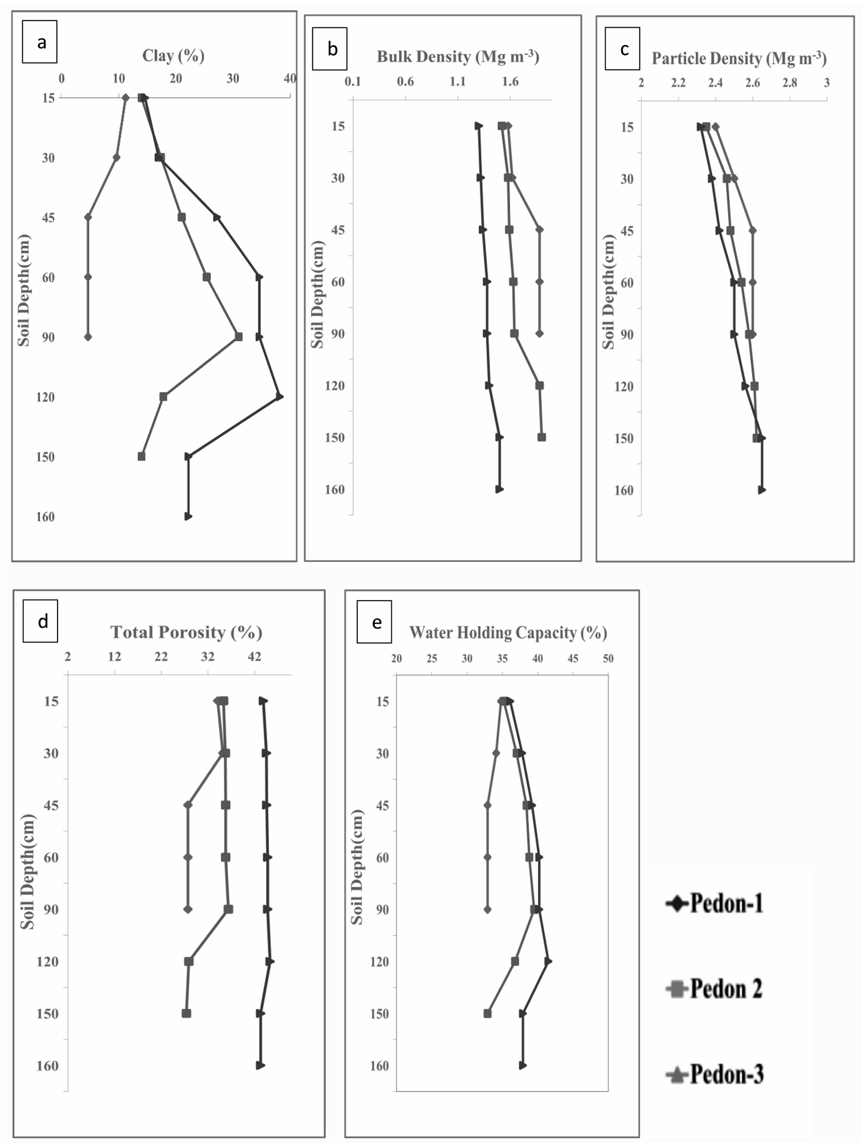

Fig. 1a—1e. Representing vertical distribution of percentage clay, bulk density, particle density, total porosity and Water Holding Capacity respectively in the representative pedons of the study area.

Bulk density

The bulk density values of pedon 1 varied between 1.58 to 1.88 Mg m^{-3} (Table 1a); that of pedon 2 were in the range of 1.52 to 1.90 Mg m^{-3} (Table 2 a); that of pedon 3 were in the range of 1.30 to 1.50 Mg m^{-3} (Table 3a). In all the three pedons maximum bulk density values were found to be in the lower most horizons which could be attributed to different reasons such as higher sand content, lower clay content, low organic carbon content and increased effect of compaction in the lowest horizons (Fig. 1 b); that of minimum bulk density values were found to be in the surface horizons which could be attributed to different reasons such as high amount of clay and organic carbon in the surface horizons (Mishra 2005).

Particle density

The particle density values of pedon 1 varied in between 2.40 to 2.60 Mg m^{-3} (Table 1 a); that of pedon 2 were in the range of 2.35 to 2.62 Mg m^{-3} (Table 2a); that of pedon 3 were in the range of 2.32 to 2.65 Mg m^{-3} (Table 3a). In all the three pedons particle density values were found to be increasing from upper horizons towards lower horizons (Fig. 1c) which might be attributed to lower organic carbon in the lower horizons than that of upper horizons of the soil profiles (Sahoo 1993).

Total porosity

Total porosity values of pedon 1 varied between 27.7 to 35.2 percentage (Table 1 a); that of pedon 2 were in the range of 27.4 to 36.4 percentage (Table 2 a); that of pedon 3 ranged between 43.3 and 45.3 percentage (Table 3 a, Fig. 1d). The total porosity was found to be positively correlated with percentage clay (r=0.60*).

Maximum water holding capacity

The maximum water holding capacity (WHC) values of pedon 1 varied from 32.9 to 34.8 percentage (Table 1 a); that of pedon 2 was in the range of 32.9 to 39.5 percentage (Table 2a); that of pedon 3 was in the range of 36.1 to 41.5 percentage (Table 3a). WHC was found to be decreasing with depth in case of pedon 1; that in case of pedon 2 and 3 found to be increasing up to last part of B horizon followed by decreasing in the C horizon (Fig.1 e) which might be attributed to the percentage of clay in different pedons (r=0.93**).

Chemical characteristics of pedons

Soil reaction

The surface soil of pedon 1 was found to be strongly acidic with a pH value of 4.60 (Table 1b) and the values increased with depth up to a pH value of 5.95 at the lower horizon. The surface soil of pedon 2 was found to be moderately acidic with a pH value of 5.27 (Table 2 b) and the values increased with depth up to a pH value of 6.15 at the lower most horizon . The surface soil of pedon 3 was found to be moderately acidic with a pH value of 5.44 (Table 3 b) and the values increased with depth up to a pH value of 6.63 at the lower most horizon. In all the three pedons the soil pH values were found to be increasing from upper horizons towards lower horizons (Fig.2a) which could be attributed to leaching of basic cations from upper horizons towards the lower horizons mostly during intensive rainfall (Kumar et al. 2012, Rajeshwar and Ramulu 2016).

Electrical conductivity

The electrical conductivity value of the soils has been presented in Tables 1b,2 b and 3 b, indicate that the EC of all the pedons remained below 1 dSm^{-1} and hence safe for all types of crop production. Such low electrical conductivity could be attributed to leaching of soluble salts during intensive rainfall as prevalent in the study area.

Organic carbon

The organic carbon content of the surface horizons of pedon 1, 2 and 3 were found to be 5.1, 9.06,12.5

Table 1b. Chemical characteristics of pedon 1 (Upland).

Hori-zon	Depth (cm)	pH (1 : 2)	EC (1: 2) dSm^{-1}	Organic carbon (g kg^{-1})	Exchangeable cations [cmol(p^+) kg^{-1}] Ca	Mg	Na	K	Sum	Exchangeable acidity [cmol (p^+) kg^{-1}] H^+	Al^{3+}	Sum	Cation exchange capacity [cmol (p^+)kg^{-1}]	Base saturation (%)	ESP
Al	0-18	4.60	0.028	5.1	2.8	0.8	0.3	0.1	4	0.4	1.6	2.0	6.2	64.5	4.8
Cl	18-67	5.50	0.032	3.9	3.0	1.2	0.4	0.2	4.8	0.4	0.6	1.0	6.0	80.0	6.7
C2	67-91	5.95	0.035	1.9	3.2	1.0	0.4	0.2	4.8	0.4	0.4	0.8	5.8	82.7	6.9
C3	91-130	Partially weathered parent material													

Table 2b. Chemical characteristics of pedon 2 (Medium land).

Horizon	Depth (cm)	pH (1:2)	EC (1:2) dSm^{-1}	Organic carbon (g kg^{-1})	Exchangeable cations [cmol (p^+) kg^{-1}] Ca	Mg	Na	K	Sum	Exchange-able aci-dity(H^+) [cmol(p^+)kg^{-1}]	CEC	Base satur-ation (%)	ESP
Ap	0-15	5.27	0.046	9.06	3.4	1.2	0.4	0.4	5.4	1.8	7.2	75.0	5.5
Bt 1	15-27	5.50	0.065	5.26	3.6	1.4	0.6	0.4	6.0	1.6	7.8	76.9	7.7
Bt21	27-45	5.59	0.069	4.71	3.8	1.6	0.6	0.4	6.4	1.2	7.8	82.0	7.7
Bt22	45-57	5.80	0.075	4.71	4.0	1.8	0.8	0.6	7.2	1.1	8.4	85.7	9.6
Bt23	57-81	5.97	0.079	2.35	4.2	1.8	0.8	0.6	7.4	1.0	8.6	86.0	9.3
BC	81-103	6.12	0.080	2.10	3.6	1.4	0.7	0.6	6.3	0.8	7.2	87.5	9.8
C	103-150	6.15	0.089	0.60	3.2	1.2	0.6	0.6	5.6	0.6	6.4	87.5	9.4

Table 3b. Chemical characteristics of pedon 3 (Low land).

Horizon	Depth (cm)	pH (1:2)	EC (1 : 2) dSm^{-1}	Organic carbon (g kg^{-1})	Exchangeable cations [cmol (p^+) kg^{-1}] Ca	Mg	Na	K	Sum	Exchangeable acidity (H^+) [cmol(p^+)kg^{-1}]	CEC	Base satur-ation (%)	ESP
Ap	0-9	5.44	0.060	12.50	3.6	1.6	0.4	0.2	5.8	1.4	7.4	78.3	5.4
A2	9-21	5.64	0.064	12.50	3.8	1.6	0.6	0.2	6.2	1.4	7.8	79.4	7.7
Bt1	21-54	6.14	0.069	6.34	4.0	1.8	0.6	0.4	6.8	1.2	8.2	82.9	7.3
Bt2	54-93	6.39	0.074	2.35	4.2	2.0	0.8	0.4	7.4	1.2	8.8	84.0	9.0
Bt3	93-129	6.62	0.084	1.08	4.4	2.2	0.8	0.2	7.6	1.0	8.6	88.3	9.3
C	129-160	6.63	0.100	0.95	4.0	1.6	0.8	0.2	6.6	0.6	7.4	89.1	10.8

g kg^{-1} respectively (Tables 1 b, 2 b, 3 b). A regular trend of decrease in organic carbon with depth was observed in all the three soil profiles. A regular trend of decrease in organic carbon with depth was observed in all the three soil profiles (Fig. 2 b). Maximum organic carbon content in the surface horizons of all the three pedons could be attributed to fresh accumulation and decomposition of crop residues every year in the surface horizons (Dorji et al. 2014, Kumar et al.2012 and Khanday et al. 2018).

Exchangeable bases

Exchangeable bases include exchangeable calcium, magnesium, sodium and potassium. The vertical distributions of these cations in different pedons has been presented in Tables 1 b, 2 b, 3 b. Concentration of exchangeable bases was found to be in order of Ca^{+2}>Mg^{+2}>Na^+>K^+ (Giri et al. 2017). In pedon 1 both calcium and magnesium increased regularly with depth. In pedon 2 both calcium and magnesium increased up to a depth of 81 cm and then gradually decreased up to150 cm; that in case of pedon 3 increased up to the depth of 129 cm and then decreased up to 160 cm (Figs. 2c, 2d). Exchangeable sodium in surface horizons in pedon 1, 2 and 3 were 0.3, 0.4, 0.4 cmol (p^+) kg^{-1} respectively. Exchangeable potassium in surface horizons in pedon 1, 2 and 3 were 0.1, 0.4, 0.2 cmol (p^+) kg^{-1} respectively.

Exchangeable acidity

Presence of exchangeable acidity was observed in all the three pedons. In case of pedon 1, both exchangeable H^+ and Al^{3+} were found to contribute to exchangeable acidity; whereas in case of pedon 2 and 3 only exchangeable H^+ was found. In all the three pedons the exchangeable acidity was found to be decreasing with soil depth (Tables 1 b, 2b, 3 b) which could be due to increase in other exchangeable cations saturating the exchange sites down the depth (Mishra 2005, Pattanayak 2016).

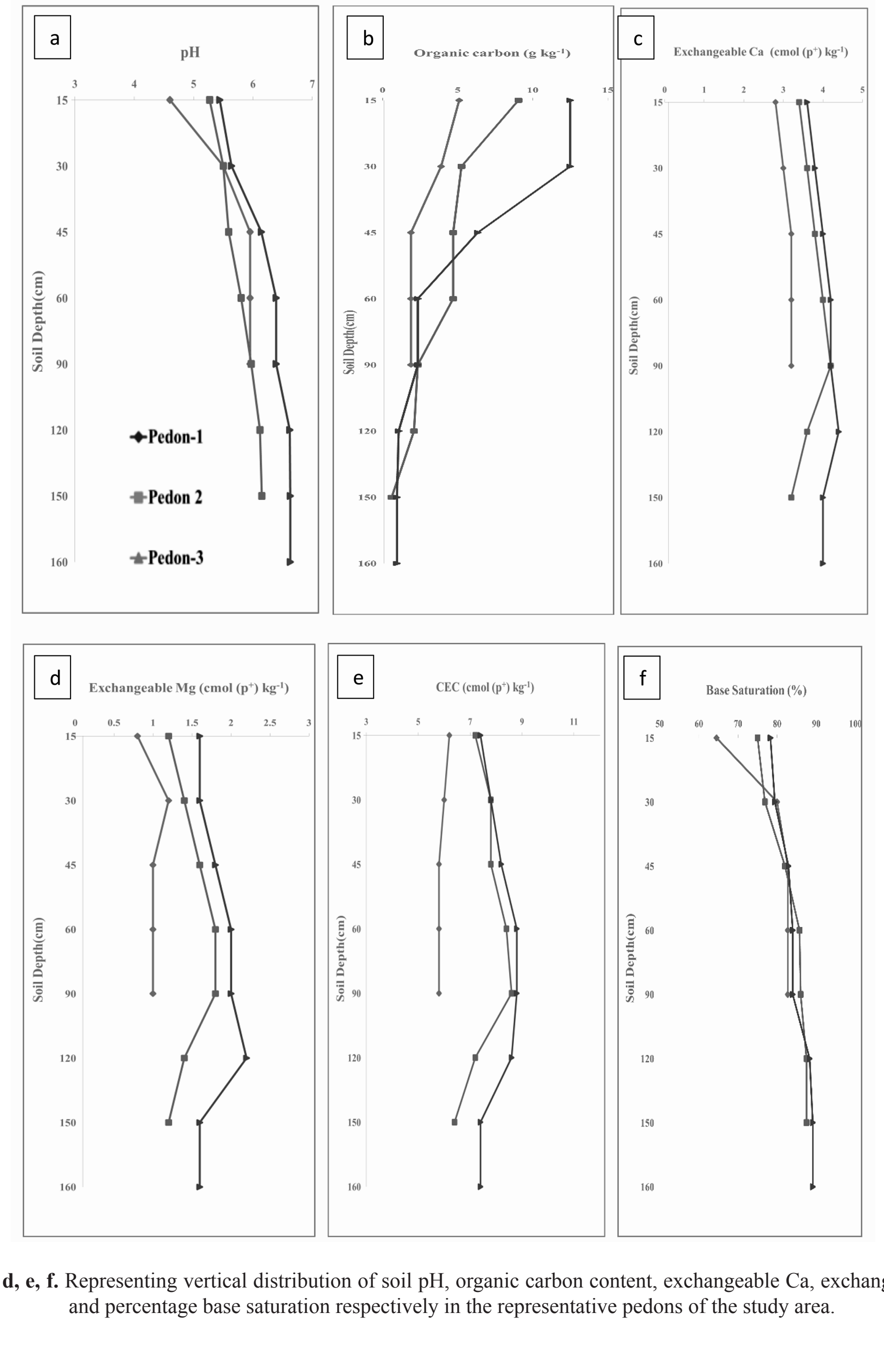

Fig. 2 a, b, c, d, e, f. Representing vertical distribution of soil pH, organic carbon content, exchangeable Ca, exchangeable Mg, CEC and percentage base saturation respectively in the representative pedons of the study area.

Cation exchange capacity

In case of pedon 1, CEC decreased regularly from 6.2 in surface horizon to 5.8 cmol (p^+) kg^{-1} in the lower most horizon (Table1 b); that in case of pedon 2, CEC in the surface horizon of was found to be 7.2 cmol (p^+) kg^{-1} which gradually increased up to a depth of 81 cm and again decreased (Fig. 2 e) up to a depth of 150 cm; that in case of pedon 3, CEC in the surface horizon of was found to be 7.4 cmol (p^+) kg^{-1} which increased up to 93 cm and again decreased up to 160 cm. In case of pedon 1, CEC was found to be positively correlated (r=0.95) with percentage clay; that in case of pedon 2, found to be positively correlated (r=0.89**) with percentage clay; that in case of pedon 3, CEC was found to be positively correlated (r=0.89*) with percentage clay. Significant positive correlation between percentage clay and CEC has also been observed by Mishra (2008).

Base saturation

The base saturation percentage of the surface soils of pedon 1, 2 and 3 were found to be 64.5, 75.0, 78.3 percentage respectively (Tables 1b, 2 b, 3 b). In case of pedon 1, base saturation was found to be positively correlated (r=0.98) with soil pH; that in case of pedon 2 found to be positively correlated (r=0.95*) with soil pH; that in case of pedon 3, was found to be positively correlated (r=0.96**) with soil pH. Significant positive correlation between soil pH and base saturation has also been observed by Mishra (2008).

Exchangeable sodium percentage

In pedon 1, 2 and 3, the range of ESP was found to be varying in between 4.8 to 6.9,5.5 to 9.8, 5.4 to 10.8 percentage respectively. There was a gradual increase in ESP throughout the profile found in all the pedons which might be attributed to leaching of sodium ions from upper horizons towards lower horizons mostly during intensive rainfall (Mishra 2008).

Taxonomic classification

Pedon 1 did not have any diagnostic horizon except orchicepipedon that could be identified ; A-C profiles with no distinct horizonation. Hence, this pedon was classified under soil order of *Entisols.* It had an organic carbon content that decreased regularly with increasing depth and reached up to a level of less than 2.5 g kg^{-1} at the depth of 91 cm; was rich in coarse fragments within a depth of 1 m and were never saturated with water. Soils of this pedon are therefore classified under sub order *Orthents.* The pedon had an *ustic* soil moisture regime and conductivity of less than 2 mmhos cm^{-1} at 25°C in all sub horizons and are therefore classified under great group of *Ustorthents.* Besides these properties stated above these soils did not have a lithic contact within 50 cm of the surface; had much less than 50% worm holes and filled animal burrows within a depth of 1 m; did not have cracks of 1 cm or more wide at any time of the year. Hence, the soils of pedon 1 are classified under sub group of *Typic ustorthents.*

As the mean annual soil temperature of the study area is 27.1°C (>22°C), mean summer and mean winter soil temperature of the study area are 39.4°C and 13.5°C respectively(>5°C difference), the soil temperature regime of the area was found to be *hyperthermic.* Hence, pedon 1 is classified under soil family of Loamy-skeletal, mixed, hyperthermic.

In order to have an argillic horizon, a soil illuvial layer must have at least 1.2 times more clay if some horizon above has 15 to 40% clay; 3% more clay content if the eluvial layer has less than 15% clay; 8% more clay if, the eluvial layer has more than 40% clay (Soil Survey Staff 1978). In case of pedon 2, the eluvial Ap horizon was found to be15 cm thick and had 14.0% clay and therefore, as per the above criteria its underlying illuviated B horizon should have at least 17.0% clay. As may be observed from Table 2a, the clay content of Btl sub horizon is 17.4% . In pedon 3, the eluvial A2 horizon is12 cm thick and has 17.0% clay and therefore the underlying illuvial Btl should contain at least 20.4% clay than that of Ap horizon . Clay content of Btl as may be seen from Table 2a and 3 a is 21.0 and 27.2% in pedon 2 and 3 respectively. Hence, both pedon 2 and 3 were found to be having argillic horizon.

Pedon 2 had an orhricepipedon ; had an argillic horizon; had a base saturation percentage of more than 35 percentage at a depth of 1.25 m; did not have cracks during any period of the year that of 1 cm or more wide at a depth of 50 cm from soil surface; hence, classified under soil order of *Alfisols*. It had an *ustic* soil moisture regime; hence, classified under sub order of *Ustalfs*. It had a clay distribution such that the percentage clay after reaching its maximum at a depth of 81 cm, decreased up to a depth of 160 cm from the soil surface; hence classified under great group of *Haplustalfs*. It had a texture finer than loamy fine sand in some or all parts of sub horizon within 50 cm of the soil surface; the soils were found to be moist in most years in some or all parts of the moisture control section for more than 90 consecutive days during the rainy season; had mottles only in the lower horizons; did not have a lithic or paralithic contact within 50 cm of the soil surface; hence classified under sub group of *Udic haplustalfs*. It was classified under soil family of Fine-Loamy, mixed, hyperthermic.

Due to similar reasons as stated above for pedon 2, pedon 3 was also classified under soil order of *Alfisols.* It had an aquic soil moisture regime; hence classified under sub order of *Aqualfs*. It had a chroma of less than 2 immediately below the Ap horizon; had mottles throughout the profile; hence classified under great group of *Ochraqualfs.* It had a color value of 4 or more, had texture finer than loamy fine sand within 50 cm of the soil surface; hence classified under sub group of *Aeric Ochraqualfs.* It was classified under soil family of Fine-Loamy, mixed, hyperthermic.

CONCLUSION

Clay percentage in medium land and low land are higher than that of upland. Electrical conductivity for all the surface soils are less than 1 dSm^{-1}; and hence, safe for all type of crop production. Organic carbon status for the surface soil is found to range between medium to high in status; soil pH is found to be acidic in the entire study area. The texture is found to become finer and heavier down the slope both in surface and sub soil. Bulk densities and particle densities of the surface soils of the pedons were found to be decreasing gradually with slope. Total porosity percentage and Water Holding Capacity percentage was found to be increasing towards the lower topographic positions. Soil reaction (pH) (1: 2), Electrical conductivity (1 : 2), Cation Exchange Capacity (CEC) and Exchangeable Sodium Percentage (ESP) content gradually increased both in horizontal and vertical directions with decreasing elevation within the toposequence of the study area. Variation in soil order within the study area is also found. Pedon 1 is classified under order *Entisols;* while that of pedon 2 and 3 to be under soil order of *Alfisols.*

Upland soils were found to be the sites of soil erosion with less moisture and more coarse fragments and low fertility status. So, these land forms should be used for growing plantation crops, tree crops, orchards, agroforestry, agri-horti-silviculture; that of medium land can be used for growing oilseeds, pulses, legumes and field crops; that of low land which are mostly characterized by impeded drainage and high water table can be used for low land paddy cultivation and pisciculture. The main conservation measures for upland are planting soil erosion resisting crops like *Vetiver* and Sisal (*Agave sisalana*) on contours and existing earthen bunds and to do silvi-horticultural plantations; that of medium land are to adopt contour cultivation; that of the low land area are to prepare water harvesting tanks in between medium land and low land to collect the runoff water during rainy season and which is to be utilized for the crops at the time of need. Hence, by taking suitable crops for different land types along with application of soil fertility status based fertilizers and manures along with ameliorating materials such as lime will help in optimizing crop production along with sustaining soil health of the study area.

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