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Morphological Characterization of Soil Profiles in a Toposequence Located in the North-Eastern Coastal Plains Agroclimatic Zone of Odisha

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ABSTRACT

This study evaluates distinguishing morphological characteristics of a natural toposequence (catena) located in the North-Eastern Coastal plains agroclimatic zone of Odisha. Studying three representative soil profiles in three different topographic positions viz., foothill land, medium land, and stream terrace land of the toposequence revealed that soils of medium and stream terrace land were well-formed with A-B-C horizons, whereas the soil profile of foothill land lacked the B horizon with an A-C profile. Soil development in medium and stream terrace land was more advanced owing to the stable topography and better soil moisture conditions, whereas soil development was poorer in the foothill land owing to its skeletal nature, prevailing soil erosion conditions, and poor soil moisture conditions. The soil color of the study area was influenced by the nature of the parent material and drainage conditions. The clay content gradually increased, grade of soil structure gradually improved, consistency became firmer, stickiness increased, plasticity increased, and the gravel content gradually decreased from the foothill land to the stream terrace land. While all soils except that of the foothill land possessed ferruginous mottles and concretions at varying soil depths, calcium concretions were observed only in the stream terrace land. The abundance of roots and pores was higher in surface soils as compared to the soils at greater depths. While soil erosion, poor soil moisture status, and weak structural aggregation were the major crop production constraints of the foothill land, poor drainage and water logging were observed to be the major constraints of the stream terrace land. Evaluating the major morphological characteristics of the soil profiles in the toposequence paved a path for determining suitable land use, crops, and soil conservation measures specific to the land types studied.

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INTRODUCTION

Soils vary from one place to another and from one horizon of a soil profile to another. Systematic description of soil characteristics holds great relevance in terms of understanding factors and processes of soil formation and grouping similar soils for mapping their extents (Dash *et al*. 2019a, Kishore *et al*. 2020). Characterization of soil profiles usually includes morphological, physico-chemical, and mineralogical characterization, out of which morphological characterization is the first and foremost characterization, most part of which is carried out in the field itself in conjunction with a few analyses in the laboratory (Choudhury *et al*. 2019). Soil morphology reflects the interplay of soil-forming factors that get manifested on the body of soil itself through its horizonation. Thus, study on soil morphology in conjunction with required supplemental characterization from the laboratory analysis go a long way in assisting interpretative grouping of soils such as soil taxonomy, soil and land irrigability classification. (Nasre *et al*. 2013).

Soil morphology is the study of soils and their description under field conditions. Such soil description forms the base for classifying the soils into defined categories (Sehgal 1996). Morphology of the soils is best evaluated from the *insitu* examination of soil horizons and sub horizons in freshly dug pits large enough for observation of a pedon (Buol *et al*. 1973). Some of the commonly used morphological characteristics in describing the soil horizons are soil color, texture, consistency, structure, clay skins, concretions, and pores. Besides these, inclusions such as coarse fragments and roots are also important.

Among the five factors of soil formation viz., climate, organisms, topography, parent material, and time (Milne 1935, Jenny 1941), the topography is a vital cause of soil variations at local extents (Dash *et al*. 2022). 'Toposequence' or 'catena' is a term given by Milne (1935), which refers to the variations observed due to variations in topography or relief, all other factors of soil formation remaining the same. Previous studies show that topography immensely influences the stage of soil development (Dash *et al*. 2019a), morphological properties (Bandyopadhyay *et al*. 2019, Rehman *et al*. 2017), soil physico-chemical properties (Dash *et al*. 2019b, Kharlyngdoh *et al*. 2015, Nagdev *et al*. 2017), as well as the nutrient status (Dash *et al*. 2019c, Tiessen *et al*. 1994) of the soils. Thus, it is important to understand and analyze the changes in major soil characteristics along a toposequence in order to suggest required soil management practices for increasing the crop productivity in each of the different land types in a toposequence. Moreover, among all the different soil characteristics, morphological characteristics are the most preliminary and easily observable characteristics studying which, many necessary interventions can be made without involving higher costs of laboratory-based chemical analysis. In this context, a natural toposequence located in the Ghasipura block of Keonjhar district, Odisha with three distinguishable land types viz., foothill land, medium land, and stream terrace land have been experimented to determine the variations in depth-wise morphological characteristics of soils along the toposequence.

MATERIALS AND METHODS

The study area

The study area is located in the administrative block Ghasipura of Keonjhar district, Odisha, India. The region comes under the North-Eastern Coastal plains agroclimatic zone of Odisha. The elevation of this study site varied from 34 to 54 meters above the mean sea level (MSL). River Baitarani flows close to the study site, which supports the major agricultural activities of this area. Tropical to sub-tropical climate is observed with temperatures varying between 12^{o}C (in winter) to 46^{o}C (in summer), with a mean annual rainfall of about 1490 mm (Five decades of Odisha Agriculture Statistics 2020).

Soil profile studies

Initially, the landform and physiography of the study area were observed by traversing the study area. Based on the observations of the landforms, three soil profiles (pits) of approximately 1m×1m×1.5m

Table 1. Details of soil profiles studied.

Soil profiles	Land type	Latitude (N)	Longitude (E)	Elevation above MSL (m)
		(Degree decimal)		
Pedon 1	Foothill land	21.122178	86.152908	54
Pedon 2	Medium land	21.125275	86.170100	40
Pedon 3	Stream terrace land	21.129759	86.181423	34

dimension were exposed at three different land types viz. foothill land (pedon 1), medium land (pedon 2), and stream terrace land (pedon 3). GPS locations of the soil profile sites were obtained using a GPS instrument (Garmin 76MAPCSx). Details of the soil profiles have been provided in Table 1. Pedon 1 is situated in the foothill position of the Panchahara hill and pedon 3 is situated closer (approximately at a distance of 1 km) to the flowing river Baitarani. After excavation, the side walls of the pits were cleaned carefully and ped faces were exposed to the sunlight by using a pocketknife. The exposed profile faces were examined carefully, starting from the top towards the bottom of the pits to notice the changes in soil characteristic properties of the soils.

Morphological analysis

Layers and horizons of different kinds have been identified as per Soil Survey Staff (2014). Capital letters have been used to designate the master horizons and lower-case letters have been used as suffixes to indicate specific characteristics of the master horizons. Arabic numerals are used as suffixes or prefixes to indicate vertical subdivisions within horizons and discontinuities. Soil color was determined using the Munsell color chart under both natural moist (M) as well as dry (D) conditions. The percent sand, silt and clay contents were determined by the Bouyoucos hydrometer method (Piper 1950). Textural classes were determined using the USDA Textural Triangular diagram. Other morphological parameters including soil structure, consistency, mottles, concretions, pores, and roots were determined following the standards procedures (Schoeneberger *et al*. 2012, Natrajan and Sarkar 2009).

RESULTS AND DISCUSSION

Soil depth and horizon boundary

The total depth of soil profiles of pedons 1, 2 and 3

Table 2. Horizon boundary information and soil color (moist and dry) of the soil profiles. D: Distinctness, T: Topography. D: d-diffuse, G-gradual, T: i-irregular, W: wavy, S-smooth.

Horizon	Depth (cm)	Horizon boundary		Soil color	Color notation	Soil color	Color notation
		D	T	Moist		Dry	
				Pedon-1 (foothill land)			
Ap	0-9	d	i	Red	10R 5/6	Red	10R 5/8
C1	10-30	d	i	Dusky red	10R 3/4	Dark red	10R 3/6
C2	31-89	d	i	Dusky red	10R 5/4	Red	10R 5/6
C3	90-120	d	i	Dusky red	10R 3/4	Red	10R 4/8
				Pedon-2 (medium land)			
Ap	0-9	g	w	Light brownish gray	10YR 6/2	Yellow	10YR 7/6
A2	10-14	g	w	Gray	10YR 5/1	Grayish brown	10YR 5/2
Bt1	15-30	g	w	Gray	10 YR 5/1	Gray	10YR 6/1
Bt2	31-60	g	w	Reddish brown	5YR 5/3	Yellowish red	5YR 5/6
BC	61-89	g	w	Reddish yellow	7.5 YR 6/6	Reddish yellow	7.5 YR 7/6
C	90-130	g	w	Reddish brown	5YR 5/4	Yellowish red	5YR 5/8
				Pedon-3 (stream terrace land)			
Ap	0-9	d	s	Pale olive	5Y 6/4	Olive yellow	5Y 6/6
Bt1	10-17	d	s	Gray	2.5Y 6/1	Light gray	2.5Y 7/2
Bt21	18-31	d	s	Gray	2.5Y 5/1	Light brownish gray	2.5Y 6/2
Bt22	32-64	d	s	Gray	2.5Y 5/1	Pale yellow	2.5Y 7/4
BC	65-99	d	s	Light brownish gray	2.5Y 6/2	Light gray	2.5Y 7/1
C	100-140	d	s	Gray	2.5Y 6/1	Pale yellow	2.5Y 7/3

was observed to be 120 cm, 130 cm, and 140 cm, respectively (Table 2). It indicates that soil depth was deeper in the stream terrace and medium land as compared to the foothill land. Depth of soil solums (A and B horizon) for pedons 1, 2 and 3 were 9 cm, 89 cm and 99 cm, respectively. No lithic or para lithic contact was observed in any of the soil profiles. A-B-C profiles were observed in pedons 2 and 3, whereas an A-C soil profile was observed for pedon 1. Pedons 2 and 3 were observed with well-formed B horizons, whereas the pedon 1 situated in the foothill land lacked a B horizon resulting in smaller soil solum depth as compared to that of pedons 2 and 3. Dash *et al*. (2019a) also observed a soil profile without a B horizon in the upland of an eastern Indian catena. B horizons in the pedons 2 and 3 were observed with translocated clay particles from upper horizons and thereby were designated with the symbol ‘t’. Soil boundaries for pedons 1 and 3 were diffuse, and that for pedon 2 was gradual. Deeper soil solum depth in the soil profile of the stream terrace land could be due to its stable topography and the prevailing conducive soil development conditions including adequate soil moisture. On the other hand, poor soil profile development in the foothill land could be because of the prevailing soil erosion conditions in the same with poor soil moisture status (Dash *et al*. 2018).

Soil color

The hue of pedon 1 was 10R for all the peds, that of pedon 2 varied from 5YR to 10 YR and that of pedon 3 varied between 2.5Y to 5Y. Values for pedon 1 ranged from 3 to 5, whereas the values for pedons 2 and 3 varied from 5 to 7. Similarly, chroma for pedon 1 ranged from 4 to 8, that of pedon 2 from 1 to 8 and that of pedon 3 from 1 through 6. In common words, the soils of pedon 1 were dusky red to dark red, that of pedon 2 were reddish-brown (bottom horizons) to grey (top horizons) and that of pedon 3 were grey to olive-yellow. Thus, in general, soils of pedon 1 were redder throughout the soil profile, that of pedon 2 was redder at the bottom horizons and grey in the upper horizons and that of pedon 3 was yellowish. Such differences may chiefly be attributed to the differences in parent materials in conjunction with the drainage conditions. Redder soils in the case of pedon 1 could be due to the higher iron content (mostly ferric oxides) in the parent material hematite, besides the excessively drained conditions of these soils because of their physiographic conditions (Dash *et al*. 2019b, Mishra 1987, Sahu 1978). In contrast, the grey soils in the case of medium land could be due to the presence of iron in the ferrous form under reducing conditions owing to higher hydration and poorer drainage conditions (Soil Survey Staff 1999). Even though lower chroma was observed in the stream terrace land, gleization was not observed indicating that the soils are not being subjected to sufficient anaerobic conditions.

Textural class

The textural class of pedon 1 was sandy loam in all the horizons, while in the case of pedons 2 and 3, the surface horizons were sandy loam and the sub-surface horizons were sandy clay loam (Table 3). The occurrence of sandy loam soil texture in the foothill land (pedon 1) can be attributed to the loss of clay particles through runoff from it to the lower slopes. In contrast, pedons 2 and 3 were observed with clay movement down the soil profile (also known as leaching effect/ illuviation) into the B horizon leading to the formation of argillic (Bt) horizons. This could be possible because of the prevailing stable topography (nearly level to very gentle slope) of the pedons located in the medium and stream terrace land. Moreover, higher clay content in soils located on the lower slope is natural because of the slope wash through which, a considerable amount of clay due to runoff is transported from the higher to the lower slopes (Ram *et al*. 2017).

Coarse fragments

The abundance of gravels (0.2-7.5 cm dia) varied from few to dominant in the case of pedon 1, very few to dominant in case of pedon 2 and very few to few in case of pedon 3 (Table 3). It indicates that being located on the foothills (uplands), finer materials have been washed away to the valley sides and valley-bottom forming these soils enriched with clay while the soils located at the foothill are of coarser texture and are more abundant in angular gravels of quartz and hematite. Very strongly to partially weathered rounded and angular gravels could be

Table 3. Horizon wise coarse fragments, textural class, and structure of the soil profiles.

Horizon	Textural class*	Coarse fragments**			Structure***				Consistency****			
		A	S1	S2	N	C	G	T	D	M	W	
											S	P
					Pedon-1 (foothill land)							
Ap	sl	f	gv	ro	vswe	m	2	sbk	ds	mvfr	wso	wpo
C1	sl	f	gv	ro	vswe	m	2	sbk	dsh	mvfr	wso	wpo
C2	sl	vfq	gv	ro, an	we	m	1	sbk	dmh	l	wso	wpo
C3	sl	d	gv	ro, an	we	m	1	sbk	dmh	l	wso	wpo
					Pedon-2 (medium land)							
Ap	sl	vf	gv	ro	vswe	m	2	sbk	ds	mvfr	wss	wps
A2	sl	f	gv	ro	vswe	m	2	sbk	dsh	mfr	wss	wps
Bt1	scl	fq	gv	ro	vswe	c	2	sbk	dmh	mfr	ws	wp
Bt2	scl	fq	gv	ro	swe	c	3	abk, sbk	dh	mfr	ws	wp
BC	scl	vfq	gv	ro	we	c	3	abk, sbk	dh	mfi	ws	wpo
C	scl	d	gv	ro	we	c	3	abk, sbk	dh	mfi	wso	wpo
					Pedon-3 (stream terrace land)							
Ap	sl	vf	gv	ro	vswe	m	2	sbk	dmh	mfr	wss	wps
Bt1	scl	vf	gv	ro	vswe	c	2	abk, sbk	dh	mfi	wss	wps
Bt21	scl	vf	gv	ro	swe	c	2	abk, sbk	dh	mfi	ws	wp
Bt22	scl	vf	gv	ro	we	c	2	abk, sbk	dh	mvfr	ws	wp
BC	scl	d	gv	ro	we	c	3	abk, sbk	dh	mvfr	ws	wp
C	scl	d	gv	ro	we	c	3	abk, sbk	dh	mvfi	wso	wpo

*sl: sandy loam, scl: sandy clay loam.
**A: abundance, S1: size, S2: shape, N: nature, vf: very few (less than 5% by volume), f: few (5-15% by volume), fq: frequent (15-40%) by volume, vfq: very frequent (40-80% by volume), d: dominant (more than 80% by volume), ro: rounded, an: angular, gv: gravel (0.2-7.5 cm), vswe: very strongly weathered, swe: strongly weathered, we: partly weathered.
***C: class, G: grade, T: type, m: medium (10-20 mm), c: coarse (20-50 mm), 1: weak (units are barely observable in palce or in a hand sample), 2: moderate (units well-formed and evident in place or in a hand sample), 3: strong (units are distinct in place (undisturbed soil) and separate cleanly when disturbed, sbk: sub-angular blocky, abk: angular blocky.
****D: dry, M: moist, W: wet, S: stickiness, P: plasticity, ds: soft, dsh: slightly hard, dmh: moderately hard, dh: hard, l: loose, mvfr: very friable, mfr: friable, mfi: firm, mvfi: very firm, wso: non sticky, wss: slightly sticky, ws: sticky, wpo: non plastic, wps: slightly plastic, wp: plastic.

found from the foothill land, whereas only rounded gravels were found in pedons 2 and 3. The shape of the gravels (rounded and angular) could be due to the differential weathering conditions. In each of the soil profiles, the abundance of gravels increased with soil depth. The gravels of the bottom horizons of each soil profile were partially weathered, whereas the same from the top horizons were very strongly weathered. Occurrence of more coarse fragments at a deeper depth of the medium and stream terrace land could be due to more deposition and less erosion, whereas the occurrence of more coarse fragments close to the surface in the case of the foothill land could be because of higher soil erosion and lesser deposition.

Soil structure

In the case of pedon 1, soil structures of only medium class (size) could be observed, whereas in pedons 2 and 3, medium and coarse classes of soil structures were observed in the top and bottom horizons, respectively (Table 3). A coarser class of soil structure closer to the soil surface in pedon 3 can chiefly be attributed to its higher clay content. Weak to moderate grades of soil structures were observed in pedon 1 and moderate to strong grades of soil structures were observed in pedons 2 and 3. Such differences could chiefly be attributed to the textural differences between the soils. While in pedon 1 only angular blocky type (shape) of soil structures were observed, in pedon 2 and 3, both sub-angular blocky and angular blocky types of soil structures were observed. The occurrence of the angular blocky structures in case of medium and low lands can chiefly be attributed to their higher clay contents (Ram *et al*. 2017).

Consistency

For pedon 1, soil consistency under dry conditions varied from soft to moderately hard, that in pedon 2 varied from soft to hard, and in the case of pedon 3, it varied from moderately hard to hard (Table 3). Soft consistency can be attributed to higher silt content, whereas hard consistency can be attributed to the combined effect of higher clay content, low organic matter content and coarse strong angular blocky structure (Mishra 1981). Consistency under moist conditions was very friable for the soils of pedon 1. The same for pedon 2 and 3 varied from very friable to firm and friable to very firm, respectively. Very friable consistency can happen with higher content of fine sand plus silt or due to high sand content with poor structure. On the other hand, loose consistency in pedon 1 under moist conditions can be attributed to the higher content of coarser sands that tend to stay apart. Firm and very firm consistency in pedons 2 and 3 can be attributed to the higher clay contents in the same. Under wet moisture conditions, the soils of pedon 1 were not sticky and non-plastic, whereas those of pedons 2 and 3 were slightly sticky and slightly plastic on the surface and sticky to plastic in the sub-surface. Such difference in plasticity among different land types could chiefly be attributed to their soil textures (particularly clay content). In the case of medium and stream terrace land, stickiness and plasticity increased with soil depth owing to the increasing clay content with soil depth (Supriya *et al*. 2019). However, soils in the C horizon of both pedons 2 and 3 were again not-sticky and non-plastic because of the presence of higher coarse fragments including the partially weathered parent materials.

Mottling

All the soils within the study area except pedon 1 (foothill land) possessed mottles (Table 4). The soils of pedon 1 were skeletal and were excessively drained because of which, mottles were not formed in pedon 1. In pedon 2 (medium land), mottles were absent in the upper soil horizons and were present

Table 4. Mottling characteristics of the soil profiles.

Horizon	A*	C**	S1***	Color	Color notation	S2****	L*****
				Pedon-1 (foothill land)			
Ap	NA	NA	NA	NA	NA	NA	NA
C1	NA	NA	NA	NA	NA	NA	NA
C2	NA	NA	NA	NA	NA	i	NA
C3	NA	NA	NA	NA	NA	NA	NA
				Pedon-2 (medium land)			
Ap	NA	NA	NA	NA	NA	NA	NA
A2	NA	NA	NA	NA	NA	NA	NA
Bt1	NA	NA	NA	NA	NA	NA	NA
Bt2	m	p	3	Dark red	10R 3/6	i	mpf, apf
BC	m	P	3	Dark red	10R 3/6	i	mpf, apf
C	m	d	3	Dark red	10R 3/6	i	mpf, apf
				Pedon-3 (stream terrace land)			
Ap	m	p	3	Light red	10R 7/6	i	mpf
Bt1	m	p	3	Light red	10R 7/6	i	mpf
Bt21	c	p	2	Light red	10R 7/7	i	mpf
Bt22	c	d	2	Light red	10R 7/8	i	mpf
BC	c	d	1	Light red	10R 7/8	i	mpf
C	f	d	1	Light red	10R 7/8	i	mpf

NA: not available
*A: abundance, f: few (less than 2% of the surface), c: common (2-20% of the surface area), m: many (more than 20% of the surface)
** C: contrast, f: faint, d: distinct, p: prominent
*** S1: size, 1: fine (less than 5 mm), 2: medium (5-15 mm), 3: coarse (more than 15 mm)
**** S2: shape, i: irregular
***** L: location, mpf: infused into the matrix along faces of peds, apf: on faces of peds

only in the bottom horizons. At the same time, mottles were observed in all the horizons of pedon 3 (stream terrace land). Such extensive occurrence of mottles in the soils of the study area could be primarily attributed to the prevailing climatic conditions creating pronounced moisture surplus and deficit periods in a year that create alternating reducing and oxidizing conditions. Besides this, growing paddy with water stagnation conditions and its subsequent drainage is also conducive for mottling in the soils. The color of mottles in pedons 2 and 3 were dark red and light red, respectively. The hue of the mottles was 10R for both the soil profiles at all horizons. Color values of 3 and 7 were observed for mottles of all the horizons of pedon 2 and 3, respectively. Mottle chroma in pedons 2 and 3 varied between 6 to 8. The production of reddish color mottles in the study area can chiefly be due to the presence of Fe_2O_3 with varying degrees of hydration. The lack of grey color mottles indicates that soils are not saturated enough and probably haven't received enough iron-enriched slope wash to develop gley horizons. Mottle contrast varied from distinct to prominent. Prominent contrast was observed in the bottom horizons. The abundance of mottles was 'many' in pedon 2 and varied between 'few' to 'many' in pedon 3. In terms of shape, all the mottles were irregular and were observed mostly on ped faces and sometimes were infused into the soil matrix along with the ped faces. However, the sizes of mottles were coarse in the case of pedon 2 and varied between fine to coarse in pedon 3. Many prominent coarse mottles in the medium land could be attributed to its physiographic position, which being very old and stable provides the most favorable condition for leaching and is least subjected to runoff (Gaikwad *et al*. 2020).

Concretions

All the soils within the study area except that of pedon 1 located in the foothill land possessed ferruginous (iron-manganese) concretions. Located on a hill slope and being skeletal in nature, the soils of pedon 1 never became saturated with water and thus there was no development of concretions. While pedons 2 and 3 possessed iron and iron-manganese concretions of light red to black in color, calcium concretions were observed only in pedon 3 (Table 5). Movement of calcium through slope wash along with finer soil separates (clay) and other bases from the upper to the lower physiographic positions could be mainly responsible for the occurrence of calcium concretions in the soils of the stream terrace land (Mishra 1981). Recently, Supriya *et al*. (2019) also observed calcium concretions (Conca) while characterizing the soils of Mahanandi Mandal in Kurnool District of Andhra Pradesh. In terms of abundance, the concretions in pedons 2 and 3 varied between plentiful to abundant. All the concretions were distinct in contrast. The size of concretions of pedon 2 varied from fine to medium, whereas that of pedon 2 varied from medium to very coarse. The coarse Ca concretions (calcretes) in pedon 3 could have been formed because of the higher clay content, greater reduced condition, and less leaching in most subsoil horizons. Ferruginous concretions of pedon 2 were all in the hue of 10R, whereas the same varied from 5YR to 10R in the case of pedon 3. All the Ca concretions in pedon 3 were white in color with Munsell color notation of 10YR 8/1. The shapes of concretions were mostly spherical and irregular with distinct concretion boundaries being located on and between the ped faces.

Pores

In terms of abundance, the pores were in the range of few to many in all the three soil profiles (Table 6). In general, the abundance of soil pores was higher in the A horizon, which could be attributed to the effect of abundant crop roots, biological activity, ploughing, liberation of gases, and aggregation effect of the organic matter. More continuous soil pores were observed in the surface soils. Irrespective of the soil texture, the A horizon possessed very fine to fine pores besides medium pores in some cases. Since most of the pores were found not between the ped faces but rather within the peds, they have been described to be imped pores. The tubular pores found in most horizons in the soils of the study area are mostly attributable to the decay of plant roots, particularly that of paddy and grass. The occurrence of greater abundance and random orientation of pores in most soils, particularly in the upper horizons could also be attributed to the fibrous roots of paddy and grass vegetation (with intense microbial and root activity). The irregular shape of pores as found in

Table 5. Concretion characteristics of the soil profiles.

Horizon	A[a]	C[b]	H[c]	S1[d]	N[e]	Color	Color notation	S2[f]	B[g]	L[h]
					Pedon-1 (foothill land)					
Ap	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
C1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
C2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
C3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
					Pedon-2 (medium land)					
Ap	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
A2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Bt1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Bt2	p	d	s	2	Fe	10R 3/6	Dark red	s, i	d	apf, bpf
BC	a	d	s	2	Fe, Fe-Mn	10R 3/6, 5YR 2.5/1	Dark red, black	s, i	d	apf, bpf
C	a	d	s	3	Fe, Fe-Mn	10R 3/6, 5YR 2.5/1	Dark red, black	s, i	d	apf, bpf
					Pedon-3 (stream terrace land)					
Ap	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Bt1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Bt21	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Bt22	p	d	h	3-5	Fe, Fe-Mn, Ca	10R 7/8, 5YR 2.5/1, 10YR 8/1	Light red, black, white	s, i	d	apf, bpf
BC	p	d	h	3-5	Fe, Fe-Mn, Ca	10R 7/8, 5YR 2.5/1, 10YR 8/1	Light red, black, white	s, i	d	apf, bpf
C	a	d	h	3-5	Fe, Fe-Mn, Ca	10R 7/8, 5YR 2.5/1, 10YR 8/1	Light red, black, white	s, i	d	apf, bpf

NA: not available
[a] A: abundance, f: few (less than 2%), p: plentiful (2-20%), a: abundant (more than 20 %)
[b] C: contrast, f: faint, d: distinct
[c] H: hardness, h: hard, s: soft
[d] S1: size, 1: very fine (less than 1 mm), 2: fine (1-2 mm), 3: medium (2-5 mm), 4: coarse (5-10 mm), 5: very coarse (more than 10 mm)
[e] N: nature, Fe: iron, Fe-Mn: iron-manganese, Ca: calcium
[f] S2: shape, s: spherical, i: irregular
[g] B: boundary, c: clear, d: diffuse
[h] L: location, apf: on faces of peds, bpf: between ped faces

the coarse-textured sub-surface horizons of pedon 1 could be due to the close packing of the sand grains. Such irregular pores have also been found in the subsoil horizons of pedons 2 and 3, where roots are usually absent and particularly that have more coarse fragments (gravels) as in the C horizons.

Roots

The quantity of the roots varied from few to many, whereas the size of the roots varied between very fine to fine (Table 6). In all the soils, the abundance of roots decreased with soil depth. The abundance of roots of fine to very fine size in the surface horizons could be attributed to the regular cultivation of crops (mostly rice) and/ or grasses. A decrease in the abundance of roots in the subsoil could also be due to the higher clay content. In most soils, 'many' followed by 'common' roots were found within a depth of 50 cm from the surface. This could be attributed to the shallow and fibrous root system of the rice crop grown in most of these lands. Less abundance of roots in the bottom horizons of soil profiles can be attributed to increased compactness, higher bulk density, and lower abundance of soil pores.

Land use and crop production suggestions

Soils of the foot hill land were observed to be the sites

Table 6. Pore and root characteristics of the soil profiles.

Horizon	Pores*						Roots		
	A	C	D1	O	D2	S	Quantity**	Size***	Location****
Pedon-1 (foothill land)									
Ap	m	n	f, m	r	in	t	m	f	p
C1	c	d	m	r	in	i	NA	NA	NA
C2	f	d	m	r	in	i	NA	NA	NA
C3	f	d	m	r	in	i	NA	NA	NA
Pedon-2 (medium land)									
Ap	m	n	vf, f	r	in	t	m	f	t
A2	m	n	vf, f, m	r	in	t	m	f	t
Bt1	c	d	f	r	in	t	c	vf	t
Bt2	f	d	f	r	in	i	f	vf	t
BC	f	d	f	r	in	i	NA	NA	NA
C	f	d	f	r	in	i	NA	NA	NA
Pedon-3 (stream terrace land)									
Ap	m	n	vf	r	in	t	c	vf	p
Bt1	c	n	vf	r	in	t	c	vf	p
Bt21	c	n	vf	r	in	t	f	vf	t
Bt22	c	d	f	r	in	i	f	vf	t
BC	c	d	f	r	in	i	NA	NA	NA
C	f	d	f	r	in	i	NA	NA	NA

*A: abundance, C: continuity, D1: diameter, O: orientation, D2: distribution, S: shape, f: few (up to 3/ square inch), c: common (4-14/ square inch), m: many (more than 14/ square inch), d: discontinuous, n: continuous, vf: very fine (less than 1 mm), f: fine (1-2 mm), m: medium (2-5 mm diameter), r: random, in: imped, t: tubular, i: irregular
** f: few (<1 per area), c: common (1 to <5 per area), m: many (more than or equal to 5)
*** vf: very fine (<1 mm diameter), f: fine (1-2 mm diameter)
**** p: between peds, t: throughout

of soil erosion with less soil moisture status and more coarse fragments. On the other hand, high water table and impeded drainage conditions were observed to be the major soil related crop production constraints of the stream terrace land. Medium land was observed to be having a stable topography with a limited constraints of soil erosion as well as drainage. Therefore, for the foothill and medium land, certain soil conservation measures including cover cropping, strip cropping, growing vegetative barriers, agroforestry, mulching, conservation tillage. are suggested. Along with this, contouring, terracing, preparing loose rock dams, and grassed water ways are important especially for the foothill land for preventing soil erosion and enhancing the soil moisture status. Growing orchards, vetiver grass with sufficient addition of organic manure can certainly be favorable in the foothill land in terms of getting better crop productivity, stabilizing the soil structure, and preventing soil erosion. On the other hand, for the stream terrace land having a higher water table and higher clay content, paddy cultivation is recommended for higher yield. Pisciculture along with low land paddy cultivation can be beneficial in the stream terrace lands having water stagnation situations. Moreover, raised bed cropping along with provision for surface and subsurface drainage should be practiced in the stream terrace land to support crop production for a wide variety of crops including legumes, pulses and vegetables.

CONCLUSION

Characterizing morphological properties of three soil profiles located in three different land types viz., foothill land, medium land, and stream terrace land of a toposequence located in the North-Eastern Coastal plains agroclimatic zone of Odisha revealed that soil depth was deeper with well form B horizons in the medium and stream terrace land owing to their stable topographies as compared to the foothill land. Soil erosion and poor soil moisture status were observed to be slowing down the soil formation process in the foothill land. The soil color changed from reddish to yellowish and soil texture became heavier from the foothill to the stream terrace land. Owing to the prevalent alternate wetting and drying conditions, mottles and concretions were abundant in the medium and stream terrace land. Presence of mottles through out the soil profile of the stream terrace land indicated the poor drainage status of the low-lying soils. Calcium concretions could be found only in the stream terrace land owing to the movement of calcium through slope wash along with finer soil separates (clay) and other bases from the upper to the lower physiographic positions followed by its subsequent precipitation as Ca concretions. Abundance of pores and roots decreased with soil depth in all land types. Thus, experimenting on variations in morphological characteristics along the toposequence helped in identifying the major constraints of different land types, which needs to be resolved using differential conservation measures.

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