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Soil characterization along a toposequence located in North-Central Plateau Agro-climatic zone of Odisha

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ABSTRACT

This study characterizes soil physico-chemical properties of a toposequence located in Patana block of Keonjhar district of Odisha. Three different representative pedons situated at three different topographic positions viz. foothill land, medium land, and stream terrace land were exposed for evaluating horizon wise soil physico-chemical characteristics. Results indicated that soil pH, clay, porosity, water holding capacity, soil organic carbon (SOC), exchangeable bases, and cation exchange capacity gradually increased from higher to lower topographies, whereas a reverse trend was observed for bulk and particle densities. Significant positive correlations have been observed for soil porosity, water holding capacity, exchangeable bases, and cation exchange capacity with clay; base saturation and exchangeable bases with pH.In contrast, significant negative correlations of bulk density and particle density with SOC; pH and exchangeable bases with exchangeable acidity have also been observed.

Key words: *Topography, Physico-chemical, Soil profiles, Acid soils*

Introduction

The biggest challenge to the mankind today is to provide basic necessities of living to the ever-growing burgeoning population from the ever shrinking and non-renewable (finite) soil resource (Lal, 2013). Moreover, the ever-increasing demand of food, fodder, other agricultural products, and fuel (bio-based energy) for the exploding population is causing rise in the international market prices.Thus, soil being a dynamic and critical natural life supporting resource for the survival of life on the earth as well as being an important factor influencing the socio-economic development, requires proper evaluation and planning to ensure its best use. In this aspect, characterizing the soils can pave the path towards restoring soil quality to enhance or at least maintain the present level of productivity and for making the crop production system more sustainable over the years to come (Prabhavati *et al.,* 2017; Singh *et al.,* 2019; Ram *et al.,* 2017).

Standard soil survey helps in gathering information about soils in a systematic manner, especially regarding their genesis, extent, potentials, suitability to different crops, and limitations for specific purposes (Vedadri and Naidu, 2018), which in turn can facilitate for adopting a sustainable and rational land use and crop plan by identifying the most appropriate use of a particular soil for different purposes (Sarmah *et al.,* 2019). In a bigger picture, soil characterization can serve vital roles in food, nutrition, and fodder security, environmental sustainability, arresting land degradation, making the agriculture more profitable, conserving soil resources for the future use, and thereby enriching prosperity of the people (Satish *et al.*, 2018).

Among different factors of soil formation, topography greatly affects soil formation at local scales (Dash *et al.,* 2022). Thus, it is important to understand the influence of micro-topographic variations at local scales on soil characteristics to impose site-specific management practices. In this aspect, the present investigation examines variations in soil physico-chemical properties along a toposequence located in the North-Central plateau agro-climatic zone of Odisha.

Materials and Methods

The study area

The study area is located in Patana block of Keonjhar district of Odisha, India. Possessing a tropical to sub-tropical climate, the region comes under the North-Central plateau agro-climatic zone of Odisha. Three soil profiles were studied at three topographic positions viz. foothill land (pedon 1), medium land (pedon 2), and stream terrace land (pedon 3). Pedon 1 (21.663722N, 85.759556E degree decimal), 2 (21.668501N, 85.761326E degree decimal), and 3 (21.671082N, 85.76249E degree decimal) were located in a row within a distance of 890 m. While Pedon 2 was 567 m apart from 1, pedon 3 was 323 m apart from pedon 2. The corresponding elevations above mean sea level for pedon 1, 2, and 3 were 1199, 1187, and 1168 m, respectively. Being closer to a stream nearby, moisture status of the soils of the stream terrace land was higher compared to other landforms.

Soil profile studies and chemical analysis

Soil pits of approximately 1m×1m×1.5m dimension were exposed. After determining the horizon boundaries following the methods outlined by Soil Survey Staff (2014), horizon wise soil samples were collected, processed, and preserved for laboratory analysis. Physical properties including soil texture (Piper, 1950), bulk density (BD; Klute, 1986), particle density (PD; Chopra and Kanwar, 1986), water holding capacity (WHC; Piper, 1950) and chemical

Table 1. Soil physical characteristics of the soil profiles

Horizons	Depth (cm)	Sand %	Silt %	Clay %	BD Mg/m^3	PD Mg/m^3	Porosity	WHC	Textural class
Pedon 1 (foothill land)									
Ap	**0-9**	68.8	20.0	11.2	1.59	2.43	34.6	31.8	Sandy loam
A1	**9-20**	73.6	15.4	11.0	1.61	2.45	34.3	32.1	Sandy loam
A2	**20-29**	71.0	14.0	15.0	1.44	2.43	40.7	32.4	Sandy loam
A3	**29-60**	72.6	13.9	13.5	1.68	2.45	31.4	30.8	Sandy loam
A4	**60-90**	69.6	13.4	17.0	1.69	2.57	34.2	33.3	Sandy loam
A5	**90-118**	70.0	15.0	15.0	1.81	2.61	30.7	33.4	Sandy loam
C	**118-140**	71.4	14.6	14.0	1.91	2.69	29.0	29.8	Sandy loam
Pedon 1 (medium land)									
Ap	**0-5**	68.0	13.0	19.0	1.57	2.43	35.4	34.4	Sandy loam
AB	**5-15**	69.4	17.4	13.2	1.69	2.46	31.3	30.8	Sandy loam
Bw1	**15-31**	72.8	10.0	17.2	1.64	2.38	31.1	32.4	Sandy loam
Bw2	**31-61**	70.6	17.2	12.2	1.67	2.38	29.8	31	Sandy loam
Bw3	**61-75**	82.0	8.0	10.0	1.72	2.45	29.8	28.8	Loamy sand
BC	**75-110**	80.0	12.0	8.0	1.74	2.45	29.0	26.2	Loamy sand
Cr	**110-145**			Weathered parent materials					
Pedon 3 (stream terrace land)									
Ap	**0-9**	70.7	10.1	19.2	1.55	2.41	35.7	32.5	Sandy loam
A1	**9-15**	61.3	17.5	21.2	1.59	2.49	36.1	33.8	Sandy clay loam
Bw1	**15-45**	61.3	15.5	23.2	1.60	2.50	36.0	34.8	Sandy clay loam
Bw2	**45-60**	69.1	7.7	23.2	1.62	2.54	36.2	34.8	Sandy clay loam
Bw3	**60-101**	70.9	5.0	24.1	1.65	2.59	36.3	32.4	Sandy clay loam
C	**101-150**	70.9	6.0	23.1	1.71	2.60	34.2	31.8	Sandy clay loam

properties including pH @1:2.5 soil: water (Jackson, 1973), electrical conductivity (EC; Jackson, 1973), soil organic carbon (SOC; Walkley and Black, 1934), exchangeable bases (Page *et al.,* 1982), exchangeable acidity (Thomas, 1996), cation exchange capacity (CEC; Chapman, 1965) were determined following respective standard procedures. Base saturation (BS) and exchangeable sodium percentage (ESP) were calculated using the observed data of exchangeable cations and CEC. For correlation studies, Pearson's correlation coefficient (r) values were determined in R version 4.2.

Results and Discussion

Physical characteristics

Soil physical properties of the representative pedons have been presented in Table 1. Percentage sand varied in the range of 68.8 to 73.6, 68.0 to 82.0, and 61.3 to 70.9% in pedon 1, 2, and 3, respectively. The corresponding clay content varied from 11.0 to 17.0, 8.0 to19.0, and 19.2 to 24.1%, respectively. While pedon 1 and 3 showed increasing trends of clay with increasing depth, pedon 2 showed a reverse trend. Increase in clay with soil depth is an indication of illuviation (clay migration) process (Lokya *et al.,* 2020). However, the increase in clay content with soil depth in any of the three soil profiles was not sufficient for designating them as argillic horizons. Moreover, higher clay in pedon 3 (stream terrace land) as compared to pedon 1 and 2 also indicates the process of clay migration from higher to lower topographies along with the surface and sub-surface run off, especially during heavy rainfall (Dash *et al.,* 2019a). It also provides the evidence of pronounced soil erosion in the higher topographic positions, which require proper soil conservation practices such as adding organic matter, growing cover crops, orchards, soil erosion resisting crops etc.

While pedon 1 located in the foothill land possessed an A-C profile, both pedon 2 and 3 possessed A-B-C profiles. It indicates that the foothill land did not possess distinct horizons and was comparatively underdeveloped than that of the medium and stream terrace lands. Poor soil development in the foothill land could be due to the prevailing soil erosion and poor soil moisture conditions.While soil

Table 2. Soil chemical characteristics of the soil profiles

Pedon	Depth (cm)	pH	EC dS/ m	SOC %	Exchangeable bases Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Sum	Exchangeable acidity Ex. Al^{3+}	Ex. H^{+}	Sum	CEC %	BS %	ESP %
					cmol(+) kg^{-1}				% cmol(+) kg^{-1} %						
Pedon 1 (foothill land)															
Ap	**0-9**	4.97	0.18	0.66	2.78	1.44	0.2	0.2	4.62	0.88	1.19	2.07	6.89	67.1	2.9
A1	**9-20**	5.21	0.24	0.52	2.88	1.44	0.2	0.3	4.82	0.00	1.12	1.12	6.14	78.5	3.3
A2	**20-29**	5.17	0.46	0.72	2.88	1.69	0.2	0.3	5.07	0.00	1.12	1.12	6.39	79.3	3.1
A3	**29-60**	5.53	0.57	0.47	2.9	1.49	0.3	0.3	4.99	0.00	1.1	1.1	6.29	79.3	4.8
A4	**60-90**	5.41	0.68	0.59	3.25	1.66	0.4	0.4	5.71	0.00	1.12	1.12	7.03	81.2	5.7
A5	**90-118**	5.66	0.91	0.39	3.35	1.69	0.5	0.4	5.94	0.00	1.12	1.12	7.26	81.8	6.9
C	**118-140**	6.04	1.01	0.32	3.31	1.82	0.6	0.4	6.13	0.00	1.1	1.1	7.43	82.5	8.1
Pedon 1 (medium land)															
Ap	**0-5**	5.48	0.52	0.72	2.62	1.68	0.5	0.4	5.2	0.20	1.38	1.58	6.88	75.6	7.3
AB	**5-15**	5.79	0.68	0.58	3.02	1.74	0.5	0.4	5.66	0.10	1.22	1.32	7.08	79.9	7.1
Bw1	**15-31**	5.84	0.75	0.7	3.56	1.92	0.6	0.5	6.58	0.00	1.14	1.14	7.82	84.1	7.7
Bw2	**31-61**	6.11	0.99	0.68	3.74	2.05	0.6	0.5	6.89	0.00	1.12	1.12	8.11	85.0	7.4
Bw3	**61-75**	5.98	1.01	0.38	3.84	2.01	0.6	0.5	6.95	0.00	1.10	1.10	8.15	85.3	7.4
BC	**75-110**	5.98	1.09	0.28	3.87	1.22	0.7	0.7	6.49	0.00	1.10	1.10	7.69	84.4	9.1
Cr	**110-145**					Weathered parent materials									
Pedon 3 (stream terrace land)															
Ap	**0-9**	5.69	0.62	0.92	3.56	2.26	0.6	0.5	6.92	0.00	1.12	41.12	8.14	85.0	7.4
A1	**9-15**	5.72	0.68	0.72	3.98	2.74	0.6	0.4	7.72	0.00	1.10	1.10	8.92	86.5	6.7
Bw1	**15-45**	5.81	0.79	0.59	4.02	2.88	0.6	0.5	8	0.00	0.98	0.98	9.08	88.1	6.6
Bw2	**45-60**	5.92	0.89	0.48	4.78	2.92	0.7	0.5	8.9	0.00	0.96	0.96	9.96	89.4	7.0
Bw3	**60-101**	6.14	1.05	0.22	4.82	3.04	0.7	0.6	9.16	0.00	0.74	0.74	10.00	91.6	7.0
C	**101-150**	6.22	1.19	0.19	4.91	3.08	0.7	0.6	9.29	0.00	0.64	0.64	10.03	92.6	7.0

texture in pedon 1 remained sandy loam all throughout the profile,the same for pedon 2 and 3 varied from sandy loam to loamy sand and sandy loam to sandy clay loam, respectively. A zigzag pattern of particle size distribution in pedon 2 could possibly owing to the fluvial processes. Increased sand contents towards the bottom horizons of pedon 2 can be linked to the underlying parent materials, which might have recently weathered to coarse sand grains.

BD varied between 1.55 and 1.91 Mg m^{-3} and PD varied between 2.38 and 2.69 Mg m^{-3} across all the pedons. In general, both BD and PD decreased from higher to lower topographies. However, irrespective of the landform, both BD and PD increased with soil depth, which could be attributed to the decreasing SOC with soil depth. BD and PD were significantly negatively correlated with SOC with r values -0.67and -0.66, respectively. Thus, addition of organic matter in the foothill land can help reducing BD for better crop production. High sand content, low clay content, and compaction might as well have caused rise in the BD (Dash *et al.,* 2019b).

Percentage porosity and WHC varied from 29.0 to 40.7% and 26.2 to 34.8%, respectively with an increasing trend towards the stream terrace land. Such effect could be attributed to the clay contents, since both porosity and WHC had significant positive correlation with clay with r values 0.59 and 0.74, respectively.

Chemical characteristics

Soil chemical properties of the representative pedons have been presented in Table 2. Overall, soil pH, EC, and SOC ranged from 4.97 to 6.22, 0.18 to 1.19 dS m^{-1}, and 0.19 to 0.92 %, respectively. Similarly, the exchangeable Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Al^{3+}, H^{+}, and CEC ranged from 2.62 to 4.91, 1.22 to 3.08, 0.2 to 0.7, 0.2 to 0.7, 0 to 0.88, 0.64 to 1.38, and 6.14 to 10.03 cmol (+) kg^{-1} across all the soil profiles. BS and ESP varied between 67 to 93% and 2.9 to 9.1%, respectively.

Surface soil pH increased in the order of pedon 1 (4.97) <pedon 2 (5.48) <pedon 3 (5.69). Soil pH also increased vertically with depth in all the pedons. In either case, increase in pH can be attributed to leaching and deposition of basic cations from higher to lower positions, especially during intensive rainfall (Kumar *et al.,* 2012; Rajeswar and Ramulu, 2016). Nevertheless, soil acidity is a major constraint for the entire area requiring application of liming materials in appropriate doses for better crop production (Singh *et al.,* 2021).

EC of soils remained below 2 dS m^{-1} imposing no salinity-based threat to crops (Dash *et al.,* 2018; Sethy *et al.,* 2019). SOC decreased with soil depth. Higher SOC in the surface horizons could be because of fresh accumulation and decomposition of crop residues every year in the surface horizons (Dorji *et al.,* 2014; Dash *et al.,* 2019c). Alike pH, SOC also increased as pedon 1<pedon 2<pedon 3. Higher SOC in the stream terrace land might be due to reduced oxidation of organic matters because of higher soil moisture status.

In general, exchangeable bases varied in order of $Ca^{+2}>Mg^{+2}>Na^{+}>K^{+}$ and their concentrations increased with soil depth having significant positive correlations with clay (r=0.71) and pH (r=0.77). BS also increased with depth and had significant positive correlation (r=0.83) with pH. CEC in general increased with soil depth and had significant positive correlation with clay (r=0.72) and exchangeable bases (r=0.83). Kishore *et al.* (2020) also observed such type of correlations. Both BS and CEC increased towards lower topographic positions, which could possibly because of the washing out and subsequent deposition of basic cations from higher to lower topographic positions, especially with run-off water (Giri *et al.,* 2017).

Exchangeable acidity i.e., sum of exchangeable Al^{3+} and H^{+} showed a reverse trend to that of the exchangeable bases and decreased with soil depth in all the pedons. Exchangeable acidity also decreased towards landforms at lower topographic positions. Decrease in exchangeable acidity might have been caused by dominance of basic cations in the exchange complex. Exchangeable acidity possessed significant negative correlationswith soil pH (r=-0.68) and exchangeable bases (r=-0.71). As the exchangeable Na^{+} content increased with soil depth, ESP also increased with the soil depth.

Conclusion

In the present investigation, three soil profiles in a toposequence have been studied for their physicochemical properties. Results indicate clay migration both from upper to lower elevations within a landscape and also from upper to lower horizons within a soil profile. In terms of higher ranges of clay content, porosity, WHC, soil pH, SOC, exchangeable bases, CEC, BS, and lower ranges of BD, exchangeable acidity, the soils of the stream terrace land were found most suitable for crop production followed by the medium and foothill lands.In contrast, soils of foothill land were characterized with lower ranges of pH (higher acidity), SOC, CEC, BS, and higher BD possessing constraints for crop production. Constraints of foothill land can be reduced by applying sufficient organic matter and adopting soil conservation measures against soil erosion.Nevertheless, soils of all the pedons need to be ameliorated for soil acidity by applying suitable liming materials at appropriate doses for better crop production.

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Conflict of interest

None

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