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Depth Wise Distribution of Soil Physico-Chemical Properties and Nutrients Across a Toposequence Located at KVK Farm, Sakhigopal, Odisha, India

Sonali Priyadarshini [a], Prava Kiran Dash [a,b*], Jatiprasad Barala [c], Antaryami Mishra [a,c], Moruboyina Aditya Kishore [a], Truptimayee Pattnaik [d] and Sirla Abhishek [a]

[a] Department of Soil Science, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, 751003, India.
[b] Regional Research and Technology Transfer Station, Mahisapat-759013, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India.
[c] Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Siksha 'O' Anusandhan University, Bhubaneswar-751029, India.
[d] Department of Basic Science and Humanities, Gandhi Institute of Excellent Technocrats, Gangapatana, Bhubaneswar, Odisha 752054, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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**Corresponding author: E-mail: dashprava111@gmail.com;*

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ABSTRACT

This study aims to identify soil-related constraints for crop production and provide insights for soil management by analyzing soil profiles across different topographic positions (upland, medium land, and lowland) at KVK farm, Sakhigopal, Puri located in the East and Southeastern Coastal Plain Agro-Climatic Zone of Odisha. The profiles were evaluated for key physico-chemical properties and nutrient contents, revealing significant variations influenced by topography. The results showed that the soil's physical and chemical properties and available nutrient status showed distinct variations among the pedons. Among soil physical properties, the sand percentage, bulk density, and particle density increased with soil depth. Whereas, the clay percentage, total porosity, and water-holding capacity decreased with soil depth. Soil pH ranged from 6.32 to 7.50 and the electrical conductivity was recorded below 1 dSm^{-1}. The organic carbon content ranged from 8.6 to 10.3 g kg^{-1}. In general, soil pH, base saturation, and exchangeable cations increased with soil depth. On the other hand, soil organic carbon content and exchangeable acidity decreased with soil depth. Available nitrogen, phosphorus, potassium, and sulphur contents decreased with soil depth. However, in general, their concentrations increased along the slope (towards low land), which may be attributed to increased levels of organic carbon and clay contents in the lower topographic positions owing to high moisture content and higher cropping intensity. The findings of this study provide valuable insights regarding soil property characterisation across a transect for sustainable land use planning.

Keywords: Topography; Sakhigopal; Puri; physico-chemical characteristics; vertical distribution of available nutrients; transect.

1. INTRODUCTION

Soil fertility and crop productivity are significantly impacted by the properties of the soil profile, which are influenced by several soil-forming processes [1-6]. Soil genesis has a significant impact on soil physico-chemical properties and available nutrient status [7,8]. The physico-chemical properties and distribution of available macronutrients provide a comprehensive idea about the fertility status of the studied area [9,10]. Of all the variables that contribute to soil formation, topography and parent material have a greater impact [11]. Given that soil and water are the primary natural resources needed for both crop production and human habitation, a thorough investigation that includes soil profile characterization and evaluation of soil nutrient status has greater importance [12,13].

Studying variations in soil properties along a toposequence not only helps to detect topography-related crop production limits but also helps in selecting suitable crops, cropping methods, land use planning and soil and water management activities for diverse land types [14]. Additionally, it will be helpful to identify soil fertility-related agricultural production constraints on the farm based on which, necessary remedial measures can be recommended for maximizing crop yield. Moreover, any research on soil survey is a great asset for future research purposes. Since works on soil characterization on various land types of KVK farm, Sakhigopal have not been previously carried out, therefore, in the present study, an attempt has been intended to characterize the soils of KVK farm, Sakhigopal with the following objectives (a) to evaluate the vertical distribution of key physico-chemical properties and macronutrient status in soils across different topographic positions (upland, medium land, and lowland) and (b) to identify soil-related constraints influenced by topography and provide insights for developing soil management practices aimed at optimizing crop productivity and sustaining soil health.

2. MATERIALS AND METHODS

2.1 The Study Area

The study area was Krishi Vigyan Kendra (KVK) farm Sakhigopal, which is located in Puri District, Odisha, India. KVK, Sakhigopal is one of the oldest Coconut Research Stations in our country and it was established in the year 1955 by the Government of Odisha. The study area is situated at 19^0 48' N latitude and 85^0 52' E longitude and is located at a distance of 20 kilometres from the Bay of Bengal.

The region comes under the East and South Eastern Coastal Plain Agro-Climatic Zone of

Odisha. The climate of the study area is relatively warm and humid, with short and mild winters. The mean annual rainfall is 1409 mm, mainly due to the southwest monsoon. The maximum average summer temperature is 39˚C. The summer season runs from March to mid-June, followed by the rainy season from June to September.

2.2 Methods of Soil Survey and Sample Collection

The landforms of the research station were determined by exploring the area and using a GPS device (Garmin MAKE; model: 76MAPCSx) to monitor and record the elevation above the Mean Sea Level (MSL) at several locations. The study area has been divided into three physiographic units based on slope and elevation such as gently sloping upland (elevation of 30 metres above the MSL), very gently sloping medium land (elevation of 26 metres above the MSL) and nearly level low land (elevation of 22 metres above the MSL). Three representative soil profiles viz., pedon 1, 2, and 3 were exposed (with size approximately 1m x 1m x 1.5m) in upland, medium land, and low land comprising of 7, 8 and 7 numbers of horizons, respectively (Fig. 1).

2.3 Soil Analysis

Horizon-wise soil samples from three soil profiles were collected from the study area. Samples were air-dried, ground with a wooden hammer and passed through a 2 mm sieve for analysis of various physico-chemical properties. Textural classes of the soils were determined by the Bouyoucous hydrometer method [15]. Soil pH was determined in 1:2.5 soil water ratio by pH meter as described by Jackson [16]. As suggested by Jackson [16], the electrical conductivity of soil-saturated pastes was determined in 1:2.5 soil-water suspension by a conductivity meter. The organic carbon content of the soils was determined by the wet digestion procedure of Walkley and Black [17]. Furthermore, the soils were analyzed for bulk density [18], particle density [19], water-holding capacity [20], cation exchange capacity [21], exchangeable acidity [22], exchangeable cations [23], available nitrogen [24], phosphorus [25], potassium [26], and sulphur [27] using standard procedures.

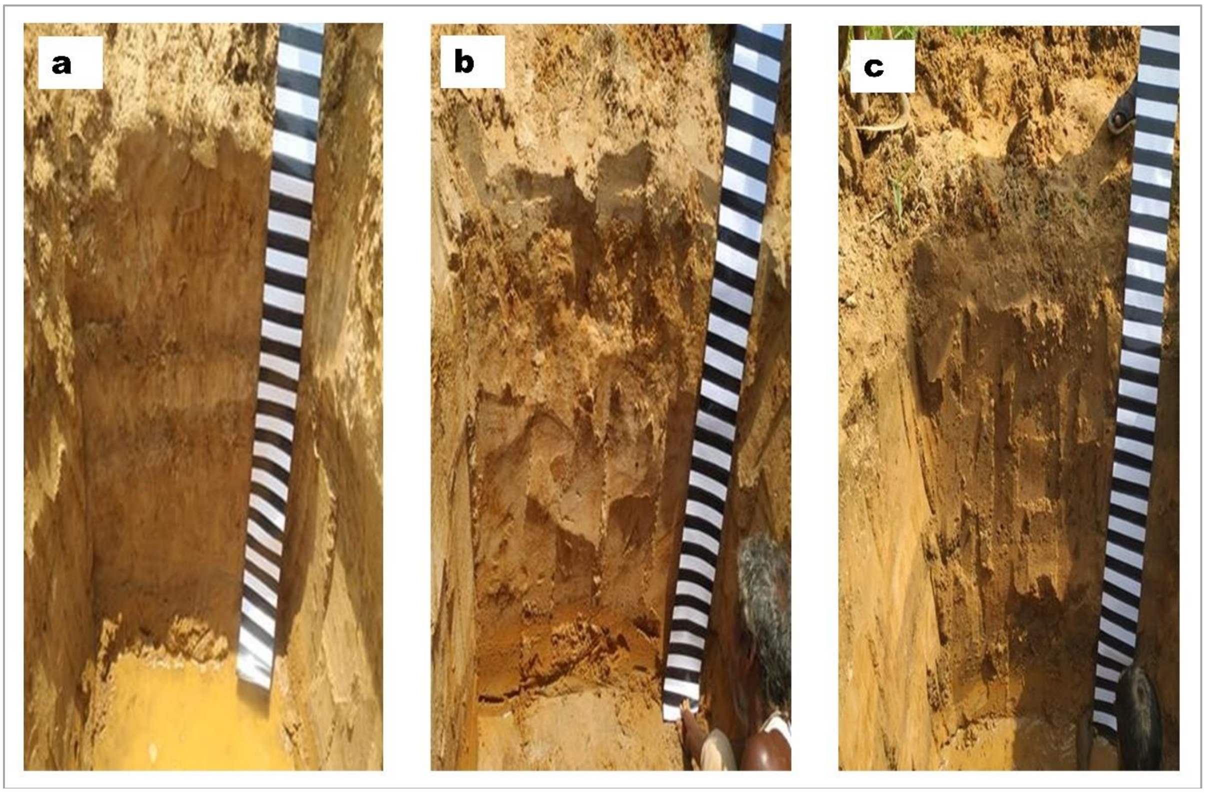

Fig. 1. Soil profiles of (a) pedon 1-upland, (b) pedon 2-medium land, and (c) pedon 3-low land. (Note: Each black and white division of the scale represents 3 cm.)

3. RESULTS AND DISCUSSION

3.1 Physical Properties of Pedons

Physical characteristics of pedons 1, 2, and 3 have been presented in Tables 1a, 1b, and 1c, respectively.

3.1.1 Particle size distribution

Soil textural class varied from sandy to loamy sand for pedon 1 and 2 and sandy to sandy clay loam for pedon 3. The percentage of sand, silt, and clay contents ranged between 88.4 to 97.4, 0.2 to 4, and 4.6 to 9.6 percentage in pedon 1 (Table 1a); 88.4 to 94.4, 0.2 to 4, and 4 to 7.6 percentage in pedon 2 (Table 1b); 64.4 to 92.4, 2 to 14 and 5.6 to 23.6 percentage in pedon 3 (Table 1c), respectively. The sand content increased gradually from the upper horizons towards the lower horizons. The clay content decreased with depth in all three pedons (Fig. 2a). Similar results were observed by Dash et al. [7]

3.1.2 Bulk density

Pedon 1, pedon 2 and pedon 3 recorded the bulk density values in the range of 1.62 to 1.91 Mg m^{-3}, 1.53 to 1.90 Mg m^{-3}, and 1.31 to 1.51 Mg m^{-3}, respectively. Higher bulk density values were recorded in lower horizons (Fig. 2b), which could be due to higher sand content, lower clay content, low organic carbon content, and increased effect of compaction in the lower horizons. Whereas, the bulk density was lower in surface horizons, possibly due to high organic carbon content. Similar findings were reported by Dash [7, 11], and Barla [28].

3.1.3 Particle density

The particle density values of 2.44 to 2.68 Mg m^{-3}, 2.36 to 2.67 Mg m^{-3}, and 2.33 to 2.58 Mg m^{-3} were recorded in pedons 1, 2 and 3, respectively. Similar to bulk density, particle densities also increased with soil depth from upper to lower horizons (Fig. 2c), which might be attributed to lower organic carbon in the lower horizons than that of the upper horizons of the soil profiles [29].

3.1.4 Total porosity

The total porosity values of pedons 1, 2 and 3 varied from 26.4 to 34%, 28.9 to 36.3%, and 41.5 to 45%, respectively. Similar to percentage clay, total porosity also decreased with soil depth. Dash et al. [7] found similar observations.

3.1.5 Maximum water holding capacity

The maximum water holding capacity (WHC) varied from 27.2 to 35.6%, 31.5 to 35.79%, and 33.6 to 44.2% in pedons 1, 2 and 3, respectively. In all three pedons, WHC decreased with soil depth (Fig. 2d), which may be related to the varying clay percentages in the pedons.

3.2 Chemical Characteristics of Pedons

Chemical characteristics of the soil properties of pedons 1, 2, and 3 have been presented in Tables 2a, 2b, and 2c, respectively.

3.2.1 Soil reaction

In pedon 1, the surface soil and lower horizons recorded pH values of 6.80 and 7.50, respectively. The slightly acidic surface soil of pedon 2 had a pH value of 6.34 and increased up to 6.55 with depth at the bottom horizon. In pedon 3, the pH values of 6.32 and 6.68 were recorded in the surface and lowermost horizons, respectively. The pH values of all three pedons showed a consistent trend of increasing from upper to lower horizons (Fig. 3a), possibly due to the leaching of basic cations from upper to lower horizons followed by heavy rainfall. Similar results were reported by Barla [28] and Kumar et al. [30].

3.2.2 Electrical conductivity

The electrical conductivity (EC) of all three soil profiles remained below 1 dSm^{-1}, making them safe for all types of agricultural production without any salinity hazard. Such lower electrical conductivity could be attributed to the leaching of soluble salts during intensive rainfall as prevalent in the study area.

3.2.3 Organic carbon

Soil organic carbon content of surface horizons of pedons 1, 2 and 3 was found to be 8.6, 9.1, and 10.3 g kg^{-1}, respectively and decreased with depth across the three soil profiles (Fig. 3b). Fresh accumulation and decomposition of crop residues in the surface horizons contributed higher organic carbon in the upper horizons. Similar findings were reported by Dorji et al. [31], Kumar et al. [30] and Khanday et al. [32].

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

Horizon	Depth (cm)	Sand	Silt	Clay	Textural Class	Bulk density	Particle density	Porosity	WHC
			(%)				(Mg m^{-3})		(%)
Ap	0-12	88.4	2	9.6	Loamy sand	1.62	2.44	34	35.6
C1	12-27	88.4	4	7.6	Loamy sand	1.63	2.45	33.5	32.4
C2	27-60	92.4	2	5.6	Sand	1.77	2.54	27.2	27.2
C3	60-96	94.4	0.2	5.4	Sand	1.90	2.65	28.4	28.9

Table 1b. Physical characteristics of Pedon 2 (Medium land)

Horizon	Depth (cm)	Sand	Silt	Clay	Textural Class	Bulk density	Particle density	Porosity	WHC
			(%)				(Mg m^{-3})		(%)
Ap	0-12	92.4	2	5.6	Sand	1.53	2.36	35.2	33.7
A2	12-27	94.4	0.2	5.4	Sand	1.56	2.44	36.1	32.8
C1	27-39	94.4	0.2	5.4	Sand	1.58	2.48	36.3	31.5
C2	39-79	88.4	4	7.6	Loamy sand	1.64	2.56	34.5	35.8
C3	79-115	92.4	2	5.6	Sand	1.84	2.65	29.6	34.2

Table 1c. Physical characteristics of Pedon 3 (Low land)

Horizon	Depth (cm)	Sand	Silt	Clay	Textural Class	Bulk density	Particle density	Porosity	WHC
			(%)				(Mg m^{-3})		(%)
Ap	0-12	64.4	12	23.6	Sandy Clay loam	1.31	2.33	44.8	37.4
C1	12-30	66.4	15	21.6	Sandy Clay loam	1.33	2.37	44	43.5
C2	30-75	64.4	14	21.6	Sandy Clay loam	1.35	2.45	44.3	44.2
C3	75-120	92.4	2	5.6	Sand	1.42	2.53	44	34.8

Table 2a. Chemical characteristics of Pedon 1 (Upland)

Horizon	Depth (cm)	pHw (1:2.5)	ECw (1:2.5)	Organic carbon (g kg^{-1})	Exchangeable cations [cmol(p$^+$) kg^{-1}]					Total exchangeable acidity	Cation Exchange Capacity	Base saturation	ESP
					Ca	Mg	Na	K	Sum	[cmol(p$^+$) kg^{-1}]		(%)	
Ap	0-12	6.80	0.01	8.6	6.6	0.9	0.7	0.5	8.7	1.3	13.3	65.4	5.2
C1	12-27	6.84	0.02	8.1	6.4	0.8	0.7	0.6	8.5	1.1	12.8	66.5	5.4
C2	27-60	7.43	0.02	6.8	6.3	0.7	0.5	0.7	8.2	1.1	12.3	66.6	5.6
C3	60-96	7.46	0.03	5.2	6.5	0.8	0.7	0.5	8.3	0.8	12.3	67.5	5.6

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

Horizon	Depth (cm)	pHw (1:2.5)	ECw (1:2.5)	Organic carbon (g kg^{-1})	Exchangeable cations [cmol(p$^+$) kg^{-1}]					Total exchangeable acidity	Cation Exchange Capacity	Base saturation	ESP
					Ca	Mg	Na	K	Sum	[cmol(p$^+$) kg^{-1}]		(%)	
Ap	0-12	6.34	0.04	9.1	7.8	0.3	0.2	0.5	8.8	1.1	12.8	68.7	3.5
A2	12-27	6.37	0.05	8.8	7.9	0.2	0.2	0.5	8.8	1.1	12.7	69.2	4.0
C1	27-39	6.43	0.05	7.6	7.5	0.3	0.2	0.7	8.6	0.9	12.6	68.2	5.4
C2	39-79	6.47	0.06	6.5	7.9	0.4	0.6	0.7	9.8	0.8	12.7	77.1	5.5
C3	79-115	6.53	0.06	5.7	7.6	0.5	0.6	0.7	9.4	0.7	11.7	80.3	5.8

Table 2c. Chemical characteristics of Pedon 3 (Low land)

Horizon	Depth (cm)	pHw (1:2.5)	ECw (1:2.5)	Organic carbon (g kg^{-1})	Exchangeable cations [cmol(p$^+$) kg^{-1}]					Total exchangeable acidity	Cation Exchange Capacity	Base saturation	ESP
					Ca	Mg	Na	K	Sum	[cmol(p$^+$) kg^{-1}]		(%)	
Ap	0-12	6.32	0.07	14.8	8.8	0.7	0.6	1.1	11.2	1	14.8	75.6	4.4
C1	12-30	6.47	0.07	14.3	8.7	0.7	0.7	1.0	11.1	1	14.4	77	5.5
C2	30-75	6.56	0.08	14.4	8.8	0.7	0.7	0.9	11.1	0.7	14.3	77.6	5.8
C3	75-120	6.70	0.08	13.6	8.6	0.6	0.8	0.9	10.9	0.5	13.6	80	5.9

Table 3. Depth-wise distribution of available nutrients in representative pedons of the study

Horizon	Depth (cm)	N	P	K	S
			(kg ha^{-1})		
Pedon 1 (Upland)					
Ap	0-12	198	22	447	1.8
C1	12-27	175	20.8	536	1.8
C2	27-60	166	19.4	543	1.7
C3	60-96	142	12.7	548	1.7
Pedon 2 (Medium land)					
Ap	0-12	218	37.5	470	2.6
A2	12-27	195	28.2	469	2.8
C1	27-39	176	25.3	552	3.3
C2	39-79	158	21.4	556	2.4
C3	79-115	137	16	561	2.2
Pedon 3 (Lowland)					
Ap	0-12	240	37.7	481	4.8
C1	12-30	196	23	552	5.2
C2	30-75	181	19.7	554	4.2
C3	75-120	162	14	565	3.2

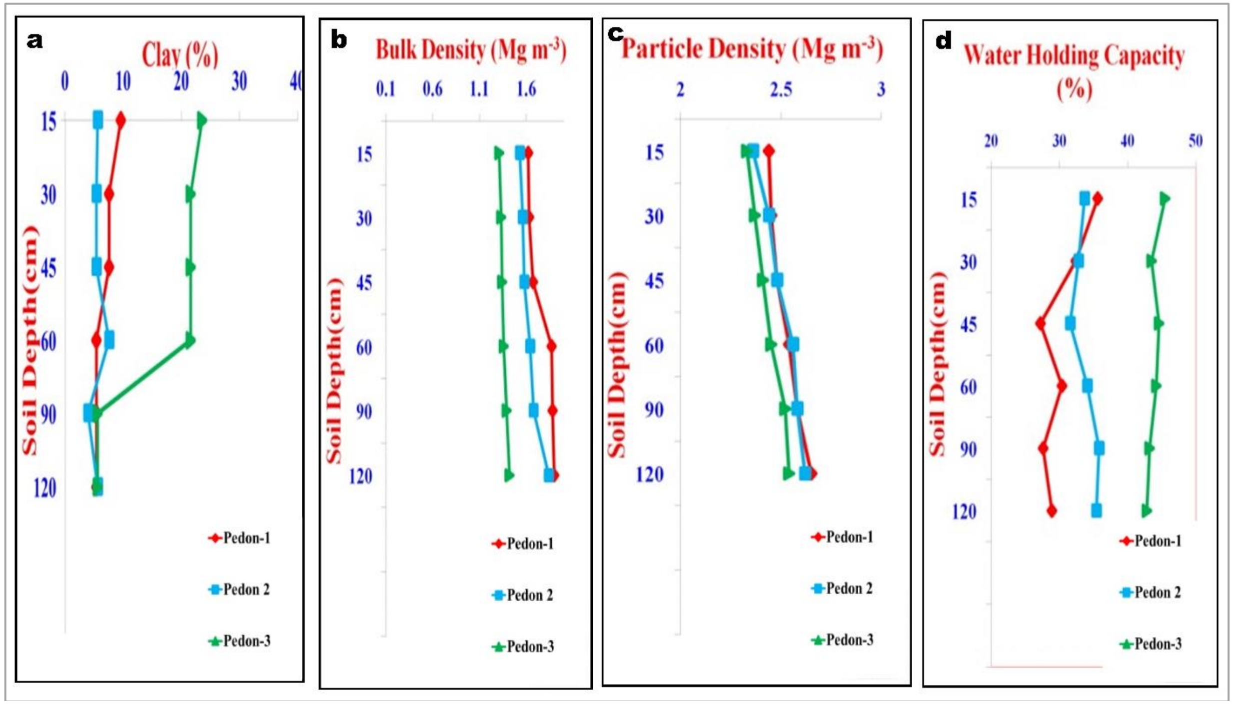

Fig. 2. Vertical distribution of (a) clay, (b) bilk density, (c) particle density, and (d) water holding capacity in the representative pedons of the study area

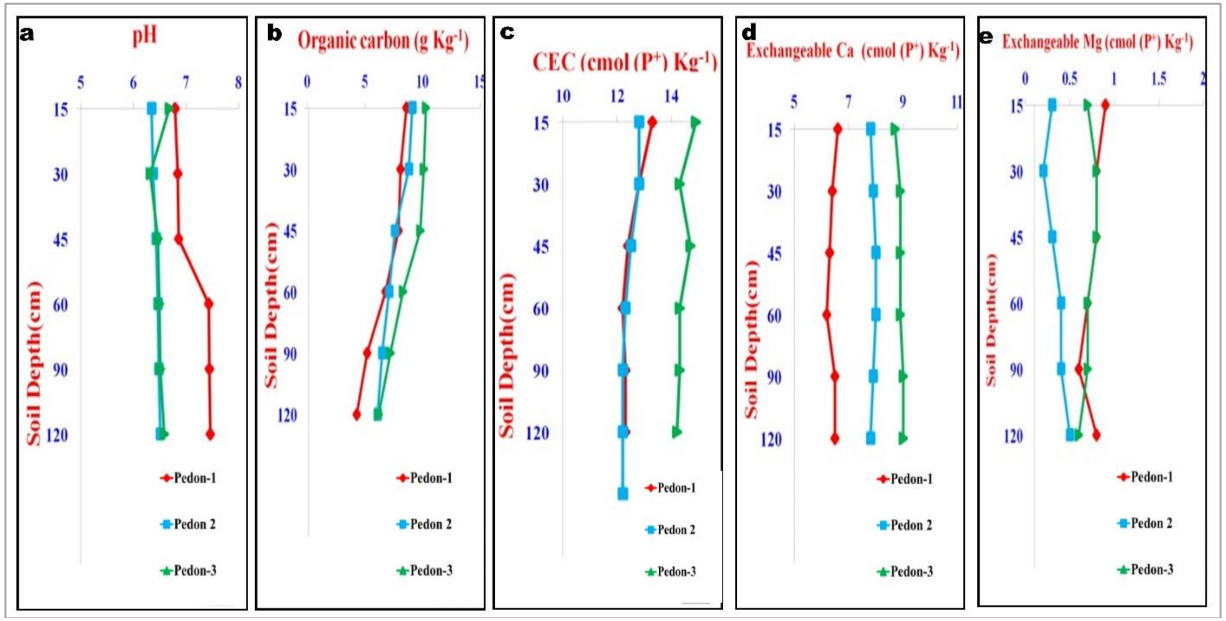

Fig. 3. Vertical distribution of (a) pH, (b) organic carbon, (c) cation exchange capacity, (d) exchangeable Ca, and (e) exchangeable Mg in the representative pedons of the study area

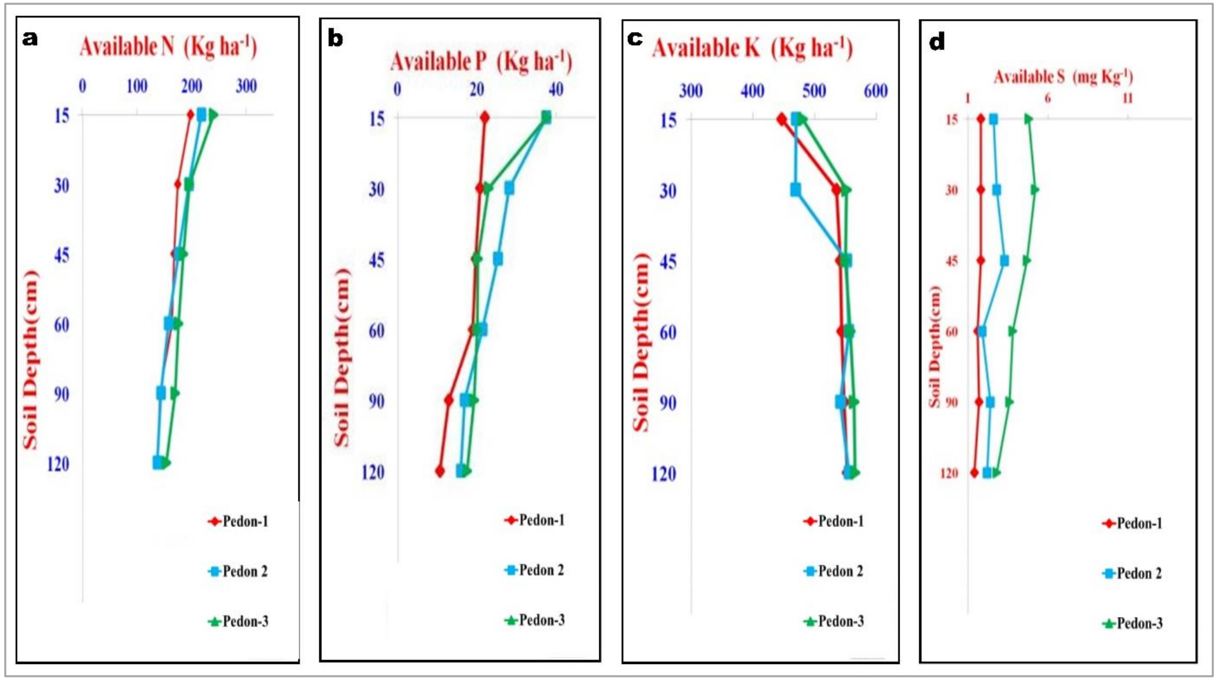

Fig. 4. Vertical distribution of (a) available nitrogen, (b) available phosphorus, (c) available potassium, and (d) available sulphur in the representative pedons of the study area

3.2.4 Exchangeable bases, cation exchange capacity (CEC), and base saturation

The concentration of exchangeable bases *viz.,* calcium, magnesium, sodium and potassium in different pedons was found to be in the order of Ca^{2+} >Mg^{2+} >Na^{+} >K^{+}. The CEC values of 13.3, 12.8, and 13.6 cmol(p^{+}) kg^{-1} were recorded in the surface horizons of pedons 1, 2 and 3, respectively, which gradually decreased with depth in all three pedons (Fig. 3c). This could be due to a decrease in clay percentage with soil depth. These results conform with the findings of Pattnaik et al. [6]. The surface horizons of pedons 1, 2 and 3 recorded base saturation percentages of 65.4, 68.7, and 75.6, respectively. Base saturation was observed to increase with soil depth, which could be attributed to an increase in the basic cations with depth in all three pedons (Fig. 3d and 3e).

3.2.5 Exchangeable Sodium Percentage (ESP)

The ESP varied from 5.2 to 5.6, 3.5 to 5.8, and 4.4 to 5.9% in pedons 1, 2 and 3, respectively. The gradual increment of ESP with depth in all three soil profiles might be due to the leaching of sodium (Na^{+}) ions from upper to lower horizons during intensive rainfall [33].

3.3 Depth-Wise Vertical Distribution of Available Macro Nutrients in Different Pedons

The depth-wise vertical distribution of available macronutrients *viz.,* nitrogen, phosphorus, potassium and sulphur are presented in Table 3. In pedon 1, the depth-wise available N, P, K and S content varied from 142 to 198, 12.7 to 22, 447 to 548, and 1.7 to 1.8 kg ha^{-1}, respectively. Similarly, the N, P, K and S content ranged from 137 to 218, 16 to 37.5, 469 to 561, 2.2 to 3.3 kg ha^{-1} in pedon 2 and 162 to 240, 14 to 37.7, 481 to 565 and 3.2 to 5.2 kg ha^{-1} in pedon 3, respectively. The concentration of available N, P, and S was higher in surface horizons and the lowest concentration was in the bottom horizons (Fig. 4a, 4b, 4c, 4d). In all three pedons, available N, P, and S content decreased with an increase in depth, whereas available K was increased with the soil depth. The increased concentrations of nitrogen, phosphorus and sulphur towards lower topographic positions could be attributed to higher organic carbon content in the low lands. The presence of potassium bearing parent materials like Feldspar and Mica could be the reason for increased potassium availability with soil depth [8, 34-37].

4. CONCLUSION

The present study provides valuable insights into the vertical distribution of physico-chemical properties and nutrient status across upland, medium land, and lowland topographic positions within the KVK farm, Sakhigopal, Puri. The findings reveal that soil properties, such as bulk density, particle density, pH, organic carbon, and exchangeable cations, vary significantly with soil depth and topographic position. These variations highlight the need for site-specific soil management practices tailored to the unique characteristics of each landscape position.

The observed increase in bulk density and particle density with depth, along with the reduction in organic carbon, nitrogen, phosphorus, and sulphur, underscores the importance of maintaining organic matter in surface soils to enhance nutrient availability and soil structure. In contrast, the increase in available potassium with depth suggests that parent material characteristics and river deposition play a key role in its distribution, which may require different nutrient management strategies for potassium.

For future research, a detailed investigation into the interaction between topography, soil depth, and cropping intensity is crucial to better understand nutrient dynamics and their long-term effects on crop productivity. Moreover, examining the role of soil organic carbon sequestration in different topographic positions can provide insights into sustainable land-use practices that enhance both soil health and climate resilience.

From a practical perspective, the findings call for the adoption of tailored nutrient management strategies that address topography-specific constraints. Practices such as applying organic amendments, ensuring proper soil aeration, and targeted nutrient supplementation can help optimize crop productivity and promote sustainable land use. This research serves as a foundation for developing precision soil management approaches that contribute to both agricultural productivity and environmental sustainability.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

The authors have declared that no competing interests exist.

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