Depthwise Distribution of Soil PhysioChemical Properties and Nutrients Across Topographic Positions at KVK Farm, Sakhigopal, Odisha, India

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 content, revealing significant variations influenced by topography. The results showed that the soil's physical and chemical properties andavailable nutrient status showed distinct variations among the pedons. Among soil physical properties, percentage sand, bulk density, and particle density increased with soil depth. Whereas percentage clay, 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, 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, their contents increased towards the lower topographic position, which maybe attributed to increased levels of organic carbon and clay contents in the lower topographic positionowing to high moisture content and higher cropping intensity.These findings can guide land-use planning and help optimize crop productivity while sustaining soil health.

Keywords:topography, Sakhigopal, Puri, physico-chemical characteristics, vertical distribution of available nutrients

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 (Digal et al. 2018, Sethy et al. 2019, Swain et al. 2019, Lokya et al. 2020, Singh et al. 2021,Pattnaiket al., 2023). Soil genesis has a significant impact on soil physico-chemical properties and available nutrient status as well (Dash et al. 2019a, 2019b). The physico-chemical properties and distribution of available macro nutrients provide a comprehensive idea about the fertility status of the studied area(Dash et al., 2023; Revathi et al., 2024). Of all the variables that contribute to soil formation, topography and parent material have a greater impact (Dash et al., 2019c). 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 statushave a greater importance (Dash et al., 2022a, 2022b).

Studying variations in soil properties along a toposequence notonly helpstodetecttopography relatedcropproductionlimits,butalsohelpsinselecting suitable crops, cropping methods, land use planning and soil and watermanagementactivitiesfordiverselandtypes (Dash et al., 2022c).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 landtypesofKVKfarm,Sakhigopalhavenotbeenpreviously carriedout, therefore,inthe present study,an attempthas been intended tocharacterize the soils ofKVKfarm, Sakhigopalwith the following objectives (a) to evaluate the vertical distribution of key physico-chemical properties and macro-nutrient 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 site-specific soil management practices aimed at optimizing crop productivity and sustaining soil health.

2. Materials and Methods

2.1. Thestudy area

The study area wasKrsihi Vigyan Kendra (KVK) farm Sakhigopal, which is located in Puri District, Odisha, India. KVK, Sakhigopal is one of the oldest Coconut ResearchStations in our country and it was established in the year 1955 by the Government of Odisha.The study areais situated between $19^{0}48'$ N latitude and $85^{0}52'$ E longitude and is locatedatadistanceof20kilometersfromtheBayofBengal.

The region comes under the East and South Eastern Coastal Plain Agro-ClimaticZoneofOdisha.The climate of the study area is relatively warm and humid, with shortandmild winters. The mean annual rainfall is 1409 mm, mainly due to the southwestmonsoon. The maximum average summer temperature is 39^{0}C. The summer seasonruns from March to mid-June, followed by the rainy season from June to September.

2.2. Methodsof soilsurveyandsamplecollection:

The landforms of the researchstation were determined by exploring theareaand using a GPS device (Garmin MAKE; model: 76MAPCSx) to monitor and recordthe elevationdata aboveMeanSeaLevel (MSL)at several locations. The study area has been divided into three physiographic units based on slopeand elevation such as gently sloping upland (elevation of 30 feet above Mean SeaLevel), very gently sloping medium land (elevation of 26 feet above Mean Sea Level)and nearly levellow land (elevation of 22 feetabove Mean SeaLevel).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 7, 8 and 7 horizons,respectively (Fig. 1).

2.3. Soil analysis

The soil samples from three soil profiles collected from the study area were air driedand ground with a wooden hammer and passed through a 2 mm sieve for analysis of various physico chemical properties.The textural classes of soil were determined by Bouyoucous hydrometer method (Bouyoucos, 1962). Soil pH was determined in 1:2.5 soil water ratio by pH meter as described by Jackson (1973). As suggested by Jackson (1973), the electrical conductivity of soil saturated paste was determined in 1:2.5 soil-water suspension by a conductivity meter. The organic carbon content of soil was determined by wet digestion procedure of Walkley and Black (1934). Furthermore the soils were analyzed for bulk density (Klute 1986), particle density (Chopra and Kanwar 1986), water holding capacity (Piper 1950), cation exchange capacity (Chapman 1965), exchangeable acidity (Thomas 1996), exchangeable cations (Page et al. 1982), available nitrogen (N; Subbiah and Asija, 1956), phosphorus (P; Bray and Kurtz, 1945), potassium (K; Hanway and Heidel, 1952) and sulphur (S; Chesnin and Yien, 1950)using standard procedures.

3. Results and Discussion

3.1. Physical properties of pedons

Physical characteristics of the soil properties of pedon 1, 2, and 3 have been presented in Table 2a, 2b, and 2c, respectively.

3.1.1. Particle size distribution

The soil texture varied from sandy to loamy sand for pedon1 and 2 and sandy to sandy clay loam for pedon 3. Thepercentageofsand,siltandclay contentrangedbetween 88.4 to 97.4, 0.2 to 4 and 4.6 to 9.6 percentage in pedon 1 (Table 1a); 88.4 to94.4, 0.2 to 4 and 4 to 7.6 percentage in pedon 2 (Table 1b) and 64.4to92.4,2to14 and 5.6 to 23.6 percentage in pedon 3 (Table 1c), respectively. The sand content increased gradually from upper horizons towards lower horizons. The clay content was found to be decreasing with depth in all the three pedons(Fig. 2a). Similar results were observed by Dash (2019a).

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 Mgm^{-3} respectively. Higher bulk density values were recorded in lower most horizons(Fig. 2b), which could possibly 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 due to high organic carbon content. Similar findings were reported by Dash (2019a, 2022a) and Barla (2021).

3.1.3. Particle density

The particle density values of 2.44to2.68Mgm^{-3},2.36 to 2.67 Mg m^{-3} and 2.33to 2.58Mgm^{-3} were recorded in pedon 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 (Acharya, 2021).

3.1.4. Total porosity

The total porosity values of pedon1, 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 decreased with soil depth. Dash (2019a) 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% for pedon 1, 2 and 3, respectively. In all three pedons, WHC was seen to be decreasing with 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 pedon 1, 2, and 3 have been presented in Table 2a, 2b, and 2c, respectively.

3.2.1. Soil reaction

In pedon 1, the surface soil and lower horizon 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 upto 6.55 with depth at lower horizon. The pH values of 6.32 and 6.68 were recorded in thesurface and lower most horizon of pedon 3, respectively. The pH values of all three pedons showed a consistent trend of increasing from upper to lower horizons(Fig. 3a), possibly due to leaching of basic cations from upper to lower horizons followed by heavy rainfall. Similar results were reported by Barla (2021) and Kumar *et al.* (2012).

3.2.2. Electrical conductivity

The electrical conductivity (EC) of all the 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 leaching of soluble salts during intensive rainfall as prevalent in the study area.

3.2.3. Organic carbon

The organic carbon content of surface horizons of pedon 1, 2 and 3 were 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 of all pedonscontributed higher organic carbon in the upper horizons. Similar findings were reported by Dorji et al. (2014), Kumar et al. (2012) and Khanday et al. (2018).

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, 12.8and 13.6 $cmol(p^{+})kg^{-1}$ were recorded in the surface horizons of pedon 1, 2 and 3, respectively, which gradually decreased with depth in all the threepedons (Fig. 3c). This could be due to adecrease in clay percentage with soil depth.These results are in conformity with the findings of Pattnaiket al. (2023).The surface horizons of pedon 1, 2 and 3 recorded base saturation percentages of 65.4, 68.7 and 75.6, respectively. Base saturation was observed to be increasing with soil depth, which could be attributed to an increase in the basic cations with depth in all the 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 pedon 1, 2 and 3, respectively. The gradual increment of ESP with depth in all the three soil profiles might be due to leaching of sodium ions from upper to lower horizons during intensive rainfall (Mishra, 2008).

3.3. Depth wise vertical distribution of available macro nutrients in different pedons

Thedepth-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}. 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}inpedon 2 and 162 to 240, 14 to 37.7, 481 to 565 and 3.2 to 5.2 kg ha^{-1}inpedon 3, respectively. The concentration of available N, P, S was higher in surface horizons and the lowest concentration was in the bottom horizons(Fig. 4a, 4b, 4c, 4d). In all the three pedons, available N, P, S content decreased with increase in depth, whereas available K was found to be increasing with the soildepth. The increased concentrations of nitrogen, phosphorus and sulphur towards lower topographic positions could be attributed to higher organic carbon content. The presence of potassium bearing parent materials like Feldspar and Mica could be the reason for increased potassium availability with soil depth (Dash et al., 2019b; Kishore et al., 2020; 2022; 2023).

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.

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Disclaimer (Artificial intelligence)

Option 1:

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 manuscripts.

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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 (Lowland)

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

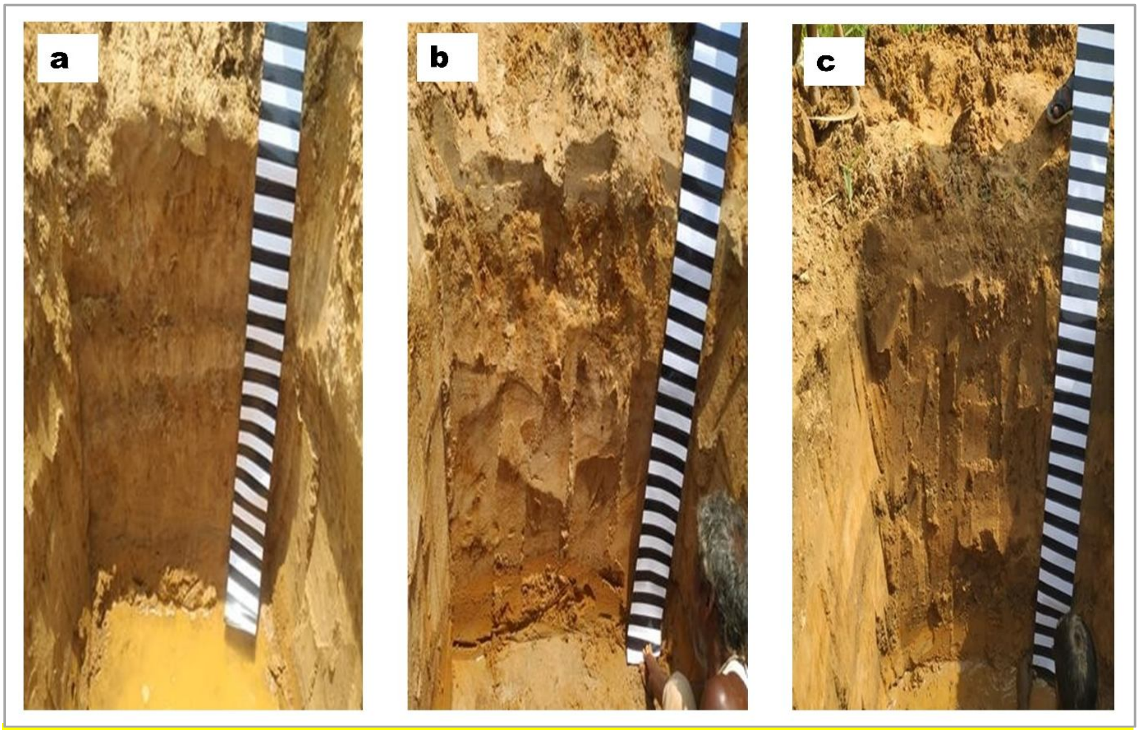

Fig. 1. Soil profiles of (a) Pedon 1-upland, (b) Pedon 2-medium land, and (c) low land. Eachblackandwhitedivisionofthe scale represents 3 cm.

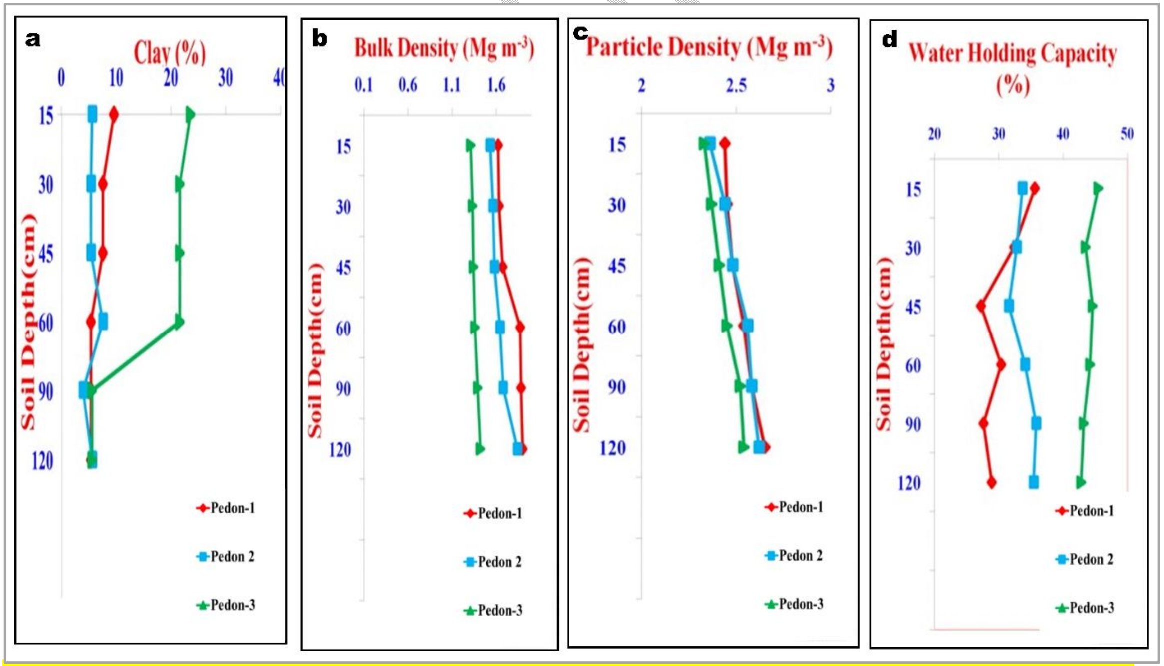

Fig. 2. Vertical distribution of (a) clay, (b) bilk density, (c) particle density, and (d) water holding capacity in the representative pedons of the study area.

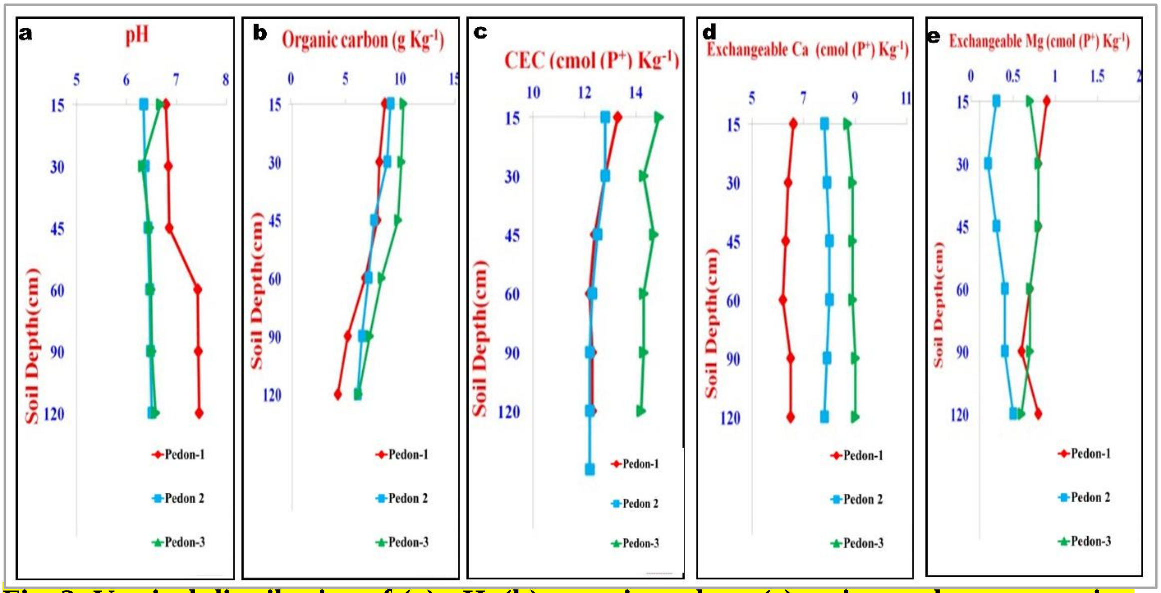

Fig. 3. Vertical distribution of (a) pH, (b) organic carbon, (c) cation exchange capacity, (d) exchangeable Ca, and (e) exchangeable Mg in the representative pedons of the study area.

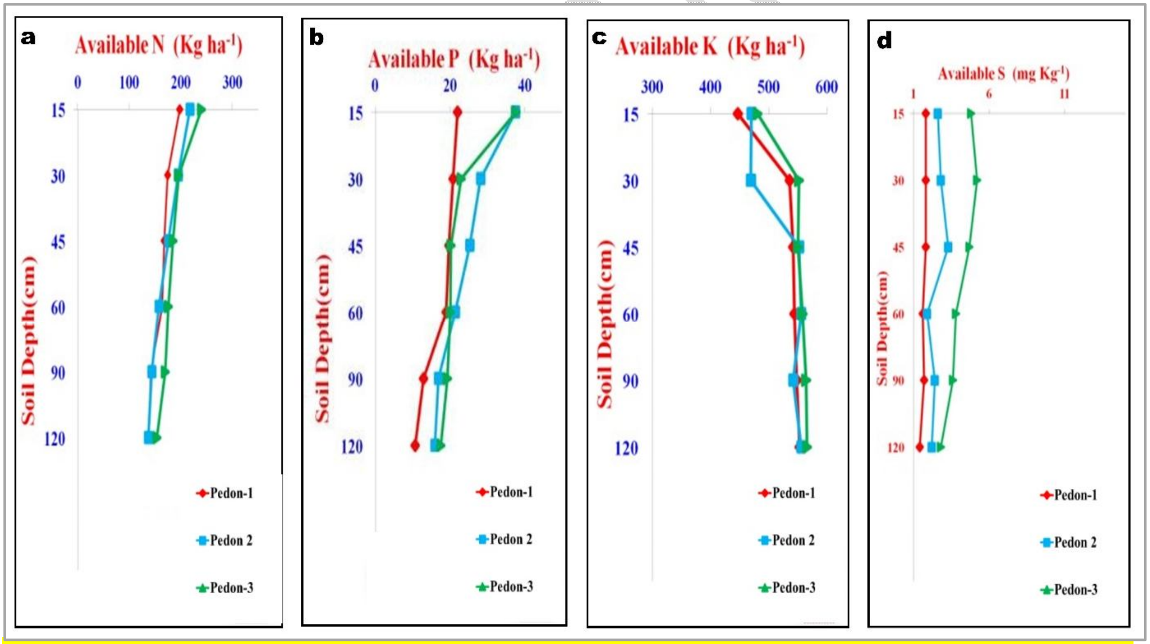

Fig. 4. Vertical distribution of (a) available nitrogen, (b) available phosphorus, (c) available potassium, and (d) available sulphur intherepresentativepedons ofthe study area.