Pedology and Environment 2024, 34 (02), 160-169
doi.org/10.47114/j.pedoenv.2024.dec 4

Soil characterisation and its carbon sequestration potential: a case study of Vemagal Hobli, Kolar District, Karnataka, India

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Abstract : A total of 46 soil profiles were studied for characterisation and classification in VemagalHobli, Kolar District, Karnataka, based on landform and land-use. The soils were grouped into seven soil series, viz., Cholaghatta, Madderi, Rajakallahalli, Ammanallur, Seethi, Alamgiri, and Vemagal, based on identifying characteristics. The soils were moderately deep to very deep, with surface colours ranging from red to dark yellowish-brown and textures varying from loamy sand to clay. Bulk density increased with depth, while sand content showed an irregular distribution. The highest clay content (38.9–52.9%) was recorded in the Alamgiri series. The soils were mostly acidic to neutral in reaction, with low electrical conductivity. A low cation exchange capacity range of 3–12 cmol(p^+) kg^{-1} was observed across all series. The Ammanallur and Alamgiri series had higher soil organic carbon stocks (2.05–4.64 kg m^{-2}) and greater carbon sequestration potential (5.02–8.74 kg m^{-2}), respectively. Characterising the soils based on their potential and limitations provides valuable insights for enhancing carbon sequestration potential and optimising productivity.

Keywords: *Soil classification; Soil organic carbon stock; Carbon sequestration potential.*

Introduction

Humanity is expected to face various interconnected challenges in the future, including climate change, human health, water, energy, food and nutrition security. Among these, soil security will play a crucial role in shaping the trajectory of these challenges (McBratney*et al.*, 2014). A slow decline scenario is characterised by stagnant productivity, continuous land degradation, and increasing threats from more unpredictable and extreme weather events. While the future remains uncertain, we should shape our expectations and take targeted actions to ensure a sustainable path forward to a resilient ecosystem. Knowledge of soil data is necessary for the scientific management of soil resources and the comprehension of soil processes. It is necessary to characterise the soils based on their properties for a better understanding due to their great diversity and dynamic nature(Lalitha *et al.*, 2016). Characterisation and classification of soils give information about their fertility status, thereby helping in the assessment of soil productivity. It also helps in the identification of soil-related constraints and in designing suitable reclamation measures.

Lalitha *et al.* (2018) assessed the fertility capability classification (FCC) in grasslands representing dry semi-arid climate of Tamil Nadu by characterising the soils and found that dry soil moisture (d+), low cation exchange capacity (e), basic reaction (b), alkalinity (n), gravel content (r), and low organic carbon content (m) as limiting factors. Lalitha *et al.* (2022)analysed the vertical distribution of soil organic

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and inorganic carbon in a silvi-pastoral system of Tamil Nadu's dry semi-arid region, highlighting the influence of soil properties on carbon stabilisation. Srinivasan *et al*. (2019) assessed the soil organic carbon (SOC) stock under cashew plantations in different management conditions of coastal Karnataka. The SOC stock was found to be higher in surface soils (2.0 to 8.23 kg C m^{-2}) compared to subsoils (0.08 to 3.28 kg C m^{-2}), and it decreased with depth. Kiran Kumara *et al.* (2023) characterised the soils with respect to different management practices to assess the carbon sequestration potential under varied sustainable agricultural practices. In this context, the present study was undertaken with the objective of characterising the soils of Vemagalhobli, Kolar district, Karnataka, to assess their potential for carbon sequestration and ecosystem sustainability.

Material And Methods

Study site description

The study area, Vemagalhobli (block) is located in Kolar district of Karnataka (Fig. 1). It covers an area of about 13,948 ha and is geographically located at 13°9'27.47" N to 13°18'17.13" N latitude and 77°56'5.32"Eto 78°5'10.43"E longitude. The study area belongs to the Central Karnataka plateau, a hot, moist and semi-arid eco-sub region. The major geology is granite and granite-gneiss. The elevation ranged from 820 to 1100 m above the mean sea level. The climate is tropical with maximum temperatures ranging from 30 to 36 °C and minimum temperatures ranging from 15 to 22°C. The annual rainfall is about 600 to 700 mm, and the major soil orders were *Alfisols* and *Inceptisols* (Reddy et al., 1996). The study area falls under a ustic soil moisture regime and an isohyperthermic soil temperature regime. The coverage of rock outcrops was found to be 2-10%. Major crops grown in the study area were mango, finger millet, tomato, eucalyptus, mulberry, red gram, brinjal, maize, *etc*.

Soil sampling and analysis

The soil profile locations were identified based on landform and land-use derived from Sentinel-2 imagery. About 46 profile locations were studied in transects and also randomly based on variations in base maps. These soil profiles were studied to the depth of 200 cm or to the depth limited by bedrock, and soil samples were collected horizon-wise from each profile. A total of 183 samples were collected from 46 identified profiles along with core samples for bulk density estimation. The collected samples were shade dried in the laboratory and then ground using a wooden pestle and mortar. The samples were passed through a 2 mm sieve to separate coarse fragments (gravel, pebbles, roots, etc). For organic carbon estimation, the soil samples were finely grinded and then sieved using a 0.2 mm sieve.

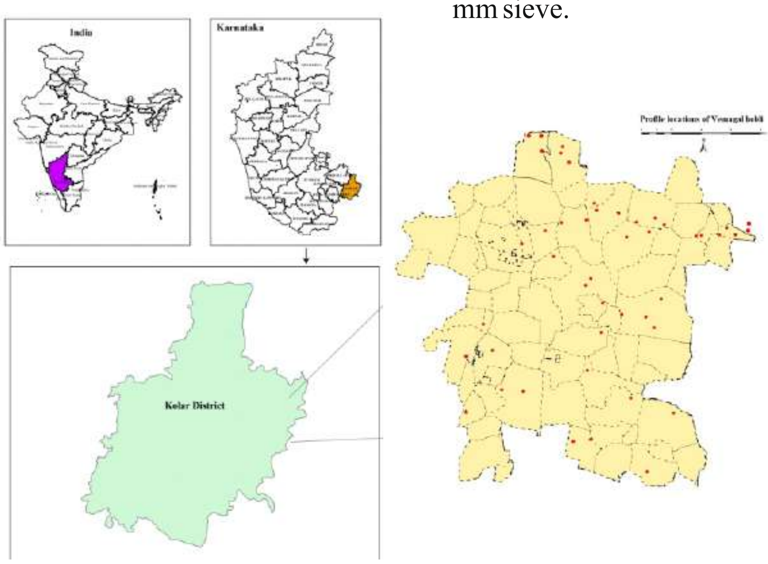

Fig. 1: Location map of Vemagalhobli, Kolar district, Karnataka, India

The processed soil samples were analysed in the laboratory for physical and chemical properties using standard analytical methods. Bulk density was determined by using the core method. Particle size analysis was carried out by the international pipette method (Jackson, 1973). Soil pH was determined by using the potentiometric method (Jackson, 1973) using a 1:2.5 soil: water ratio. Electrical Conductivity was determined by using the conductivity bridge method (Jackson, 1973). Soil organic carbon was determined by the wet digestion method (Walkley & Black, 1934).Cation exchange capacity was determined by the ammonium acetate leaching method described by Jackson (1973) by using neutral normal ammonium acetate solution. Available Water Capacity (AWC) was estimated by using the pedo-transfer functions given by Dharumarajan *et al*. (2019).

$$\text{Field Capacity (FC)} = 39.18 - 0.041(\text{Clay}) - 0.371(\text{Sand}) + 0.257(\text{CEC})$$

$$\text{Permanent Wilting Point (PWP)} = 8.227 + 0.168(\text{Clay}) - 0.101(\text{Sand}) + 0.217(\text{CEC})$$

$$\text{AWC (\%)} = \text{FC} - \text{PWP}$$

Available Water Capacity values in % was converted into mm by using the formula mentioned below.

$$\text{AWC (mm)} = (\text{AWC (\%)} \times \text{BD} \times \text{Depth})/10$$

Soil organic carbon (SOC) stock

Soil organic carbon stock was estimated for each layer of the soil profile by using the equation presented below (Dharumarajan *et al*., 2021).

$$\text{SOC stock (kg m}^{-2}) = (\text{OC \%}/100) \times \text{BD} \times \text{D} \times (1-\text{G}) \times 10$$

Where, SOC stock = Soil organic carbon stock in kg m^{-2}

OC = Organic carbon in %

BD = Bulk density in Mg m^{-3}

D = Depth of each horizon in cm

G = % Gravel content /100

Soil organic carbon sequestration potential

Carbon sequestration potential (CSP) was calculated by using the equations (Hassink, 1997) given below.

Potential C saturation (C_{sat}) = 4.09 +0.37 x (clay (%) + silt (%))

C saturation deficit ($C_{sat-def}$) = C_{sat} - C_{cur}

Where, $C_{sat-def}$= C saturation deficit (mgg^{-1})

C_{sat} = Potential C saturation (mgg^{-1})

C_{cur} = Current C concentration of the clay and silt fraction

CSP (kg m^{-2}) = $C_{sat-def}$ x BD x (1-G) x D x 10^{-2}

Where, CSP = Carbonsequestration potential (kg m^{-2})

$C_{sat-def}$ = C saturation deficit (mgg^{-1})

BD = Soil bulk density (Mgm^{-3})

D = Depth of the sampled soil layer (cm)

G = % Gravel content/100

Results and Discussion

Morphological properties

Table 1 represents the morphological properties of the master pedons of the identified soil series. Among them, Cholaghatta, Madderi and Rajakallahalli series were moderately deep (75-100 cm) to deep (100-150 cm), Ammanallur, Seethi and Vemagal series were deep (100-150 cm),and Alamgiri series was very deep (>150 cm). The deep to very deep soils mostly occurred in the lower topography (Maji *et al*., 2005). Argillic (Bt) sub-surface horizons were present in all the series except the Vemagal series, whose sub-surface horizon was cambic (Bw). The colour ranged from red to dark red, yellowish red to dark red, dark reddish brown to dark red, dark brown to red, yellowish red to red, yellowish red to dark reddish brown and brown to dark yellowish brown. The red colour of the soils might be due to the presence of hematite, and soils of yellow hue often contain goethite (Maejima*et al.,* 2000). Soil texture ranged from loamy sand to sandy clay loam in Cholaghatta series, loamy sand to sandy clay in Madderi series, sandy clay in Rajakallahalli series, sandy clay loam to sandy clay in AmmanallurandSeethi series, sandy clay to clay in Alamgiri series and sandy clay loam to clay in Vemagal series. Surface soil structure was moderate, medium, sub-angularblocky in most of the series except Cholaghattaand Madderi series, which exhibited weak, medium sub-angular blocky, whereas Alamgiri series exhibited strong, medium, sub-angular blocky structure. The Vemagal series exhibited all forms of consistency from non-sticky, non-plastic to very sticky, very plastic

Table 1: Morphological properties of representative profiles

Horizon	Depth (cm)	Boundary	Texture	Colour (moist)	Structure	Consistency
Cholaghatta series						
Ap	0-13	gs	ls	2.5YR 4/6	1 m sbk	s_o& p_o
Bt_1	13-55	gs	sc	2.5YR 3/6	2 m sbk	ms&mp
Bt_2	55-99	-	scl	2.5YR 3/6	2 m sbk	ss &sp
Madderi series						
Ap	0-20	as	ls	5YR 4/6	1 m sbk	s_o& p_o
Bt_1	20-53	as	sc	2.5YR 3/6	2 m sbk	ms&mp
Bt_2	53-92	-	sc	2.5YR 3/6	2 m sbk	ms&mp
Rajakallahalli series						
Ap	0-15	as	sc	2.5YR 3/4	2 m sbk	ms&mp
Bt_1	15-65	cs	sc	2.5YR 3/4	2 m sbk	ms&mp
Bt_2	65-110	cs	sc	2.5YR 3/4	2 m sbk	ms&mp
CB	110-140	-	sc	2.5YR 4/6	2 m sbk	ms&mp
Ammanallur series						
Ap	0-13	cs	scl	7.5YR 3/3	2 m sbk	ss &sp
Bt_1	13-49	gs	sc	5YR 4/6	2 m sbk	ms&mp
Bt_2	49-89	as	sc	5YR 4/6	2 m sbk	ms&mp
Bt_3	89-134	-	sc	2.5YR 4/6	1 m sbk	ms&mp
Seethi series						
Ap	0-17	cs	scl	5YR 4/6	2 m sbk	ss &sp
Bt_1	17-49	gs	sc	2.5YR 4/6	2 m sbk	ms&mp
Bt_2	49-99	gs	sc	2.5YR 4/6	2 m sbk	ms&mp
Bt_3	99-140	-	sc	2.5YR 4/6	2 m sbk	ms&mp
Alamgiri series						
Ap	0-17	cs	sc	5YR 4/6	3 m sbk	ms&mp
Bt_1	17-51	cs	c	2.5YR 3/4	2 m sbk	vs &vp
Bt_2	51-89	cs	c	2.5YR 3/6	2 m sbk	vs &vp
BC	89-151	-	c	2.5YR 3/4	2 m sbk	vs &vp
Vemagal series						
Ap	0-16	cs	scl	10YR4/3	2 m sbk	ss &sp
Bw_1	16-44	gs	sl	7.5YR4/4	2 m sbk	s_o& p_o
Bw_2	44-110	gs	sc	10YR4/4	2 m sbk	ms&mp
Bw_3	110-149	-	c	10YR3/6	2 m sbk	vs &vp

cs – clear smooth, **gs** – gradual smooth, **as** – abrupt smooth, **2 m sbk** – moderate medium sub-angular blocky, **3 m sbk** – strong medium sub-angular blocky, **1 m sbk**–weak medium sub-angular blocky, s_o – non-sticky, **ss** – slightly sticky, **ms** – moderately sticky, **vs** – very sticky, p_o – non-plastic, **sp** – slightly plastic, **mp** – moderately plastic, **vp** – very plastic

consistency, and it was related to the clay content (Tripathi *et al*., 2006).

Physical and chemical properties

The bulk density ranged from 1.24 to 1.64 (Mg m^{-3}) and it increased with depth (Table 2). This indicates that the sub-surface soils are more compact than surface soils, which might be due to tillage operations. All the series exhibited an irregular trend in sand content except the Alamgiri series (50.21 to 32.59 %),where sand content decreased with depth due to illuviation of clay particles. The clay content in the Alamgiri series was relatively high, ranging from 38.96 to 52.96%. The soils of Madderi and Alamgiri series exhibited an increase in clay content (4.59 to 37.21% and 38.96 to 52.96%) with depth, whereas other profiles showed an irregular trend with depth (Fig. 2). The increase in clay content might be due to an illuviation process that favours the accumulation of clay in sub-surface soil layers. With respect to silt content, an irregular trend with depth was noticed in all series. This irregular trend in sand, silt and clay content of most of the profiles might be due to different stages of pedological development (Sarkar *et al.,* 1997). The available water capacity (AWC) was highest in the Alamgiri series (9.45 to 11.73 %) in comparison with other series, which might be due to high clay content. The soils of all the series showed an irregular trend in

Table 2: Physical properties of representative profiles

Horizon	Depth (cm)	BD ($Mg\ m^{-3}$)	Sand (%)	Silt (%)	Clay (%)	AWC (%)
Cholaghatta series						
Ap	0-13	1.34	79.5	11.9	8.61	7.78
Bt_1	13-55	1.36	46.5	13.4	40.2	10.2
Bt_2	55-99	1.47	57.9	11.9	30.1	9.24
Madderi series						
Ap	0-20	1.38	84.2	11.2	4.59	7.33
Bt_1	20-53	1.45	49.2	14.1	36.7	10.3
Bt_2	53-92	1.50	49.3	13.5	37.2	10.2
Rajakallahalli series						
Ap	0-15	1.24	46.8	17.4	25.8	11.0
Bt_1	15-65	1.51	49.7	14.1	36.3	10.1
Bt_2	65-110	1.60	48.3	15.8	35.8	10.6
CB	110-140	1.62	48.9	16.0	35.1	10.6
Ammanallur series						
Ap	0-13	1.33	70.0	5.44	24.5	7.19
Bt_1	13-49	1.39	48.5	15.6	35.9	10.7
Bt_2	49-89	1.44	48.7	16.2	35.1	10.7
Bt_3	89-134	1.56	45.6	11.6	42.8	10.1
Seethi series						
Ap	0-17	1.24	62.7	11.3	26.0	8.75
Bt_1	17-49	1.34	49.3	12.4	38.3	9.89
Bt_2	49-99	1.48	46.6	15.7	37.7	10.8
Bt_3	99-140	1.64	49.0	14.5	36.5	10.4
Alamgiri series						
Ap	0-17	1.42	50.2	10.8	38.9	9.45
Bt_1	17-51	1.47	39.0	14.4	46.6	10.9
Bt_2	51-89	1.51	33.9	16.1	50.0	11.7
BC	89-151	1.58	32.6	14.5	52.9	11.4
Vemagal series						
Ap	0-16	1.36	69.7	20.9	9.33	10.4
Bw_1	16-44	1.48	75.1	16.6	8.31	9.08
Bw_2	44-110	1.49	21.7	36.9	41.3	16.5
Bw_3	110-149	1.57	35.0	30.1	34.8	14.6

AWC with depth (Fig. 2). Clay content and cation exchange capacity mostly influence the available water capacity of the soils (Lalitha *et al.,* 2019). The soils of Madderi series and Rajakallahalli series were acidic with pH ranging from 4.07 to 5.61 and 4.27 to 4.39, respectively (Table.3). The soils of Ammanallur series (6.63 to 7.84) and Vemagal series (6.45 to 7.37) were neutral. Soil pH of Cholaghatta series (4.86 to 5.68), Madderi series (4.07 to 5.61), Alamgiri series (5.32 to 6.46) and Vemagal series (6.45 to 7.37)increased with depth, while other profiles showed an irregular trend with depth (Fig. 9). Soils were non-saline (0.1 to 0.2 dS m^{-1}). Organic carbon (OC) content varied from low to high in surface horizons (0.18 to 1.52%) than sub-surface horizons. Soils of Madderi series (1.25 to 0.85%), Ammanallur series (1.52 to 0.72%) and Seethi series (1.13 to 0.4%) exhibited a decrease in organic carbon content with depth (Fig. 2). High OC in surface soils might be due to the addition of crop residues from crop cultivation. The low cation exchange capacity (CEC) of

Table 3: Chemical properties of representative profiles

Horizon	Depth (cm)	pH	EC (dS m^{-1})	OC (%)	CEC (cmol(p^+) kg^{-1})
Cholaghatta series					
Ap	0-13	4.86	0.05	0.18	2.74
Bt_1	13-55	5.26	0.03	0.12	5.19
Bt_2	55-99	5.68	0.03	0.24	5.49
Madderi series					
Ap	0-20	4.07	0.044	1.25	4.86
Bt_1	20-53	4.78	0.040	0.96	8.33
Bt_2	53-92	5.61	0.036	0.85	7.45
Rajakallahalli series					
Ap	0-15	4.28	0.050	1.12	4.51
Bt_1	15-65	4.31	0.027	0.8	3.43
Bt_2	65-110	4.39	0.022	0.53	5.49
CB	110-140	4.27	0.024	0.55	3.82
Ammanallur series					
Ap	0-13	6.72	0.156	1.52	6.76
Bt_1	13-49	6.63	0.051	1.04	7.64
Bt_2	49-89	6.68	0.149	0.76	4.41
Bt_3	89-134	7.84	0.098	0.72	10.58
Seethi series					
Ap	0-17	5.44	0.039	1.13	3.92
Bt_1	17-49	4.75	0.033	0.96	6.47
Bt_2	49-99	5.46	0.031	0.6	7.45
Bt_3	99-140	5.84	0.031	0.4	8.53
Alamgiri series					
Ap	0-17	5.32	0.01	0.57	4.80
Bt_1	17-51	6.14	0.01	0.33	7.55
Bt_2	51-89	6.28	0.05	0.12	9.31
BC	89-151	6.46	0.01	0.36	8.43
Vemagal series					
Ap	0-16	6.45	0.05	0.39	5.93
Bw_1	16-44	6.49	0.03	0.15	3.27
Bw_2	44-110	7.16	0.10	0.15	3.94
Bw_3	110-149	7.37	0.17	0.33	10.68

soils (3-12 cmol(p^+) kg^{-1}) (Fig. 2) might be due to the presence of kaolinite mineral (Chi & Richard, 1999).

SOC stock status and carbon sequestration potential

The depth-wise distribution of SOC stock and carbon sequestration potential of the representative profiles is shown in Table 4. The SOC stock ranged from 0.39 to 4.64 kg m^{-2}. The higher SOC stock (2.05 to 4.64 kg m^{-2}) observed in the Ammanallur series is attributed to the mango land use system, which likely contributes more biomass to the soil surface through litter deposition (Srinivasan *et al*., 2019). The Alamgiri series showed a comparatively higher carbon sequestration potential (5.02 to 8.74 kg m^{-2}) (Fig. 2). The soils were under a cashew inter-cropped with field bean land use system, where intensive tillage practices during cultivation might have caused the depletion of organic carbon, thereby increasing the potential for sequestration of organic carbon. Higher carbon sequestration potential may also be attributed to the presence of finer soil fractions (Wiesmeier*et al*., 2014).The results indicate

Table 4: Depth-wise distribution of SOCstock and CSP of representative profiles

Depth (cm)	SOC stock (kg m^{-2})	CSP (kg m^{-2})
Cholaghatta series		
0-25	0.54	6.44
25-50	0.43	8.21
50-75	0.79	6.32
75-100	0.86	5.85
Madderi series		
0-25	3.58	2.95
25-50	1.71	3.21
50-75	2.32	4.99
75-100	2.41	5.25
Rajakallahalli series		
0-25	1.14	2.09
25-50	0.97	2.27
50-75	0.95	2.67
75-100	0.84	3.24
Ammanallur series		
0-25	4.64	4.97
25-50	3.29	5.71
50-75	2.99	7.55
75-100	2.05	5.47
Seethi series		
0-25	3.71	5.14
25-50	2.45	4.65
50-75	1.69	5.81
75-100	1.65	5.79
Alamgiri series		
0-25	1.78	7.95
25-50	1.14	8.74
50-75	0.39	6.88
75-100	0.52	5.02
Vemagal series		
0-25	0.98	4.49
25-50	0.45	5.26
50-75	0.42	9.02
75-100	0.42	9.02

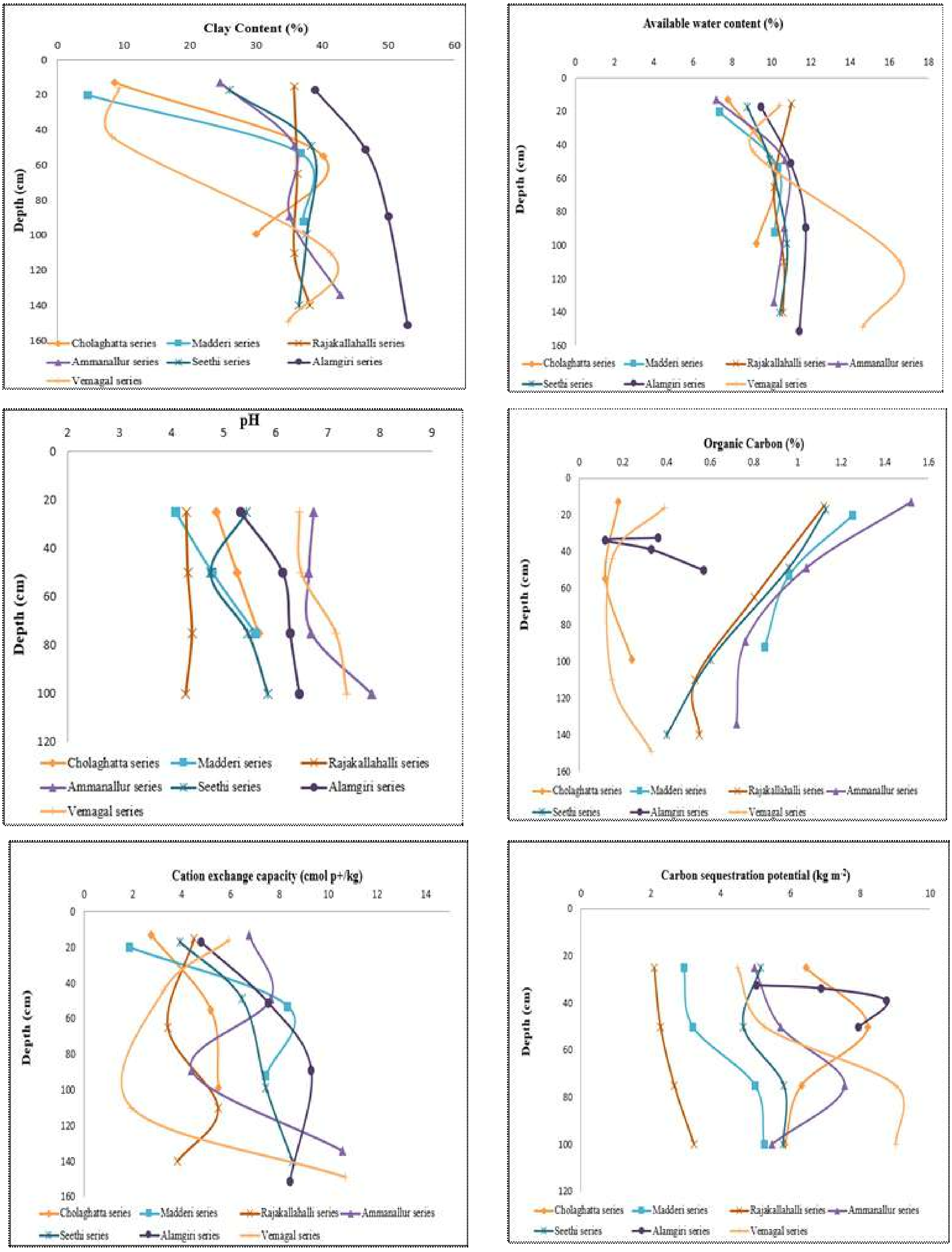

Fig. 2: Depth-wise distribution of clay, available water capacity (AWC), pH, organic carbon, cation exchange capacity (CEC) and carbon sequestration potential (CSP)

that subsurface soils have more potential in sequestering soil carbon compared to surface soils.

Conclusions

The soils of Vemagal block were characterised based on identifying characteristics (depth, colour, texture, gravel content, and horizon sequence) and grouped into seven soil series, namely Cholaghatta series, Madderi series, Rajakallahalli series, Ammanallur series, Seethi series, Alamgiri series, and Vemagal series. The soils of the selected profiles were moderately deep to very deep, with a red to dark yellowish-brown surface colour and a loamy sand to clay surface texture. Most of the seriesexhibited an irregular trend in sand and silt content, while the clay content of the Madderi and Alamgiriseriesincreased with depth. The available water capacity showed an irregular trend with depth in most of the profiles. Soils were moderately acidic to slightly alkaline in reaction and were non-saline. The surface horizons of the profiles had higher organic carbon (OC) content than the sub-surface horizons. Higher SOC stock and higher carbon sequestration potential (CSP) were noticed in profiles of the Ammanallur series and the Alamgiri series, respectively. Thecharacterisation of soil resources in the Vemagal block has aided in identifying the potential and limitations of soils which could contribute to carbon sequestration for agriculture and ecosystem sustainability.

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Received: September 2024 Accepted: November 2024