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Characterization, classification and fertility evaluation of vertisols and associated soils under different land use systems in seloo tehsil, wardha district, Maharashtra

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Abstract
Reliable information on the characterization, classification and fertility status of soils under prevailing land use systems is fundamental for rational land-use planning and sustainable crop management in swell-shrink (Vertisol) landscapes. The present study characterized and classified eight representative soil pedons occurring under agricultural, horticultural and forest land use systems in Seloo tehsil of Wardha district, Maharashtra, developed on Deccan basalt parent material under a hyperthermic temperature and ustic moisture regime. The soils were deep to moderately shallow (58-150 cm), well drained, predominantly clayey (13.2-65.1% clay) and displayed characteristic vertic features such as pressure faces, slickensides and seasonal cracks. Particle-size distribution showed sand, silt and clay contents ranging from 1.4-56.0, 23.6-42.5 and 13.2-65.1%, respectively, while bulk density (1.3-1.6 $Mg\ m^{-3}$), saturated hydraulic conductivity (0.3-2.5 $cm\ h^{-1}$) and coefficient of linear extensibility (0.11-0.23) confirmed a moderate to high shrink-swell potential. The soils were slightly acidic to strongly alkaline in reaction (pH 5.7-8.9), non-saline (EC 0.013-0.090 $dS\ m^{-1}$), calcareous in the agricultural and horticultural profiles ($CaCO_3$ 3.4-11.5%) and dominated by exchangeable calcium over magnesium, sodium and potassium, with a high cation exchange capacity (5.72-63.70 $cmol(p^+)\ kg^{-1}$) and base saturation (59.6-115.7%); exchangeable sodium percentage (0.6-4.7%) indicated the complete absence of sodicity hazard. Fertility evaluation revealed low to high available nitrogen (37.6-267.3 $kg\ ha^{-1}$), low to high available phosphorus (2.5-62.3 $kg\ ha^{-1}$) and medium to very high available potassium (120.1-466.1 $kg\ ha^{-1}$), together with adequate DTPA-extractable Fe, Mn, Zn and Cu, all of which declined with increasing depth and were comparatively higher under forest and horticultural systems than under continuous cultivation. Based on the diagnostic morphological, physical and chemical criteria of USDA Soil Taxonomy, the pedons were classified into the orders Inceptisols (Vertic and Typic Haplustepts) and Vertisols (Typic Haplusterts), reflecting differing degrees of expression of shrink-swell properties among land use systems. The study demonstrates that land use exerts a discernible influence on the physico-chemical make-up and fertility status of these basaltic Vertisols, and provides baseline benchmark information useful for soil-based land-use planning, fertility management and taxonomic mapping of similar swell-shrink soils of the Wardha basin.

Keywords: Vertisols; inceptisols; land use systems; soil characterization; soil classification; soil fertility; wardha district

Introduction

Soil is the most fundamental and least renewable of agricultural resources, and its judicious management underlies the sustainability of food production systems. The concept of soil quality integrates the physical, chemical and biological attributes of soil into a single evaluative framework and is now widely accepted as the principal indicator of the direction of change under a given management or land-use regime (Karlen *et al*., 1997; Doran, 2002) [7, 15]. A detailed understanding of the morphological, physical, chemical and fertility characteristics of soils, together with their systematic classification, therefore forms the essential first step for interpreting soil behaviour, diagnosing constraints and formulating site-specific management and land-use recommendations. Vertisols and associated shrink-swell soils constitute one of the most extensive and agriculturally important soil groups of the tropics, occupying about 257 million hectares worldwide across Asia, Africa, Australia and the Americas. In India, these soils occupy more than 26 million hectares, of which a substantial proportion occurs in Maharashtra, developed largely on alluvium derived from the weathering of Deccan Trap basalt (Murthy *et al*., 1982) [19]. These soils are characterized by a high content of expanding 2:1 smectitic clay minerals that impart pronounced shrink-swell behaviour, expressed morphologically through deep and wide seasonal cracks, slickensides, pressure faces and wedge-shaped peds, and are typically associated with a hyperthermic temperature regime and ustic to typic tropustic soil moisture regime in the semi-arid tracts of peninsular India (Van Wambeke, 1985) [33]. Wardha district of the Vidarbha region, including Seloo tehsil, lies within this basaltic terrain and supports a mosaic of agricultural, horticultural and forest land uses on deep, clayey, well-drained soils. Continuous and often intensive cultivation, together with variation in vegetation cover and management, is known to alter the physical condition, chemical equilibrium and nutrient status of such soils over time, while their inherent vertic properties simultaneously govern workability, water relations and nutrient supplying power. Although the black soils of the Wardha and adjoining Vidarbha tracts have received attention in earlier characterization and classification studies (Kadu *et al*., 2009; Gaikwad *et al*., 2020; Warhade *et al*., 2022) [8, 14, 34], site-specific benchmark information comparing agricultural, horticultural and forest land use systems within Seloo tehsil is limited, and such information is essential for calibrating land-use planning and fertility management at the tehsil scale.The present investigation was therefore undertaken with the specific objective of characterizing and classifying the soils occurring under different land use systems of Seloo tehsil, Wardha district, Maharashtra, and of evaluating their fertility status with respect to major nutrients (nitrogen, phosphorus and potassium) and DTPA-extractable micronutrients (iron, manganese, zinc and copper), so as to generate reliable benchmark data for sustainable soil and land resource management in this important agricultural tract of central India.

Materials and Methods

Study area

The study was carried out in Seloo tehsil of Wardha district, Maharashtra, located between 20°41'22.9" to 21°02'10.0" N latitude and 78°31'27" to 78°55'38" E longitude, and covering an area of approximately 765.75 km². The tehsil forms part of the Wardha Plain and exhibits a varied physiography comprising plateaus, uplands, lowlands, valleys, alluvial plains and scarp landforms. Geologically, the area is dominated by the Deccan Trap basaltic formation, represented by massive, vesicular and fractured lava flows, together with localized Recent to sub-Recent alluvium along the Wardha River and its tributaries. Weathering of the basaltic parent material under the prevailing semi-arid climate has given rise to deep, dark-coloured, clayey soils, including Vertisols and associated Vertic Inceptisols. The tehsil experiences a tropical dry to sub-humid climate with hot summers and a monsoon-dominated rainy season; mean annual rainfall is about 1099.8 mm, received mostly from the south-west monsoon (June-September) over approximately 61 rainy days. Natural vegetation is of the tropical dry deciduous type, dominated by teak, neem, palas, babul and ber, confined mainly to upland, plateau and scarp landscapes, whereas the plains support intensive agriculture (cotton, soybean, pigeonpea, chickpea and wheat) along with horticultural crops such as orange, banana and papaya.

Selection of pedons and soil sampling

Eight representative benchmark pedons, *viz*., Antargaon, Shivangaon, Madni, Garamsur, Dhondgaon, Ramana, Ridhora and Raipur, were selected to represent agricultural (soybean-chickpea, cotton-pigeonpea, sugarcane, cotton monocrop), horticultural (orange-based and banana-papaya) and forest (mixed dense and mixed degraded forest) land use systems (Table 1) on nearly level (o-1) to gently sloping (0-8%) landscapes at elevations ranging between 248 and 428 m above mean sea level. Pedons were dug to a depth of 150 cm or occurrence of a root-restricting layer, and were morphologically described horizon-wise in the field following the USDA Soil Survey Manual (Soil Survey Staff, 1995). Horizon-wise soil samples were collected from each pedon, air-dried, ground and passed through a 2 mm sieve; the processed samples were thoroughly mixed, labelled and stored for laboratory analysis.

Table 1: Site characteristics of the studied pedons under different land use systems, Seloo tehsil, Wardha district

Soil series	Soil depth (cm)	Slope (%)	Drainage	Erosion	Land use system
Antargaon	150	0-1	Well drained	Moderate	Agricultural (Soybean-Chickpea)
Shivangaon	80	1-3	Well drained	Moderate-V.slight	Agricultural (Cotton-Pigeonpea)
Madni	150	0-1	Well drained	Very slight	Agricultural (Sugarcane)
Garamsur	90	3-8	Well drained	Severe	Horticultural (Orange + Soybean-Chickpea)
Dhondgaon	150	1-3	Well drained	Moderate	Horticultural (Banana-Papaya)
Ramana	150	0-1	Well drained	Moderate	Agricultural (Cotton monocrop)
Ridhora	128	1-3	Well drained	Moderate	Forest (Mixed dense forest)
Raipur	58	1-3	Well drained	Moderate	Forest (Mixed degraded forest)

Note: Stoniness of surface (<3%) and ground water depth (1.0 m to >10 m) did not show any consistent relationship with land use and are not tabulated

Laboratory analysis

Particle-size distribution (sand, silt and clay) was determined by the international pipette method (Jackson, 1979) [12]. after removal of calcium carbonate with 1 N sodium acetate buffer (pH 5.0), oxidation of organic matter with 30% H_2O_2, removal of free iron and aluminium oxides by the citrate-bicarbonate-dithionite treatment (Mehra and Jackson, 1960) [18]. and dispersion of the sample (Jackson, 1956). Bulk density was determined by the core method (Blake and Hartge, 1986) [6], and the coefficient of linear extensibility (COLE) was computed from the moist and dry lengths of undisturbed soil clods following Schaffer and Singer (1976) [27]. Saturated hydraulic conductivity was measured by the constant-head method based on Darcy's law (Richards, 1954) [26], and moisture retention at 1/3 bar (field capacity) and 15 bar (permanent wilting point), from which available water capacity (AWC) was derived, was determined using a pressure plate/membrane apparatus (Klute and Dirksen, 1986) [16].

Soil reaction (pH) and electrical conductivity (EC) were measured in a 1:2.5 soil-water suspension using a glass electrode pH meter and a conductivity bridge, respectively

(Jackson, 1973; Richards, 1954) [11, 26]. Free calcium carbonate was estimated by the rapid titration method (Piper, 1950) [25]. Cation exchange capacity (CEC) and exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) were determined following sodium/ammonium acetate saturation procedures (Richards, 1954; Piper, 1950) [25, 26], from which base saturation percentage and exchangeable sodium percentage (ESP) were computed. Available nitrogen was estimated by the alkaline potassium permanganate method (Subbiah and Asija, 1956) [30], available phosphorus by the Olsen sodium bicarbonate extraction method (Olsen *et al*., 1954) [21]. and available potassium by neutral normal ammonium acetate extraction followed by flame photometry (Jackson, 1973) [11]. DTPA-extractable micronutrients (Fe, Mn, Zn and Cu) were estimated following Lindsay and Norvell (1978) [17]. using an atomic absorption spectrophotometer.

Soil classification

The soils were classified up to the family level following the criteria of the USDA Soil Taxonomy (Soil Survey Staff, 2014), based on diagnostic morphological, physical and chemical properties, including soil depth, horizon sequence, texture, structure, consistence and the presence of vertic features such as slickensides, pressure faces and seasonal cracks, together with particle-size class, mineralogy class and soil temperature regime.

Results and Discussion

Site characteristics and soil morphology

The eight studied pedons occurred on nearly level to gently sloping landscapes (0-8% slope) at elevations of 248-428 m above mean sea level, and were uniformly well drained despite their clayey texture, indicating efficient removal of excess water through the well-developed vertic structure (Table 1). Erosion ranged from very slight to severe depending upon slope gradient, being most pronounced in the horticultural pedon (Garamsur) occupying the steepest position. Soil depth varied from 58 cm (Raipur, degraded forest) to 150 cm (Antargaon, Madni and Ramana, under cultivation), so that the soils could be grouped as moderately shallow to very deep; the comparatively greater depth of the cultivated and horticultural pedons reflects their occurrence on more stable landform positions and prolonged pedogenic development from basaltic parent material and basalt-derived colluvium/alluvium. The matrix colour of the soils ranged from 7.5YR 3/2 to 10YR 4/3, with surface horizons generally darker (10YR 3/2, very dark greyish brown) than the subsurface horizons, a pattern attributable to relatively higher organic matter accumulation near the surface and to the influence of parent material and titaniferous magnetite at depth (Zonn, 1986) [35]. Texture was predominantly clay throughout the profile in the cultivated and horticultural pedons, whereas the forest pedons (Ridhora and Raipur) were comparatively coarser (loam to sandy clay loam in places), reflecting reduced translocation of fines and a shallower stage of profile development. Surface horizons generally showed moderate to strong, medium sub-angular blocky structure, grading to strong sub-angular to angular blocky structure with depth, consistent with progressive clay illuviation and repeated shrink-swell activity. Consistence was hard to very hard when dry, friable to firm when moist and very sticky-very plastic when wet in the clay-rich pedons, a behaviour typical of smectite-dominated black soils and indicative of a high shrink-swell potential (Table 2, mprphological properties).

Roots were generally more abundant in the surface and upper subsurface horizons and decreased with depth, while the soils showed slight to strong effervescence with dilute HCl, confirming the calcareous nature of the cultivated and horticultural pedons; the acidic forest pedons (Ridhora and Raipur) were non-calcareous. Diagnostic vertic features, namely deep clayey solum, Bss horizons, angular blocky structure and very sticky-very plastic consistence, together with well-developed pressure faces on ped surfaces of the subsurface Bw horizons and prominent slickensides originating at 40-80 cm depth, were recorded in the Madni, Dhondgaon and Ramana pedons, while incipient vertic expression (cracks and high COLE without slickensides) characterized the Antargaon and Ridhora pedons. Seasonal surface cracks exceeding 2 cm in width were observed in all pedons during the dry period, penetrating to variable depths depending on the intensity of vertic development. These morphological features collectively reflect intense pedoturbation driven by alternate wetting and drying of expanding 2:1 clay minerals and are consistent with descriptions of Vertisols of the Deccan basalt tract reported elsewhere in Maharashtra (Gaikwad *et al*., 2020; Warhade *et al*., 2022) [8, 34].

Table 2: Morphological Properties of soils under different land use systems

Horizon	Depth (cm)	Boundary		Matrix Colour	Texture	Structure				Consistence		Pores	Effervescence		Other Features
		D	T			S	G	Ty	D	M	W	S	Q		
Series 1: Antargaon (Fine, smectitic, hyperthermic, Vertic Haplustepts)															
Ap	0-17	c	s	10YR 3/2	c	m	2	sbk	h	fr	vs,vp	vf	m	ev	-
Bw1	17-44	c	s	10YR 3/2	c	m	3	sbk	-	fr	vs,vp	vf	m	ev	-
Bw2	44-80	c	s	10YR 3/1	c	m	3	sbk	-	fr	vs,vp	vf	m	ev	pf
Bw3	80-113	c	s	10YR3/4	scl	f	1	sbk	-	-	vs,vp	c	m	ev	-
Bck	113-150	c	s	10YR 4/3	c	m	2	sbk	-	-	vs,vp	f	m	ev	-
Series 2: Shivangaon (Fine, mixed, hyperthermic, Typic Haplustepts)															
Ap	0-21	c	s	10YR 3/2	c	m	2	sbk	h	fr	vs,vp	vf	m	ev	-
Bw1	21-56	c	s	10YR 4/3	c	m	1	sbk	-	fr	vs,vp	m	m	ev	-
Bw2	56-80	c	s	10YR 3/2	c	m	2	sbk	-	fr	vs,vp	f	m	ev	-
Cr	80+	Weathered parent material													
Series 3: Madni (Very fine, smectitic, hyperthermic, Typic Haplusterts)															
Ap	0-19	c	s	10YR 3/2	c	m	2	sbk	h	fr	vs.vp	vf	m	es	-
Bw	19-45	c	s	10YR 3/1	c	m	3	sbk	-	fr	vs.vp	vf	m	es	-
Bss1	45-74	c	s	10YR 3/1	c	m	3	abk	-	fr	vs.vp	vf	m	es	pf
Bss2	74-111	c	s	10YR 3/2	c	m	3	abk	-	fr	vs.vp	vf	m	ev	ss

BC	111-150	-	-	10YR 4/2	c	m	2	abk	-	fr	vs.vp	vf	m	ev	ss
Series 4: Garamsur (Fine mixed, hyperthermic, Typic Haplustepts)															
Ap	0-21	c	s	10YR 3/2	c	m	2	sbk	h	fr	vs,vp	vf	m	es	-
Bw1	21-54	c	s	10YR 3/1	c	m	3	sbk	-	fr	vs,vp	vf	m	ev	-
Bw2	54-90	c	s	10YR 4/2	cl	m	2	sbk	-	fr	vs,vp	f	m	ev	-
Cr															
Series 5: Dhondgaon, (Fine, smectitic, hyperthermic, Typic Haplusterts)															
Ap	0-19	c	s	10YR 3/2	c	m	2	sbk	h	fr	vs,vp	vf	m	es	-
Bw	19-48	c	s	10YR 3/2	c	m	3	sbk	-	fl	vs,vp	vf	m	ev	pf
Bss1	48-79	c	s	10YR 3/1	c	m	3	abk	-	fl	vs,vp	vf	m	ev	ss
Bss2	79-117	c	s	10YR 3/1	c	m	3	abk	-	fi	vs,vp	vf	m	ev	ss
Bss3	117-150	-	-	10YR 3/3	c	m	2	abk	-	fl	vs,vp	vf	m	ev	ss
Series 6: Ramana, (Very Fine, smectitic, hyperthermic, Typic Haplusterts)															
Ap	0-19	c	s	10YR 3/2	c	m	2	sbk	vh	fr	vs,vp	vf	m	es	-
Bw	19-46	c	s	10YR 3/1	c	m	3	sbk	-	fr	vs,vp	vf	m	es	ws/pf
Bss1	46-74	c	s	10YR 3/1	c	m	3	abk	-	fr	vs,vp	vf	m	es	ss
Bss2	74-108	c	s	10YR 3/1	c	m	3	abk	-	fr	vs,vp	vf	m	es	ss
Bss3	108-150	-	-	10YR 3/3	c	m	2	abk	-	fr	vs,vp	vf	m	es	ss
Series 7: Ridhora, (Fine, smectitic, hyperthermic, Vertic Haplustepts)															
Ap	0-14	-	-	10YR 3/2	l	m	2	sbk	h	sfr	vs,vp	vf	m	--	-
Bw1	14-53	-	-	10YR 3/3	cl	m	3	sbk	-	fi	vs,vp	vf	m	-	-
Bw2	53-88	-	-	10YR 3/1	cl	m	3	sbk	-	fl	vs,vp	vf	m	-	-
Bw3	88-128	-	-	10YR 2/2	cl	f	1	sbk	-	fr	ss,sp	f	m	-	-
Series 8: Raipur (Fine mixed hyperthermic Typic Haplustepts)															
A	0-9	-	-	10YR 3/2	sl	m	2	sbk	l	fr	So,po	m	m	-	-
Bw1	9-21	-	-	7.5YR3/2	cl	m	3	sbk	-	fl	vs,vp	f	m	-	-
Bw2	21-58	-	-	10YR 3/3	c	m	3	sbk	-	vfl	vs,vp	vf	m	-	-
Cr	58+	-	-	10YR 3/4	cl	m	2	sbk	-	fr	sp	f	m	-	-

Physical properties of soils

Particle-size distribution of the surface horizons varied widely with land use, sand content ranging from 1.4 to 56.0%, silt from 23.6 to 42.5% and clay from 13.2 to 65.1% across the profile (Table 3). The cultivated and horticultural pedons (Antargaon, Shivangaon, Madni, Garamsur, Dhondgaon and Ramana) were dominated by clay (52-65%) throughout most of the solum, whereas the forest pedons (Ridhora and Raipur) contained appreciably more sand (44-56% in the surface horizon) and correspondingly less clay, reflecting a comparatively lower degree of weathering and clay translocation under continuous vegetative cover. According to USDA textural grouping, most horizons of the cultivated and horticultural pedons fell in the clay class, while forest soils were classed as sandy clay loam to clay loam.

Bulk density of the surface layers ranged from 1.3 to 1.4 Mg m^{-3} and increased slightly with depth to 1.3-1.6 Mg m^{-3} in subsurface horizons, the comparatively lower values under forest land use being attributable to greater biological activity and organic matter incorporation, consistent with the trend reported by Naitam and Bhattacharyya (2004) [20]. for shrink-swell soils under contrasting land use in the sub-humid tropics of India. Saturated hydraulic conductivity was generally low, varying from 0.3 to 2.5 cm h^{-1} and decreasing with depth in most pedons, indicating imperfect to poor internal drainage typical of clay-dominated, smectite-rich horizons where swelling of clay reduces effective pore continuity; comparatively higher conductivity was noted in the coarser-textured forest pedons. The coefficient of linear extensibility (COLE), an index of shrink-swell potential, ranged from 0.11 to 0.23 and generally increased with depth, with the highest values recorded in the cultivated Vertisol pedons (Madni, Dhondgaon and Ramana), corroborating their field classification as Vertisols; lower COLE values under forest land use are consistent with the moderating influence of organic matter on volume change reported for smectitic Vertisols by Pal *et al*. (2012) [23]. (Table 3, physical properties).

Moisture retained at field capacity (1/3 bar) ranged from 8.0 to 51.6% and at permanent wilting point (15 bar) from 3.9 to 30.9%, both increasing with depth in line with the corresponding increase in clay content, while available water capacity (AWC) varied from 4.1 to 21.0%. The comparatively lower water-retention values recorded in the forest pedons reflect their coarser texture, whereas the high water-holding capacity of the clay-dominated agricultural and horticultural pedons is a characteristic feature of smectitic Vertisols and Vertic Inceptisols of the Deccan basalt tract.

Table 3: Physical properties of soils under different land use systems

Horizon	Depth (cm)	Particle Size Distribution			sHC	B.D.	COLE (cm)	Water Retention (%)		
		Sand (%)	Silt (%)	Clay (%)	(cm h^{-1})	(Mg m^{-3})		1/3 bar	15 bar	AWC (%)
Series 1: Antargaon (Very fine, smectitic, hyperthermic, Vertic Haplustepts)										
Ap	0-17	8.6	39.0	52.4	0.9	1.4	0.12	38.9	27.1	11.8
Bw1	17-44	10.4	38.0	51.6	0.8	1.4	0.19	41.3	26.5	14.8
Bw2	44-80	13.1	39.5	47.3	0.6	1.5	0.17	36.7	24.1	12.6
Bw3	80-113	54.9	23.6	21.5	1.1	1.6	0.13	27.9	13.0	14.9
Bck	113-150	11.8	38.8	50.2	0.5	1.5	0.17	46.4	30.4	16.0
Series 2: Shivangaon (Fine, mixed, hyperthermic, Typic Haplustepts)										
Ap	0-21	4.1	39.0	52.4	0.8	1.4	0.13	42.6	26.2	16.3
Bw1	21-56	27.1	38.0	51.6	1.0	1.3	0.13	37.7	22.3	15.3
Bw2	56-80	11.7	39.5	47.3	0.6	1.4	0.14	39.8	21.6	18.2
Series 3: Madni (Very fine, smectitic, hyperthermic, Typic Haplusterts)										
Ap	0-19	3.9	39.5	56.5	0.8	1.4	0.12	48.1	30.6	17.5
Bw	19-45	6.9	35.5	57.6	0.7	1.5	0.11	50.9	30.9	20.0
Bss1	45-74	5.4	37.6	57.0	0.6	1.5	0.13	51.6	30.6	21.0
Bss2	74-111	7.2	38.4	54.4	0.5	1.6	0.15	50.9	30.2	20.7
Bc	111-150	6.2	39.1	54.7	0.8	1.6	0.16	48.5	27.5	21.0
Series 4: Garamsur (Fine mixed, hyperthermic, Typic Haplustepts)										
Ap	0-21	12.6	31.7	55.7	0.8	1.3	0.12	30.8	14.4	16.4
Bw1	21-54	9.6	35.3	55.1	0.6	1.3	0.13	33.7	17.3	16.4
Bw2	54-90	27.6	42.5	29.9	1.0	1.4	0.14	34.6	18.1	16.5
Series 5: Dhondgaon, (Very fine, smectitic, hyperthermic, Typic Haplusterts)										
Ap	0-19	6.8	28.1	65.1	0.7	1.4	0.15	48.1	30.6	17.5
Bw	19-48	7.0	34.4	58.7	0.6	1.4	0.19	50.9	30.9	20.0
Bss1	48-79	8.3	34.8	56.9	0.5	1.4	0.20	51.6	30.6	21.0
Bss2	79-117	7.5	33.9	58.6	0.4	1.5	0.21	50.9	30.2	20.7
Bss3	117-150	10.1	34.0	55.9	0.3	1.5	0.23	48.5	27.5	21.0
Series 6: Ramana (Very Fine, smectitic, hyperthermic, Typic Haplusterts)										
Ap	0-19	2.5	34.4	63.1	0.7	1.4	0.22	48.1	30.6	17.5
Bw	19-46	2.3	34.2	63.5	0.6	1.4	0.11	50.9	30.9	20.0
Bss1	46-74	1.4	33.7	64.9	0.5	1.5	0.13	51.6	30.6	21.0
Bss2	74-108	3.5	34.4	62.1	0.4	1.6	0.15	50.9	30.2	20.7
Bss3	108-150	5.8	38.4	55.8	0.3	1.6	0.16	48.5	27.5	21.0
Series 7: Ridhora, (Fine, smectitic, hyperthermic, Vertic Haplustepts)										
Ap	0-14	44.5	34.2	21.3	1.2	1.3	0.12	14.2	6.2	8.0
Bw1	14-53	32.1	37.7	30.2	1.1	1.3	0.13	19.3	10.7	8.6
Bw2	53-88	36.3	33.5	30.1	0.9	1.4	0.14	20.8	11.6	9.1
Bw3	88-128	31.9	29.9	38.3	0.7	1.4	0.15	19.0	11.2	7.8
Series 8: Raipur (Fine mixed hyperthermic Typic Haplustepts)										
A	0-9	56.0	30.8	13.2	2.5	1.3	0.19	8.0	3.9	4.1
Bw1	9-21	35.2	31.3	33.5	1.1	1.4	0.20	16.9	10.3	6.6
Bw2	21-58	28.1	30.2	41.6	0.9	1.3	0.21	19.3	12.6	6.7
Cr	58+	36.2	26.4	37.4	1.7	1.3	0.23	17.9	11.7	6.2

BD = Bulk density; sHC = saturated hydraulic conductivity; COLE = coefficient of linear extensibility; FC = field capacity; WP = wilting point; AWC = available water capacity

Chemical properties of soils

Soil reaction (pH, 1:2.5 soil-water) ranged from 5.7 to 8.9 across the studied pedons, increasing consistently with depth, and the soils could be broadly grouped as slightly acidic (forest pedons, pH 5.7-6.4) to neutral-moderately/strongly alkaline (agricultural and horticultural pedons, pH 8.0-8.9) (Table 4). The comparatively lower pH recorded under forest land use is attributable to continuous litter decomposition and organic acid production, whereas the alkaline reaction of the cultivated soils reflects their basaltic parent material and high base saturation, in agreement with Gaikwad *et al*. (2020) [8]. and Warhade *et al*. (2022) [34]. for Vertisols of the Vidarbha region and Kadu *et al*. (2009) [14]. for irrigated soils of the Upper Wardha command area. Electrical conductivity was uniformly low (0.013-0.090 dS m^{-1}), confirming that all the soils, irrespective of land use, are non-saline and free from any soluble-salt hazard to crop growth. Free calcium carbonate, confined to the agricultural and horticultural pedons, ranged from 3.4 to 11.5% and generally increased with depth, consistent with the pedogenic redistribution of Ca^{2+} as secondary carbonate described for black soils of the region by Balpande *et al*. (1996) [2]. and Vaidya and Pal (2002) [32]; the acidic forest pedons were entirely non-calcareous, since continuous organic-acid production under litter decomposition does not favour carbonate precipitation. Among the exchangeable bases, calcium was dominant, followed by magnesium, sodium and potassium (Ca^{2+} 3.1-42.5, Mg^{2+} 1.0-32.6, Na^{+} 0.06-2.7 and K^{+} 0.2-0.7 cmol(p^{+}) kg^{-1}), a sequence characteristic of Vertisols derived from basaltic parent material; forest soils recorded comparatively lower exchangeable Ca^{2+} and Mg^{2+}, in keeping with their lower pH and reduced base status.

Cation exchange capacity (CEC) ranged from 5.72 to 63.70 cmol(p^{+}) kg^{-1} and was consistently higher in the clay-rich horizons of the agricultural and horticultural Vertisols than in the coarser-textured forest Inceptisols, reflecting the dominance of high-activity smectitic clay. Base saturation was uniformly high (59.6-115.7%), indicating good inherent fertility, with the highest values recorded under agricultural and horticultural land use and comparatively lower values under the acidic forest pedons; the persistence of high base status in these soils, despite a semi-arid, seasonally leaching climate, has been attributed by earlier workers to the buffering action of zeolitic minerals still persisting in the Deccan basalt weathering products (Bhattacharyya *et al*., 1993, 1999) [3, 4]. Exchangeable sodium percentage (ESP) was low throughout, ranging from 0.6 to 4.7% and increasing slightly with depth, well below the threshold (ESP > 15) at which sodicity begins to impair soil physical properties, confirming the complete absence of a sodicity hazard in the studied soils, regardless of land use (Table 4, chemical properties).

Table 4: Chemical properties of soils under different land use systems

Horizon	Depth (cm)	pH	EC (dSm^{-1})	SOC ($g\ kg^{-1}$)	$CaCO_3$ (%)	Exchangeable Bases (meq 100 g^{-1})				Sum	BS (%)	CEC cmol(p^+) kg^{-1}
						Ca^{2+}	Mg^{2+}	Na^+	K^+			
Series 1: Antargaon (Very fine, smectitic, hyperthermic, Vertic Haplustepts)												
Ap	0-17	8.0	0.06	5.0	7.0	39.5	19.0	0.6	0.5	59.6	99.2	60.1
Bw1	17-44	8.4	0.04	3.8	6.8	40.5	20.4	0.6	0.5	62.0	97.3	63.7
Bw2/Bss	44-80	8.4	0.04	2.6	6.2	40.1	21.0	0.6	0.4	62.1	104.9	59.2
Bw3	80-113	8.6	0.03	2.3	5.8	29.6	13.0	0.4	0.2	43.2	111.0	38.9
Bck	113-150	8.5	0.05	1.2	5.3	24.7	11.8	0.7	0.4	37.5	93.4	40.2
Series 2: Shivangaon (Fine, mixed, hyperthermic, Typic Haplustepts)												
Ap	0-21	8.2	0.05	5.5	4.6	35.2	18.0	0.5	0.6	54.4	112.6	48.3
Bw1	21-56	8.5	0.04	4.3	4.0	37.5	12.1	0.6	0.2	50.4	105.1	47.9
Bw2	56-80	8.5	0.04	4.0	3.5	37.1	14.7	0.6	0.3	52.7	115.3	45.7
Series 3: Madni (Very fine, smectitic, hyperthermic, Typic Haplusterts)												
Ap	0-19	8.1	0.05	7.5	7.3	32.1	21.8	0.5	0.7	55.1	107.5	51.3
Bw	19-45	8.4	0.04	5.9	6.3	42.5	22.5	0.7	0.5	66.2	112.3	59.0
Bss1	45-74	8.6	0.03	3.4	4.6	38.0	25.6	1.2	0.5	65.3	116.1	56.3
Bss2	74-111	8.7	0.06	3.0	9.6	31.5	32.6	2.4	0.5	67.0	114.3	58.6
Bc	111-150	8.9	0.074	2.8	6.3	32.6	30.7	2.8	0.2	66.2	112.7	58.7
Series 4: Garamsur (Fine mixed, hyperthermic, Typic Haplustepts)												
Ap	0-21	8.1	0.05	8.3	6.6	31.5	19.0	0.9	0.6	51.9	115.2	45.1
Bw1	21-54	8.4	0.05	5.6	6.1	28.4	18.7	1.0	0.2	48.3	103.3	46.7
Bw2	54-90	8.7	0.04	2.4	5.7	27.4	14.2	0.6	0.2	42.3	96.3	44.0
Series 5: Dhondgaon, (Very fine, smectitic, hyperthermic, Typic Haplusterts)												
Ap	0-19	8.3	0.05	8.1	3.4	37.8	16.7	0.9	0.5	55.8	111.9	49.9
Bw	19-48	8.4	0.04	5.6	11.5	35.7	18.4	0.8	0.3	55.2	115.7	47.7
Bss1	48-79	8.4	0.06	5.2	9.1	30.2	15.3	0.8	0.3	46.7	103.9	44.9
Bss2	79-117	8.5	0.05	5.6	10.0	39.3	17.1	0.8	0.3	57.6	110.3	52.2
Bss3	117-150	8.5	0.06	3.2	2.1	31.4	18.5	0.8	0.3	51.1	102.9	49.6
Series 6: Ramana (Very Fine, smectitic, hyperthermic, Typic Haplusterts)												
Ap	0-19	8.2	0.04	4.5	3.4	33.1	16.8	0.3	0.5	50.7	98.9	51.3
Bw	19-46	8.2	0.03	3.6	11.5	32.1	17.7	0.3	0.5	50.6	95.4	53.0
Bss1	46-74	8.2	0.03	3.3	9.1	31.0	22.0	0.4	0.5	53.8	108.4	49.7
Bss2	74-108	8.3	0.04	3.2	10.0	27.4	14.8	0.4	0.5	43.2	92.3	46.8
Bss3	108-150	8.4	0.04	3.0	2.1	31.5	17.2	0.5	0.6	49.7	113.1	43.9
Series 7: Ridhora, (Fine, smectitic, hyperthermic, Vertic Haplustepts)												
Ap	0-14	5.8	0.014	12.6	-	5.6	3.2	0.06	0.22	9.1	69.4	13.1
Bw1	14-53	5.7	0.09	11.0	-	8.3	4.6	0.12	0.35	13.5	69.4	19.4
Bw2	53-88	5.9	0.09	10.4	-	10.2	4.6	0.13	0.45	15.4	71.7	21.5
Bw3	88-128	6.4	0.09	9.8	-	11.1	5.1	0.15	0.42	16.8	77.1	21.8
Series 8: Raipur (Fine mixed hyperthermic Typic Haplustepts)												
A	0-9	6.2	0.01	11.6	-	3.1	1.0	0.1	0.2	4.4	76.6	5.7
Bw1	9-21	6.0	0.01	10.4	-	5.2	2.1	0.2	0.3	7.7	62.6	12.3
Bw2	21-58	6.1	0.01	9.5	-	6.5	2.2	0.2	0.3	9.2	59.6	15.4
Cr	58+	6.1	0.01	8.9	-	5.9	2.0	0.2	0.3	8.4	62.9	13.4

Ca^{2+}, Mg^{2+}, Na^+ and K^+ expressed as cmol(p^+) kg^{-1} (exchangeable bases); *CEC in cmol(p^+) kg^{-1}; BS = base saturation; ESP = exchangeable sodium percentage; BDL = below detection limit (non-calcareous).

Soil fertility status under different land use systems

Available nitrogen ranged from 37.6 to 267.3 kg ha^{-1} across the profile and was generally rated low to medium in the agricultural pedons but medium to high under horticultural and, particularly, forest land use, where the surface horizon of the forest pedon Ridhora recorded the highest value (267.3 kg ha^{-1}) (Table 5). Nitrogen content declined sharply with depth in all pedons, mirroring the corresponding decline in biological activity and organic matter turnover down the profile; this pattern of higher N under forest and horticultural systems relative to continuously cultivated soils is consistent with the findings of Kadu *et al*. (2009) [14]. for Vertisols of the Upper Wardha command. Available phosphorus varied widely, from 2.5 to 62.3 kg ha^{-1}, with the highest surface values recorded under horticultural (Madni-type sugarcane and Dhondgaon banana-papaya systems) and forest land use, and generally decreased sharply in subsurface horizons on account of increased phosphate fixation by clay and reduced organic matter input at depth. The comparatively higher P status of the surface soils under horticultural and forest systems reflects greater biological cycling and reduced fixation associated with continuous organic matter turnover, in agreement with the general role of soil organic matter in regulating P availability outlined by Tiessen and Moir (1993) [31]. and Hinsinger (2001) [9]. Available potassium ranged from 120.1 to 466.1 kg ha^{-1} and was rated medium to very high throughout, the comparatively higher values in the cultivated and horticultural pedons reflecting the release of potassium on weathering of basalt-derived 2:1 clay minerals, which more than compensates for crop removal under the prevailing management, while forest soils maintained potassium largely through litter cycling. DTPA-extractable micronutrients showed considerable variation with land use and depth: iron ranged from 0.38 to 61.68 mg kg^{-1}, manganese from 0.92 to 57.19 mg kg^{-1}, zinc from 0.06 to 0.69 mg kg^{-1} and copper from 0.2 to 4.2 mg kg^{-1}, with markedly higher concentrations of Fe and Mn recorded in the surface horizons of the forest pedons (Ridhora and Raipur) than under agricultural or horticultural use. In general, surface horizons contained higher concentrations of all four micronutrients than subsurface horizons, reflecting their close association with organic matter accumulation and biological cycling, consistent with the well-established influence of organic matter and soil reaction on micronutrient availability (Alloway, 2008) [1]. The comparatively lower zinc status recorded in some of the calcareous, high-pH agricultural pedons is characteristic of intensively cultivated Vertisols and merits attention in integrated nutrient management planning for the tract (Table 5)..

Table 5: Fertility status (available macronutrients and DTPA-extractable micronutrients) of soils under different land use systems

Horizon	Depth(cm)	Soil Fertility Parameters			Micronutrient			
		N	P	K	Fe	Mn	Zn	Cu
		(kg ha^{-1})			(mg kg^{-1})			
Series 1: Antargaon (Very fine, smectitic, hyperthermic, Vertic Haplustepts)								
Ap	0-17	125.4	13.9	400.0	1.5	11.7	0.63	3.0
Bw1	17-44	112.9	6.0	312.1	0.5	5.1	0.28	2.4
Bw2/Bss	44-80	100.4	3.4	259.3	0.4	3.8	0.21	2.0
Bw3	80-113	75.3	5.1	175.8	1.3	1.0	0.17	0.5
Bck	113-150	62.7	6.7	282.2	2.8	0.9	0.1	0.2
Series 2: Shivangaon (Fine, mixed, hyperthermic, Typic Haplustepts)								
Ap	0-21	138.0	20.2	393.9	0.5	10.9	0.54	2.1
Bw1	21-56	87.8	16.3	137.3	1.6	2.4	0.19	1.1
Bw2	56-80	62.7	4.7	220.7	1.9	2.7	0.21	1.1
Series 3: Madni (Very fine, smectitic, hyperthermic, Typic Haplusterts)								
Ap	0-19	150.5	62.3	466.1	1.5	15.2	0.53	1.5
Bw	19-45	112.9	5.4	329.2	2.1	6.3	0.32	1.1
Bss1	45-74	75.3	5.6	332.2	2.0	5.0	0.21	1.5
Bss2	74-111	62.7	9.2	326.1	1.0	3.3	0.15	1.3
Bc	111-150	50.2	8.1	132.5	0.5	2.02	0.14	0.5
Series 4: Garamsur (Fine mixed, hyperthermic, Typic Haplustepts)								
Ap	0-21	163.1	21.06	355.6	1.49	9.82	0.32	3.6
Bw1	21-54	75.3	6.94	136.08	1.33	5.42	0.16	4.2
Bw2	54-90	50.2	7.39	120.06	0.86	1.35	0.15	1.9
Series 5: Dhondgaon, (Very fine, smectitic, hyperthermic, Typic Haplusterts)								
Ap	0-19	163.1	20.61	311.36	0.38	12.02	0.44	2.4
Bw	19-48	150.5	4.93	180.09	1.17	6.52	0.26	2.2
Bss1	48-79	87.8	6.50	201.82	2.28	5.04	0.24	1.8
Bss2	79-117	75.3	6.72	196.44	1.17	3.84	0.21	1.9
Bss3	117-150	62.7	5.15	220.19	1.33	2.65	0.18	1.9
Series 6: Ramana (Very Fine, smectitic, hyperthermic, Typic Haplusterts)								
Ap	0-19	125.4	4.93	328.72	2.6	6.33	0.18	1.2
Bw	19-46	87.8	5.15	293.88	2.28	5.66	0.14	1.1
Bss1	46-74	75.3	4.26	310.12	2.28	5.04	0.18	1.2
Bss2	74-108	62.7	5.15	359.52	1.96	3.27	0.13	1.1
Bss3	108-150	37.6	2.46	376.54	1.96	2.26	0.13	1.1
Series 7: Ridhora, (Fine, smectitic, hyperthermic, Vertic Haplustepts)								
Ap	0-14	267.3	16.58	153.55	41.9	57.19	0.64	1.5
Bw1	14-53	234.7	9.86	235.87	61.7	46.67	0.15	2.5
Bw2	53-88	177.2	11.20	271.48	39.4	36.52	0.14	2.0
Bw3	88-128	157.8	10.30	230.16	21.6	22.45	0.09	1.7
Series 8: Raipur (Fine mixed hyperthermic Typic Haplustepts)								
A	0-9	200.7	18.14	121.63	43.8	29.97	0.69	0.4
Bw1	9-21	200.7	25.54	187.93	27.0	26.33	0.3	1.3
Bw2	21-58	175.6	9.63	215.15	20.2	2.001	0.08	1.1
Cr	58+	150.5	10.30	227.58	3.7	1.767	0.06	0.7

Soil classification

On the basis of the diagnostic morphological, physical and chemical criteria used in USDA Soil Taxonomy (Soil Survey Staff, 2014), the eight studied pedons were grouped into two soil orders, Inceptisols and Vertisols (Table 1). The Antargaon, Shivangaon, Garamsur, Ridhora and Raipur pedons displayed an Ap-Bw-Cr horizon sequence with a well-developed cambic (Bw) subsurface horizon beneath a light-coloured ochric epipedon, predominantly clayey texture and sub-angular blocky structure, indicating an appreciable but incomplete stage of pedogenic development; under the ustic soil moisture regime prevailing in the tract, these pedons qualified for the Ustept suborder. Among these, Antargaon and Ridhora possessed shrinkage cracks, high swelling clay content and elevated COLE values but lacked well-expressed slickensides, and were accordingly placed in the Vertic subgroup as Vertic Haplustepts, while Shivangaon, Garamsur and Raipur, lacking vertic properties despite exceeding 50 cm depth, were classified as Typic Haplustepts. By contrast, the Madni, Dhondgaon and Ramana pedons possessed more than 35% clay, wide and deep seasonal cracks extending to about 100 cm depth, well-developed slickenside zones (Bss horizons) at 40-80 cm depth and high COLE values with correspondingly high water-retention capacity. These diagnostic features placed the three pedons in the order Vertisols, suborder Usterts, great group Haplusterts and subgroup Typic Haplusterts. Family-level classification further revealed a predominance of fine to very fine particle-size classes with smectitic mineralogy and a hyperthermic soil temperature regime across most of the pedons, the occurrence of smectitic clay being responsible for the high CEC, high water-storage capacity and pronounced seasonal cracking and swelling recorded in Section 3.3. The concurrent occurrence of true Vertisols alongside Vertic Haplustepts within the same tehsil illustrates a continuum in the degree of expression of shrink-swell characteristics, governed jointly by clay content, mineralogy, depth and the stability of the landform on which each pedon has developed, rather than by land use alone (Table 6).

Table 6: Family-level classification of the studied soil series under different land use systems

Soil series	Land use system	Family classification (USDA Soil Taxonomy)	Order
Antargaon	Agricultural	Fine, smectitic, hyperthermic Vertic Haplustepts	Inceptisols
Shivangaon	Agricultural	Fine, mixed, hyperthermic Typic Haplustepts	Inceptisols
Madni	Agricultural	Very fine, smectitic, hyperthermic Typic Haplusterts	Vertisols
Garamsur	Horticultural	Fine, mixed, hyperthermic Typic Haplustepts	Inceptisols
Dhondgaon	Horticultural	Fine, smectitic, hyperthermic Typic Haplusterts	Vertisols
Ramana	Agricultural	Very fine, smectitic, hyperthermic Typic Haplusterts	Vertisols
Ridhora	Forest	Fine, smectitic, hyperthermic Vertic Haplustepts	Inceptisols
Raipur	Forest	Fine, mixed, hyperthermic Typic Haplustepts	Inceptisols

Conclusion

The soils of Seloo tehsil, Wardha district, developed on Deccan basalt under a hyperthermic-ustic bioclimatic environment, are predominantly deep, clayey, well-drained soils exhibiting distinct vertic characteristics such as slickensides, pressure faces and seasonal cracks. Based on diagnostic morphological, physical and chemical properties, the pedons were classified as Inceptisols (Vertic and Typic Haplustepts) and Vertisols (Typic Haplusterts), the true Vertisols being confined to the deeper, more clay-rich pedons under cultivation and horticulture. The soils were non-saline throughout and free of any sodicity hazard, calcareous and alkaline under agricultural and horticultural use but slightly acidic and non-calcareous under forest cover, with a generally high cation exchange capacity and base saturation reflecting their smectitic mineralogy. Fertility evaluation showed that available nitrogen and phosphorus, together with DTPA-extractable iron and manganese, were comparatively higher under forest and horticultural land use than under continuous agricultural cultivation, whereas available potassium remained medium to very high across all land use systems owing to continuous release from weathering basaltic minerals. These findings underline those differences in land use exert a measurable influence on the physico-chemical and fertility status of these swell-shrink soils even while their taxonomic identity remains governed principally by inherent clay content, mineralogy and depth. The benchmark characterization and classification data generated in this study can serve as a useful reference for land capability assessment, site-specific fertility management and taxonomic soil mapping of the Vertisols and associated soils of the Wardha basin, and similar basaltic tracts of central India.

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