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Spectral Reflectance Properties of Vertisols and Associated Soils of Nagpur District in Maharashtra

Preeti C. Solanke*, Rajeev Srivastava, Jagdish Prasad, M.S.S. Nagaraju, N.G. Patil, R.A. Nasre, R.K. Naitam and R.R. Wakode

ICAR-National Bureau of Soil Survey and Land Use Planning, Nagpur, 440033, Maharashtra, India

Morphological, physical, chemical and spectral reflectance properties of soils of Nagpur district, Maharashtra were studied to understand the relationship between soil spectral reflectance and physical and chemical properties of soil. A total of 290 soil samples (both surface and sub-surface and profiles) were collected from 143 sites representing different physiographic units. The soils varied distinctly in Munsell colour hue and the soil texture ranged from sandy loam to clay with smectite as the dominant clay minerals. The soil pH varied from 4.9 to 9.2 and organic carbon (OC) content ranged from 1.0 to 24.4 g kg^{-1}. The soil exchange complex was dominated by calcium (Ca) followed by magnesium (Mg), sodium (Na) and potassium (K). In general, most of the soils were rich in available iron (Fe), manganese (Mn) and copper (Cu) but deficient in zinc (Zn). Reflectance spectra of the soils showed prominent absorption features around 1400, 1900 and 2200 nm wavelength region. The soils with colour hue of 7.5YR, 5YR and 2.5YR showed a broad absorption features around 550 in visible and 950 nm in NIR region due to the presence Fe-oxides. Derivative soil reflectance data were calibrated with different soil attributes using step-wise multiple linear regression technique to develop spectral models for prediction of soil attributes. The developed spectral models showed relatively good prediction of sand (r^2 = 0.74; RPD=1.86), clay (r^2 = 0.73; RPD=1.85), pH (r^2 = 0.72; RPD=1.87), OC (r^2 = 0.70; RPD=1.82), exch Ca (r^2 = 0.61; RPD=1.48), CEC (r^2 = 0.70; RPD=2.16), $CaCO_3$ (r^2 = 0.62; RPD=1.54), Fe_2O_3 (r^2 = 0.53; RPD=1.43), DTPA-Fe (r^2 = 0.79; RPD=2.11) and DTPA-Cu (r^2 = 0.77; RPD=1.96) in the validation datasets indicating that reliable prediction of these properties from soil reflectance data.

Key words: Soil properties, Vertisols, soil reflectance, soil spectroscopy

Soil reflectance in the visible near infrared (VNIR) region (350-2500 nm) are the results of interactions between the electromagnetic energy and the bonds in molecules of soil constituents. The soil's spectral reflectance is largely influenced by its properties such as organic matter content, clay minerals, iron (Fe) oxide content, soluble salts, soil roughness and moisture content in the soil (Ben-Dor *et al.* 1999). Thus, it provides an opportunity to derive information about various soil properties through analysis of soil reflectance data in different wavelength regions.

The analysis of soil spectra, mostly relies on multivariate calibration techniques to relate the spectra with the targeted soil properties (determined through a laboratory method) as a function of soil reflectance (Martens and Naes 1989). Once calibrated, the calibration equation can be used to predict the property on new samples from their reflectance spectra. The spectral reflectance measurement (spectroscopy) of a soil in the laboratory takes a few seconds and it can be used to predict multiple soil properties simultaneously from a single soil spectrum. The advantages of soil reflectance spectroscopy are its simplicity of sample preparation (sieving of soils), no use of chemical reagents, non-destructive nature, apart from speed, economy and precision.

The soil reflectance spectroscopy has been widely tested for characterization of various attributes of soil (Ben-Dor and Banin 1995; Shepherd and Walsh 2002; Islam *et al.* 2003; Srivastava *et al.* 2004, 2015, 2017; Brown *et al.* 2006; Viscarra Rossel *et al.* 2006; Summers *et al.* 2011; Gaikwad *et al.* 2020). However, being empirical, these models have limited applicability and therefore, developments of region-specific spectral models have been emphasized. Keeping this in view, the present investigation was

*Corresponding author (Email: preetisdeshmukh5@gmail.com)

carried out in Nagpur district of Maharashtra to study the spectral reflectance characteristics of Vertisols and associated soils and also to relate it with physical and chemical properties for prediction of soil properties.

Materials and Methods

Study area

The Nagpur district (20°30′ to 25°45′ N, and 78°15′ to 79°40′ E), with total geographical area of 9931 km^2, is situated at an elevation ranging from 150 and 600 m above mean sea level (Fig. 1). Physiographically, area covers hills and ridges, very gently to gently sloping plateau, gently to moderately sloping plateau, subdued hills and valleys, alluvial plain and flood plain. Much of the topography of the area is typically that of Deccan trap having flat topped hills and isolated knolls. The climate of Nagpur area is characterized by a hot summer and generally dry weather except during the south-west monsoon season. The mean annual precipitation is 1127 mm and mean annual temperature is 26.8 °C. The soil temperature and moisture regimes are 'hyperthermic' and 'ustic', respectively. The dominant trees species of the area are babul (*Accacia arabica*), ber (*Zizyphus jujuba*), palas (*Butea frondosa*), neem (*Azadirchta indica*), teak (*Tectona grandis*).The agricultural crops grown during *kharif* include sorghum (*Sorghum bicolor*), cotton (*Gossypium* spp), soybean (*Glycine max*), rice (*Oryza sativa*), pigeonpea (*Cajanus cajan*), cowpea (*Vigna sinensis*) while wheat (*Triticum* spp.) and gram (*Cicer arietinum*) are the two important *rabi* crops of the area. Important horticultural crop of the area is mandarin (*Citrus reticulata)*.

Soil sampling and soil analysis

To characterize the soils, 247 soil samples (surface and sub-surface) were collected from 132 sites representing different physiographic units. In addition to this, horizon-wise soil samples were also collected from 11 pedons representing dominant soil series of the district. Morphological characteristics of the pedons and individual horizons were studied in the field as per the procedures laid out in Soil Survey Manual (Soil Survey Division Staff 2000). Soil samples were ground and passed through 2 mm sieve. Soils were analyzed for particle-size distribution using International pipette method, bulk density (BD), pH and electrical conductivity (EC) (1:2.5; soil: water), organic carbon (OC), calcium carbonate, exchangeable cations (Ca, Mg, Na and K) and cation exchange capacity (CEC) using standard methods (Walkley and Black 1934; Richards 1954; Piper 1966; Jackson 1973). Free iron oxides in soil was determined using citrate-bicarbonate-dithionite mixtures (Sarma *et al.* 1987). Available micronutrient cations (Fe, Mn, Zn and Cu) were extracted by DTPA-$CaCl_2$ extractant at pH 7.3 (Lindsay and Norvell 1978) and were determined by atomic absorption spectrophotometer.

Spectral reflectance measurement of soils

Soil diffuse reflectance spectra were recorded for each sample using a FieldSpec FR spectroradiometer (Analytical Spectral Devices Inc., Boulder, Colorado) at wavelengths from 350 to 2500 nm with a spectral sampling interval of 1 nm under laboratory condition. The average of thirty spectra was recorded for each soil sample to minimize

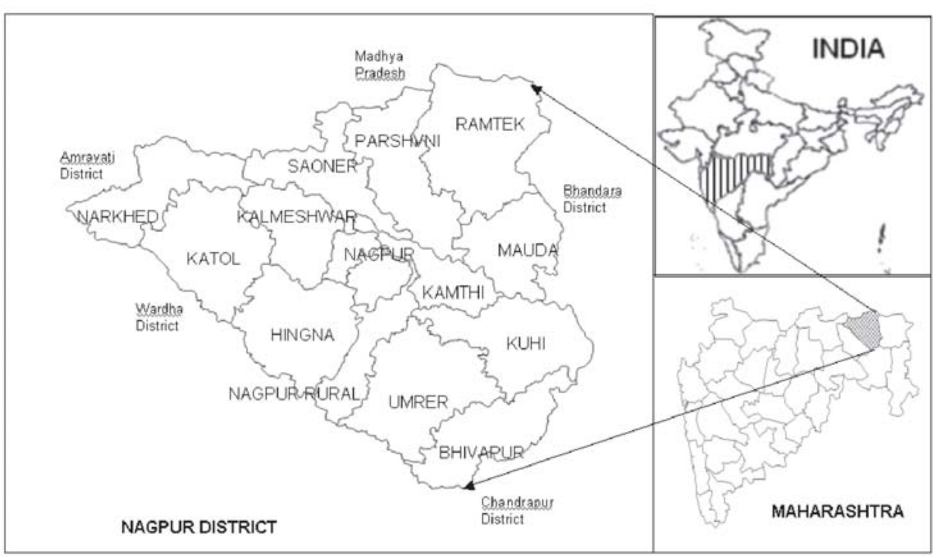

Fig. 1. Location map of the study area

instrument noise. Before reading each sample, thirty white reference spectra were recorded using calibrated spectralon (Labsphere, Sutton, NH) placed at the same distance from the fore-optic as that of the soil sample.

Data processing and transformation

The original soil reflectance spectra consisting of 2151 data points (at 1 nm interval) between 350 and 2500 nm range were resampled by selecting every tenth-nanometer value from 350-2500 nm. This was done to reduce the volume of data for analysis and to match it more closely to the spectral resolution of the instrument (3-10 nm). Wavebands in regions of low signal to noise ratio or displaying noise because of splicing between the individual spectrometers (Analytical Spectral Devices Inc.) were omitted. The omitted bands were 350 through 380 nm, 970 through 1010 nm and 2460 through 2500 nm. The reflectance values (at 10 nm wavelength) were transformed with first derivative processing. Derivative transformation is known to minimize variation among samples caused in grinding and optical set-up.

Development of spectral models

To develop the spectral model for prediction of soil properties, 50% of the analyzed soil samples were randomly selected for calibration to develop a predictive equation and the remaining samples were used to validate the predictive equation. The step-wise multiple linear regression (SMLR) technique was used to relate the 198 derivative reflectance spectra with measured soil properties in the calibration set. The calibration equation obtained using step-wise multiple regression technique can be summarized as follows:

$$\text{Soil variable } (e.g.\ \text{OC}) = a_0 + a_1 d_1 + a_2 d_2 + \ldots\ldots\ a_n d_n \quad \ldots(1)$$

where, $a_{0,}\ a_{1,}\ a_{2,} \ldots\ a_n$ are regression coefficients and d_1, d_2, …d_n are first derivative of reflectance at wavelength λ_1, λ_2 , … λ_n, *etc.*

The statistical analysis was performed using SPSS software. The best model was chosen based on the high values of coefficient of determination (r^2), low root mean square error of prediction (RMSEP) and the ratio of prediction to deviation (RPD) of validation datasets. The RPD is the ratio of the standard deviation (SD) of the measured value of a soil property in the prediction set to the RMSEP (Starr *et al.* 1981). Chang *et al.* (2001) suggested three categories based on RPD in the ranges >2.0, 1.4-2.0 and <1.4 to indicate excellent, acceptable and poor predictions, respectively.

Results and Discussion

Soil characterization

The salient physical and chemical characteristics of soils are given in table 1. The soils varied distinctly in colour and had Munsell hue of 2.5YR, 5YR, 7.5YR, 10YR and 2.5Y. The Munsell values varied between

Table 1. Salient characteristics of the soils

Soil properties	No. of samples analyzed	Minimum	Maximum	Percentiles				
				10	25	50	75	90
Sand (%)	182	1.4	91.1	3.9	7.2	17.2	36.2	60.8
Silt (%)	182	4. 6	46.6	15.2	25.2	30.7	35.2	38.7
Clay (%)	182	4.4	79.9	18.0	32.1	51.6	58.7	64.7
Soil pH (1:2.5 soil water)	290	4.9	9.2	6.3	7.3	7.9	8.1	8.2
EC (dS m^{-1})	290	0.03	1.20	0.08	0.14	0.18	0.25	0.33
OC (g kg^{-1})	280	0.4	24.9	3.1	4.3	5.9	7.8	9.9
Ca [cmol(p^+)kg^{-1}]	182	4.5	58.7	9.49	24.1	35.0	43.2	50.1
Mg [cmol(p^+)kg^{-1}]	182	0.41	26.1	2.1	5.3	8.5	11.8	16.0
Na [cmol(p^+)kg^{-1}]	182	0.03	17.85	0.23	0.35	0.52	0.73	1.31
K [cmol(p^+)kg^{-1}]	182	0.04	2.38	0.16	0.27	0.51	0.80	1.05
CEC [cmol(p^+)kg^{-1}]	182	6.1	72.7	16.15	36.03	53.27	60.33	65.14
BS (%)	182	55.5	105.6	79. 9	85.9	91.5	94.9	100.5
$CaCO_3$ (%)	227	0.5	22.4	1.9	3.2	5.2	8.9	11.9
Fe_2O_3 (%)	268	0.4	10.7	0.9	1.4	2.5	3.3	4.3
DTPA-Fe (mg kg^{-1})	260	2.1	63.6	4.3	5.1	6.6	11.0	20.3
DTPA-Mn (mg kg^{-1})	249	1.0	57.0	1.5	2.0	8.3	17.5	32.5
DTPA-Zn (mg kg^{-1})	260	0.06	1.08	0.17	0.24	0.35	0.48	0.66
DTPA-Cu (mg kg^{-1})	260	0.19	7.89	0.85	1.22	1.80	2.82	3.98

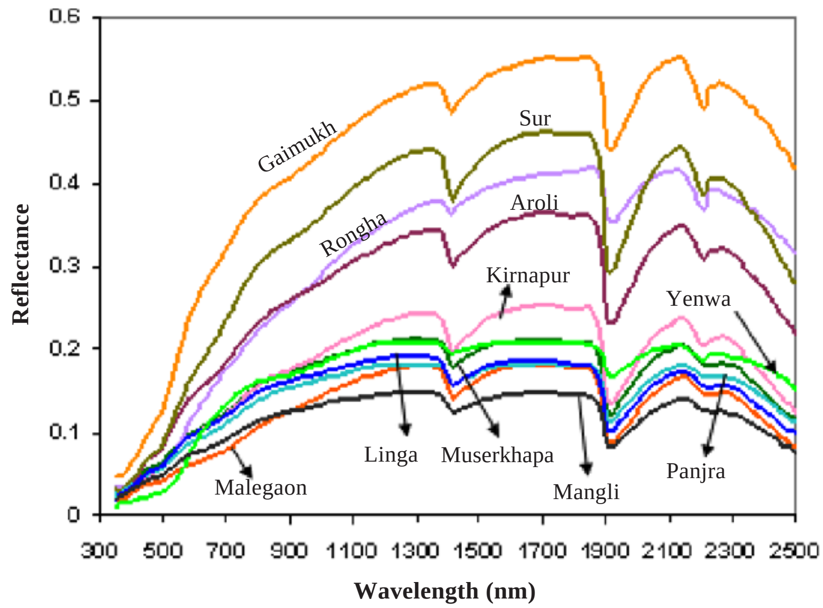

Fig. 2. Reflectance spectra of surface soils of selected soil series of Nagpur District

2 and 6 and chroma between 1 and 4. The texture of soils varied from sandy loam to clay. Majority of the soils (more than 75%) were rich in clay content which varied from 32.0 to 79.9%. The soil pH ranged from strongly acidic (4.9) to strongly alkaline (9.2) and the free calcium carbonate in fine earth fraction varied from almost 0.0 (non-calcareous soils) to 17.0% (calcareous soils). The EC (1:2.5 soil:water) ranged between 0.03-1.2 dS m^{-1}. The OC content in soils varied from 0.4 to 24.9 g kg^{-1}. The exchangeable Ca, Mg, Na and K varied from 4.5 to 58.7, 0.4 to 26.1, 0.03 to 17.85 and 0.04 to 2.38 cmol(p^+)kg^{-1}, respectively. The CEC of soils ranged between 6.1 and 72.7 cmol(p^+)kg^{-1}, whereas the base saturation varied from 55.5 to 105.6%. Free Fe-oxides in soils varied from 0.4 to 10.7%. Most of the soils are rich in Fe, Mn and Cu but deficient in Zn and it ranged from 2.1 to 63.6, 1.0 to 57.0, 0.19 to 7.89 and 0.06 to 1.08 mg kg^{-1}, respectively. The eleven soil pedons studied in the area were correlated with the already established soil series of the Nagpur district and classified according to Keys to Soil Taxonomy (Soil Survey Staff 2003) as Typic Haplusterts, Typic Hapustepts, Typic Haplustalfs, Typic Ustifluents and Lithic Ustorthents subgroups.

Spectral reflectance properties Soils

The untransformed spectra of surface soils of the 11 widely occurring soil series in Nagpur district, Maharashtra are presented in fig. 2 and the salient soil characteristic are given in table 2.

Table 2. Soil characteristics of the surface horizon of correlated soil series of Nagpur

Soil series	Soil subgroup	Colour	Sand (%)	Silt (%)	Clay (%)	pH (1:2 water)	OC (g kg^{-1})	$CaCO_3$ (%)	CEC [cmol(p^+) kg^{-1}]	Fe_2O_3 (%)
Linga	Typic Haplusterts	10YR 3/2	2.2	41.7	56.1	7.98	6.9	3.1	62.9	3.1
Panjra	Typic Haplusterts	10YR 3/2	6.7	29.8	63.5	7.93	7.4	6.3	66.2	0.8
Malegaon	Typic Haplusterts	10YR 3/1	3.8	34.6	61.6	7.92	7.1	4.3	65.4	2.6
Kirnapur	Typic Haplusterts	2.5Y 3.5/2	23.7	27.1	49.2	7.93	6.0	2.9	36.6	0.9
Aroli	Typic Haplusterts	2.5Y 4/3	36.6	26.6	36.8	6.80	7.5	0.5	44.4	0.4
Mangli	Sodic Haplusterts	10YR 3/2	7.8	35.5	56.7	8.37	7.8	6.7	56.6	3.2
Muserkhapa	Typic Haplustepts	10YR 3/2	5.7	33.8	60.5	7.83	7.3	6.2	63.9	4.3
Yenwa	Lithic Ustorthents	5YR 3/2	26.7	35.5	37.8	6.18	15.7	-	55.2	3.3
Rongha	Typic Haplustalfs	7.5YR 3/3	76.4	10.3	13.3	6.06	24.4	-	15.9	3.2
Gaimukh	Typic Haplustepts	10YR 4/4	65.6	14.4	20.0	6.71	7.5	-	21.2	4.3
Sur	Typic Ustifluents	10YR 4/3	72.3	10.6	17.1	6.39	7.1	-	11.3	10.7

Table 3. Statistical parameters of calibration datasets

Soil properties	Calib. r^2	RMSEC	No. of calib samples	Pred. r^2	RMSEP	No. of pred. samples	RPD
*Sand (%)	0.87	7.91	91	0.74	12.24	91	1.86
*Silt (%)	0.61	6.03	91	0.45	6.53	91	1.33
*Clay (%)	0.89	6.81	91	0.73	9.43	91	1.85
#Soil pH (1:2.5)	0.79	0.36	145	0.72	0.41	145	1.87
*EC (dS m^{-1})	0.37	0.13	145	-	-	-	-
*OC (g kg^{-1})	0.78	0.15	140	0.70	0.18	180	1.82
#Ca [cmol(p^+)kg^{-1}]	0.85	7.59	100	0.61	9.1	82	1.48
#Mg [cmol(p^+)kg^{-1}]	0.57	3.79	100	0.34	4.38	82	1.19
#Na [cmol(p^+)kg^{-1}]	0.63	0.25	100	0.28	0.25	82	1.18
#K [cmol(p^+)kg^{-1}]	0.80	0.17	100	0.34	0.22	82	1.50
#CEC [cmol(p^+)kg^{-1}]	0.91	7.99	100	0.70	7.79	82	2.16
*$CaCO_3$ (%)	0.78	1.89	116	0.62	2.62	111	1.54
*Fe_2O_3 (%)	0.64	0.98	143	0.53	1.05	147	1.43
#Fe (mg kg^{-1})	0.86	3.99	130	0.79	4.39	130	2.11
#Mn (mg kg^{-1})	0.76	8.33	130	0.24	14.04	130	1.02
#Zn (mg kg^{-1})	0.28	0.20	130	-	-	-	-
#Cu (mg kg^{-1})	0.71	0.72	130	0.77	0.66	130	1.96

*Square root transformation, #Logarithmic transformation were applied on the soil laboratory data

All the soils displayed an increase in reflectance with increasing wavelength. Soil reflectance spectra followed the same basic shape as described by different workers (Ben Dor *et al*. 1999; Shephard and Walsh 2002; Srivastava *et al*. 2004) with prominent absorption features around 1400, 1900 and 2200 nm. These features are associated with clay minerals. For example, OH features of free water around 1.4 and 1.9 µm and lattice OH features at 1.4 and 2.2 µm (Hunt 1982).

Surface soils of Mangli and Malegaon series showed relatively low reflectance because of darker colour (10YR 3/2) and heavy texture (high clay content) whereas, soils of Gaimukh, Sur and Rongha series exhibited relatively higher reflectance because of lighter texture (sandy loam to sandy clay loam) and brighter colour (Table 2). Broad absorption features around 550 nm in the visible and 950 nm in the NIR regions were prominent in soils of Yenwa series due to absorption caused by the iron oxides.

Prediction of soil properties from soil reflectance data

Derivative soil reflectance data were calibrated using SMLR technique with different soil attributes to develop prediction models. The data (Table 3) indicate that the values of coefficient of determination (r^2) of different models in the calibration set ranged between 0.57 and 0.91 (which explained 57-91% of the variation of the appropriate dependent soil property). Good calibration models were obtained for sand (r^2 = 0.87), silt (r^2 = 0.61), clay (r^2 = 0.89), pH (r^2 = 0.79), OC (r^2 = 0.78), exch Ca (r^2 = 0.85), exch Mg (r^2 = 0.57), exch Na (r^2 = 0.63), exch K (r^2 = 0.80), CEC (r^2 = 0.91), $CaCO_3$ (r^2 = 0.78), Fe_2O_3 (r^2 = 0.64), DTPA-Fe (r^2 = 0.86), DTPA-Mn (r^2 = 0.76) and DTPA-Cu (r^2 = 0.71) with acceptable RMSEC values. The calibration of soil reflectance data with EC (r^2 = 0.37) and DTPA-Zn (r^2 = 0.28) resulted in r^2 <0.5 due to relatively low variability of these soil properties in the dataset, suggesting that calibration models of EC and DTPA-Zn are not suitable for further validation testing.

The application of calibration models (r^2 >0.5) on the validation dataset (Fig. 3) resulted in good validation r^2 (0.61 - 0.79) for sand (r^2 = 0.74), clay (r^2 = 0.73), pH (r^2 = 0.72), OC (r^2 = 0.70), exch Ca^{2+} (r^2 = 0.61), CEC (r^2 = 0.70), $CaCO_3$ (r^2 = 0.62), Fe_2O_3 (r^2 = 0.53), DTPA-Fe (r^2 = 0.79), DTPA-Cu (r^2 = 0.77). The high values of RPD (>2.0) obtained for CEC (2.16) and DTPA-Fe (2.11) indicates good prediction of these properties from spectral data (Table 3). The RPD values (1.4 – 2.0) for sand (1.86), clay (1.85), soil pH (1.87), OC (1.82), exch Ca (1.48), exch K (1.50), $CaCO_3$ (1.54), and DTPA-Cu (1.96) indicate acceptable prediction whereas RPD values less than 1.4 for silt (1.33), exch Mg (1.19), exch Na (1.18), and DTPA-Mn (1.02) indicate poor prediction of these properties. Similar results were also reported by Islam *et al*. (2003) and Srivastava *et al*. (2004) while predicting soil properties from soil reflectance data.

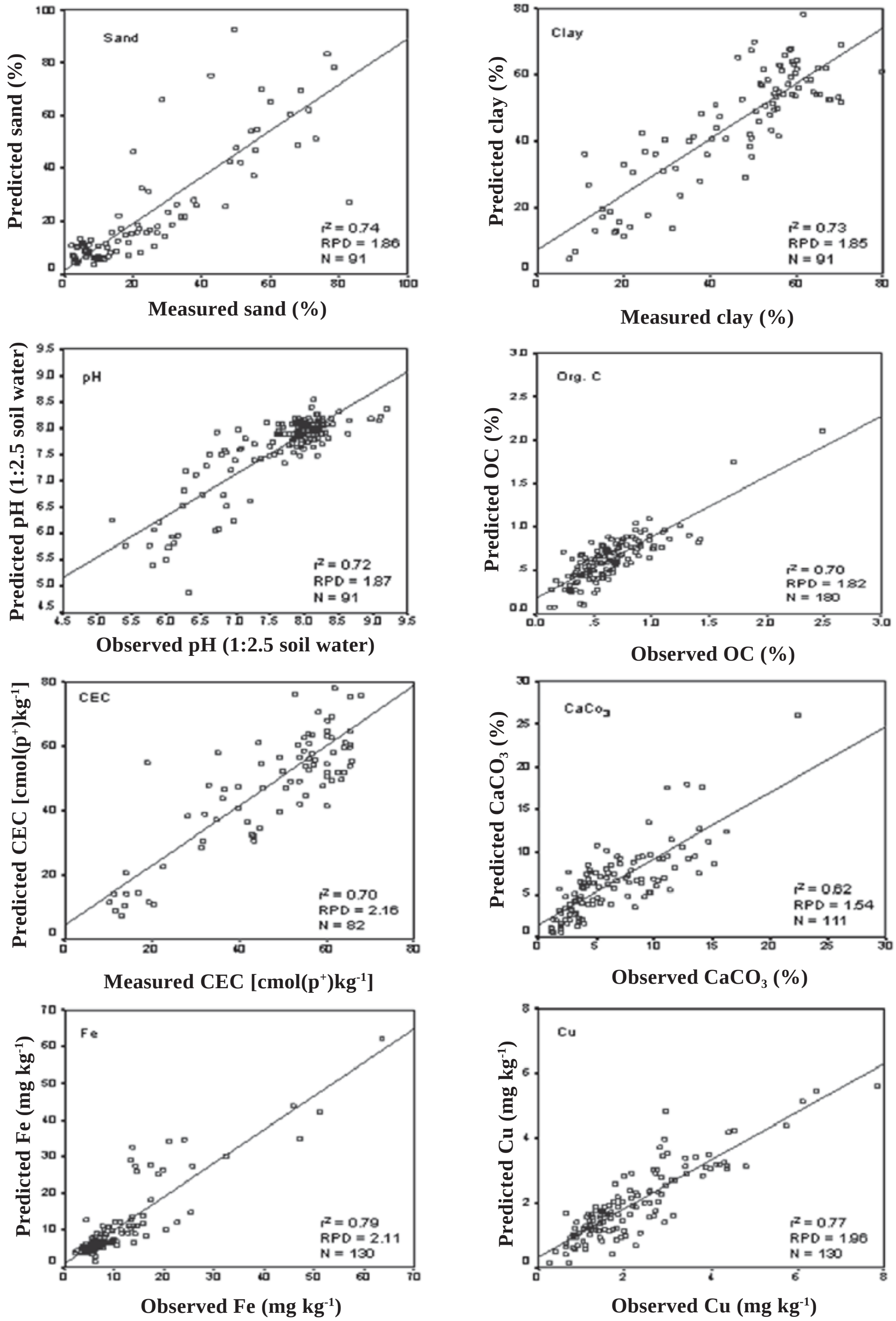

Fig. 3. Scatter plots of observed and predicted values of different soil properties in the validation datasets

Conclusions

It can be concluded that spectral reflectance properties of Vertisols and associated soils of Nagpur District are greatly influenced by their morphological, physical and chemical characteristics and the soil reflectance spectroscopy can be utilized for deriving useful information about several physical and chemical properties of soils.

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