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Spectral reflectance properties of some shrink-swell soils of Central India as influenced by soil properties

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Abstract : In view of lack of information on spectral reflectance of soils of the country, an attempt was made to record the spectral reflectance properties of some shrink-swell soils (Typic Haplusterts, Typic Hapustepts, Lithic Haplustepts, Typic Ustorthents and Lithic Ustorthents subgroups) of Central India in the laboratory between 350 to 2500 nm regions using FieldSpec FR spectroradiometer. The smectitic soils varied distinctly in Munsell colour hue, were moderately acidic (pH 5.7) to very strongly alkaline (pH 9.4), and had organic carbon 0.09 to 2.03 per cent. The soils were rich in bases and had high CEC and exchangeable Ca.

The soil reflectance spectra showed distinct spectral signature between 350 to 2500 nm region with prominent absorption features around 1415, 1910 and 2210 nm. Broad absorption features in the visible (350 -700 nm) and in the NIR region around 950 nm were prominent in soils having colour 7.5YR or redder. Albedo (relative reflectance averaged across the entire spectrum) of soils ranged from 0.09 to 0.40. Soil spectra of surface and subsurface diagnostic horizons of different soil pedons showed similar shape indicating the presence of similar composition of chemical compounds and clay minerals in soils with depth. Based on limited dataset, calibration models were developed for different soil attributes. The application of calibration model for given soil attribute resulted in good validation (r^2 >0.56), indicating that spectral approach helps in comprehending soil properties through such non-destructive way in the laboratory.

Additional keywords: *Soil albedo, Soil optical properties, Vertisols, Black cotton soils*

Introduction

Spectral signatures of materials are defined by their reflectance or absorbance, as a function of wavelength in the electromagnetic spectrum. Under controlled conditions, the signatures result from electronic transitions of atoms and vibrational stretching and bending of structural groups of atoms that form molecules or crystals. Fundamental features in reflectance spectra occur at energy levels that allow molecules to rise to higher vibrational states (Shepherd and Walsh 2002).

The spectral composition of soil-reflected energy is mostly dependent on the biogeochemical (mineral and organic) constituents, geometrical optical scattering (particle-size, aspect and roughness) and moisture conditions of the surface (Baumgardner *et al.* 1985 and Irons *et al.* 1989). Soil clay minerals have very distinct spectral signatures in the short-wave infrared region because of strong absorption of the overtones of SO_4^{2-}, CO_3^{2-}, and OH^- and combinations of fundamental features of H_2O and CO_2 (Hunt 1982; Clark 1999). The visible (0.4 – 0.7 μm) region has been widely used for colour determinations in soil and geological applications as well as in the identification of Fe oxides and hydroxides (Ben-Dor *et al.* 1999). Recent research has demonstrated the ability of reflectance spectroscopy to provide non-destructive rapid prediction of physical, chemical, and biological properties of soils in the laboratory (Ben-Dor and Banin 1995; Ingleby and Crowe 2000; Shepherd and Walsh 2002).

Regarding spectral properties of Indian soils, no systematic and comprehensive information is available. The studies made earlier (Sinha 1986; Kalra and Joshi 1994) were mainly done using coarse resolution spectroradiometers. Recently, National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur undertook a mission mode research programme under NATP (National Agricultural Technology Project) to develop soil reflectance libraries of Indian soils between 350 to 2500 nm region of the electromagnetic radiation. Saxena *et al.* (2003) discussed the spectral reflectance characteristics of some dominant soils occurring on different altitudinal zones in Uttaranchal Himalayas. In the present paper, preliminary results obtained on the spectral reflectance properties of some dominantly occurring shrink-swell soils of Central India and their relationship with the spectral reflectance data are presented.

Materials and Methods

Soil Characterization

Soils from surface and subsurface horizons of shrink-swell soils that are predominantly occurring in Nagpur, Akola, Wardha and Bhandara districts in Maharashtra, Indore (M.P.) and Raipur (Chattisgarh) were collected. A total of 135 soil samples were used in present study. Soil samples were ground and passed through 2mm sieve. Soils were analyzed for particle-size distribution, bulk density, pH and E.C. (1:2.5 H_2O), organic carbon, calcium carbonate, exchangeable cations

(Ca, Mg, Na and K) and CEC using standard methods.

Reflectance Measurements

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. Samples were illuminated from above (Fig. 1) with two tungsten quartz halogen filament lamps in housings with aluminum reflectors (Lowel pro-lamp, Lowel-Light Manufacturer Inc., New York, NY) with 50W bulb;~3200K colour temperature (WelchAllyn, Skaneateles Falls, NY).

Reflected light was collected with a 25° field-of-view foreoptic kept vertically above at a distance of 5 cm from the sample. Air-dried soil samples ground to pass a 2-mm sieve were packed in 23 mm deep, 55-mm diameter black polypropylene dishes. Air-dried soils were used to minimize the effects of variation in soil moisture on reflectance. The dishes were over-filled with soil and then excess soil was scraped off using a blade to ensure a flat surface flush with the top of the dish. An average of thirty spectra was recorded for each soil sample to minimize 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 foreoptic as that of the soil sample. Reflectance readings for each wavelength band were expressed relative to the average of the white reference readings. Variation in overall spectral shape among soil samples were studied by plotting the relative reflectance values against different wavebands. Spectra were also plotted in function of continuum-removed in ENVI software (Research Systems Inc. 1999), to detect subtle differences in spectral absorption features among soils. Continuum removal is used to normalize reflectance spectra so that individual absorption features could be compared from a common baseline. The continuum is a convex hull, consisting of straight-line segments fitted over local spectral maxima (Research Systems Inc. 1999).

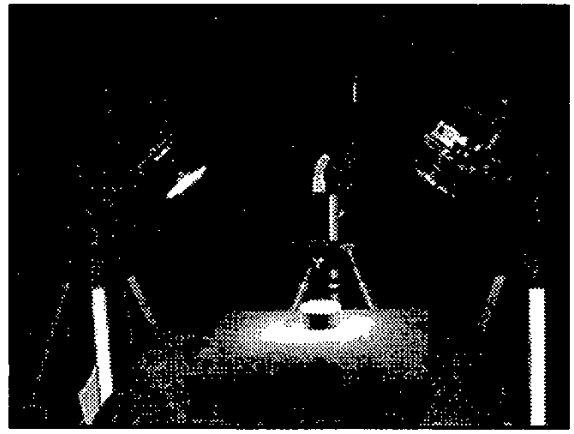

Fig. 1. Optical setup used for soil reflectance measurements with a portable spectroradiometer.

Statistical analysis

Prior to statistical analysis, the raw spectral reflectance data were re-sampled by selecting every tenth-nanometer value from 350 to 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 to 10 nm). The reflectance values were then transformed with first derivative processing.

Derivative transformation is known to minimize variation among samples caused in grinding and optical set-up (Marten and Naes 1989). 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 leaving 198 wavebands for analysis. The omitted bands were 350 through 380 nm, 970 through 1010 nm and 2460 through 2500 nm.

Statistical correlation between individual soil variables and derivative reflectance at each waveband were also explored to understand the relationship between soil properties and soil reflectance. Individual soil variables were then calibrated against the 198-reflectance wavebands through stepwise multiple linear regression (SMLR) using SPSS software. Sixty-five soil samples were used for calibration and the remaining 70 samples were used for validation of the model. Shepherd and Walsh (2002) observed that for the purpose of calibrating soil properties to spectral characteristics, it is preferable to use information over the entire spectrum, rather than attempting to interpret individual absorption features. Soil spectra result from overlapping absorption features of many organic and inorganic components, thus subtle differences in spectral shape may provide valuable information about soil properties.

Results and Discussion

Soil characteristics

The soils varied distinctly in colour and have Munsell hue of 2.5Y, 10YR, 7.5YR, 5YR and 2.5YR. The Munsell values of soils varied between 2 and 6 and chroma 1 and 4. There was wide variation in individual physical and chemical properties of soils (Table 1). The soils, in general, are clayey in texture and the clay content varied from 24.0 to 76.6 per cent. The soils are moderately acidic (pH 5.7) to

Table 1 ***Salient characteristics of the soils***

Soil Properties	No. of samples	Minimum	Maximum	Percentiles				
				5	25	50	75	95
Sand (%)	135	0.6	58.3	2.3	5.8	11.0	26.6	41.9
Silt (%)	135	10.6	53.6	16.6	23.4	28.1	32.3	40.6
Clay (%)	135	24.0	76.6	36.0	45.1	58.5	65.5	72.2
pH (1:2.5 soil water)	135	5.7	9.4	6.2	6.8	7.7	8.2	8.7
EC (dSm^{-1})	135	0.0	1.7	0.0	0.1	0.1	0.2	0.5
Org. C. (%)	135	0.1	2.0	0.1	0.3	0.6	0.8	1.4
$CaCO_3$ (%)	135	0.0	17.3	0.0	1.5	3.8	9.3	14.7
Exch. Ca [c mol (p+) kg^{-1}]	135	7.8	63.6	16.3	21.8	28.0	43.8	54.6
Exch. Mg [c mol (p+) kg^{-1}]	135	2.1	62.7	3.6	6.5	8.7	12.1	26.4
Exch. K [c mol (p+) kg^{-1}]	135	0.1	2.7	0.2	0.3	0.4	0.8	1.7
Exch. Na [c mol (p+) kg^{-1}]	135	0.1	13.1	0.1	0.3	0.4	0.6	2.3
CEC [c mol (p+) kg^{-1}]	135	19.3	68.1	26.7	32.5	40.5	51.5	64.8
ESP	135	0.2	25.2	0.4	0.6	1.1	1.6	4.2
CEC: Clay ratio	135	0.45	1.40	0.52	0.65	0.74	0.87	1.15

very strongly alkaline (pH 9.4) in reaction and the calcium carbonate content varied from 0 to 17.3 per cent. The organic carbon content ranged between 0.1 and 2.0 per cent. The soils were rich in bases and their CEC ranged from 19.3 to 68.1 cmol p(+) kg^{-1}. The exchangeable Ca was the dominant cation followed by Mg, K and Na. The exchangeable Ca, Mg, Na and K varied from 7.8 to 63.6, 2.1 to 62.7, 0.1 to 13.1 and 0.1 to 2.7 c mol p (+) kg^{-1}. The CEC: clay ratio varied from 0.45 to 1.40 indicating the dominance of smectitic clay minerals in soils. According to Keys to Soil Taxonomy (Soil Survey Staff 1998), the soils were classified as Typic Haplusterts, Typic Hapustepts, Lithic Haplustepts, Lithic Ustorthents and Typic Ustorthents subgroups.

Spectral properties of soils

The untransformed soil reflectance spectra of shrink-swell soils (Fig. 2) followed the same basic shape as described by other workers (Shepherd and Walsh 2002; Ben-Dor *et al.* 1999) with prominent absorption features around 1415, 1910 and 2210 nm. These features are associated with clay minerals, for example OH features of free water around 1.4 and 1.9μm, and lattice OH features at 1.4 and 2.2 μm (Hunt 1982). Broad absorption features in the visible (350 -700 nm) and in the NIR region around 950 nm were prominent in soils with Munsell colour hue of 7.5YR or redder.

Albedo (relative reflectance averaged across the entire spectrum) of all the soils ranged from 0.09 to 0.40 (Fig. 2). The lowest albedo was recorded in soil with Munsell colour of 10 YR 3/1 and organic carbon content of 0.73 per cent whereas the highest albedo was observed in soil sample that has lighter color (10YR 6/4) and relatively low organic carbon (0.34%). The soil albedo showed significant correlation with soil Munsell colour value (r =0.505**), chroma (r =0.496**), organic carbon content (r = -0.39**), clay (r =-0.263**) and cation exchange capacity (r = -0.405**). (Ben-Dor *et al.* 1999). have also reported that differences in soil albedo are broadly related to soil organic matter contents.

Basic physical and chemical proper-

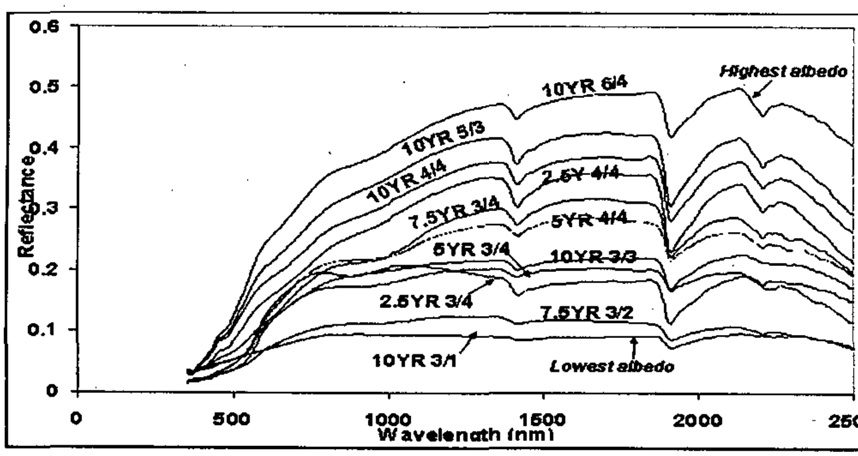

Fig. 2. Diffuse reflectance spectra of some shrink-swell soils with different Munsell colour notation

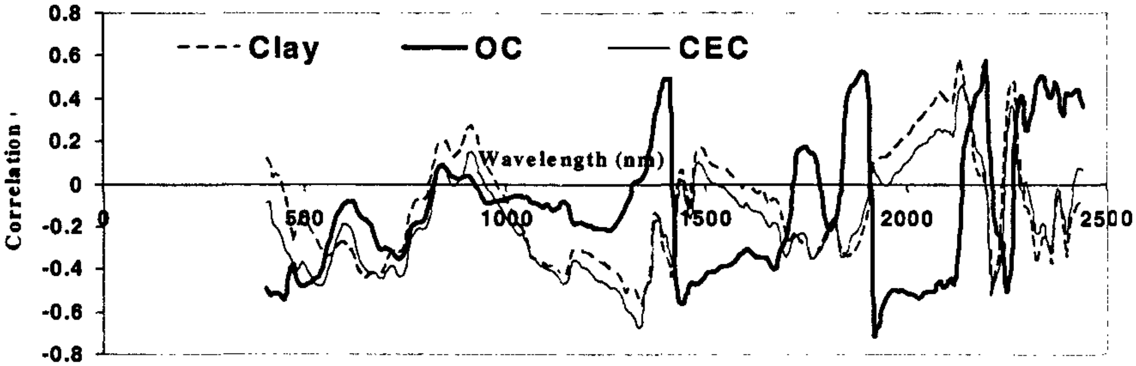

Fig. 3. Correlation of soil organic carbon, cation exchange capacity and clay content with the first derivative of the reflectance at different wavelength

ties of soils showed significant correlation with derivative reflectance values both within the visible and short-wave infrared wavelength regions (Fig. 3). Shepherd and Walsh (2002) observed high correlation with derivative reflectance values near the principal absorption features

Soil colour vs spectral reflectance

Spectral plots of soils with different Munsell colour (Fig. 2) broadly indicate that soil reflectance increases with increase in value and chroma. Soils with Munsell colour 7.5YR or redder showed broad absorption features (Fig. 4) in the visible and NIR region (850- 1100 nm). These features are commonly associated with Fe^{2+} and Fe^{3+} (Hunt 1982), but can also be influenced by organic matter (Ben-Dor *et al.* 1999).

Surface and subsurface soil reflectance

Soil spectra of surface and subsurface diagnostic horizons of different soil pedons (Typic Haplusterts, Typic Haplustepts and Lithic Haplustepts) showed similar shape (Fig. 5) indicating the presence of similar elemental composition and clay minerals in soils with depth. However, no remarkable trend of increase or decrease in soil reflectance with depth was

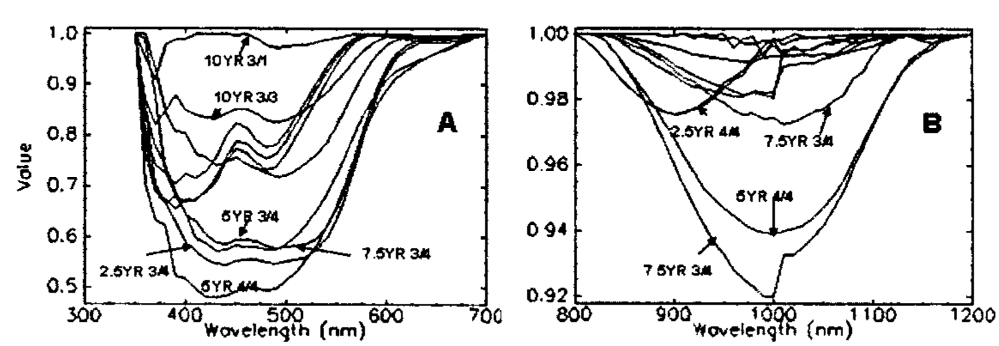

Fig. 4. Visible (A) and near infra red (B) wavelength part of the spectra shown continuum removed to highlight the absorption features. The spectral splicing around 1000 nm is due to change in individual spectrometers (visible to SWIR 1 spectrometer)

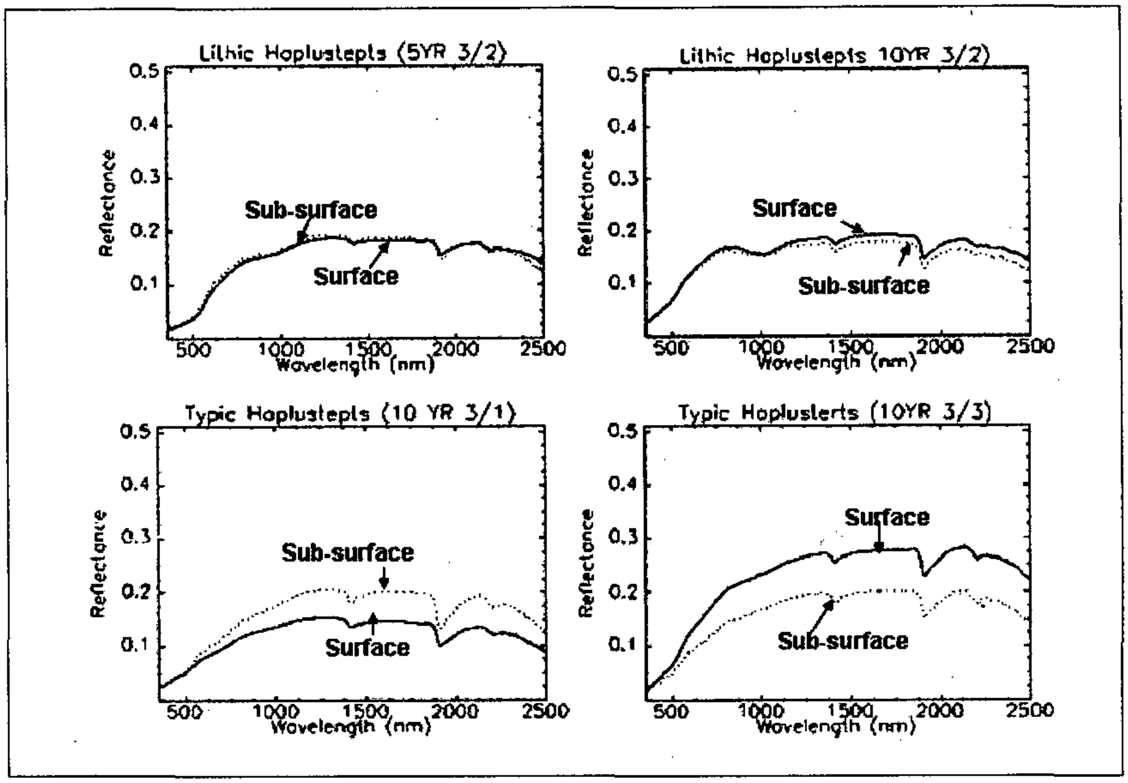

Fig. 5. Soil reflectance spectra of surface and subsurface samples from some typical pedons

noticed.

Prediction of soil properties based on soil reflectance

Based on limited dataset, calibration models were developed for different soil attributes. Good calibrations were obtained for pH (R^2 =0.87**), organic carbon (R^2 =0.71**), cation exchange capacity (R^2 =0.77**) and clay (R^2 =0.61**). The application of calibration model for given soil attribute (Fig. 6) also resulted in good validation r^2 (0.56** to 0.77**). This indicates that soil reflectance properties could be used as a potential tool to provide information on wide range of soil properties. However, there were some samples in the dataset which showed relatively large variations between the measured and predicted values for different soil variables, and the reasons thereof need to be explored using larger dataset both for calibration and validation. Further, the technique for detecting spectral outliers among new samples need to be developed for shrink-swell soils. The detection of spectral outliers (Shepherd and Walsh 2000) will help in identifying the samples which are not the part of the model (calibration dataset) and the prediction for such samples would not be acceptable unless such samples are made part of the calibration dataset.

Conclusions

From the study, it can be concluded that spectral reflectance properties of soils are greatly influenced by their physical and chemical characteristics and do not show

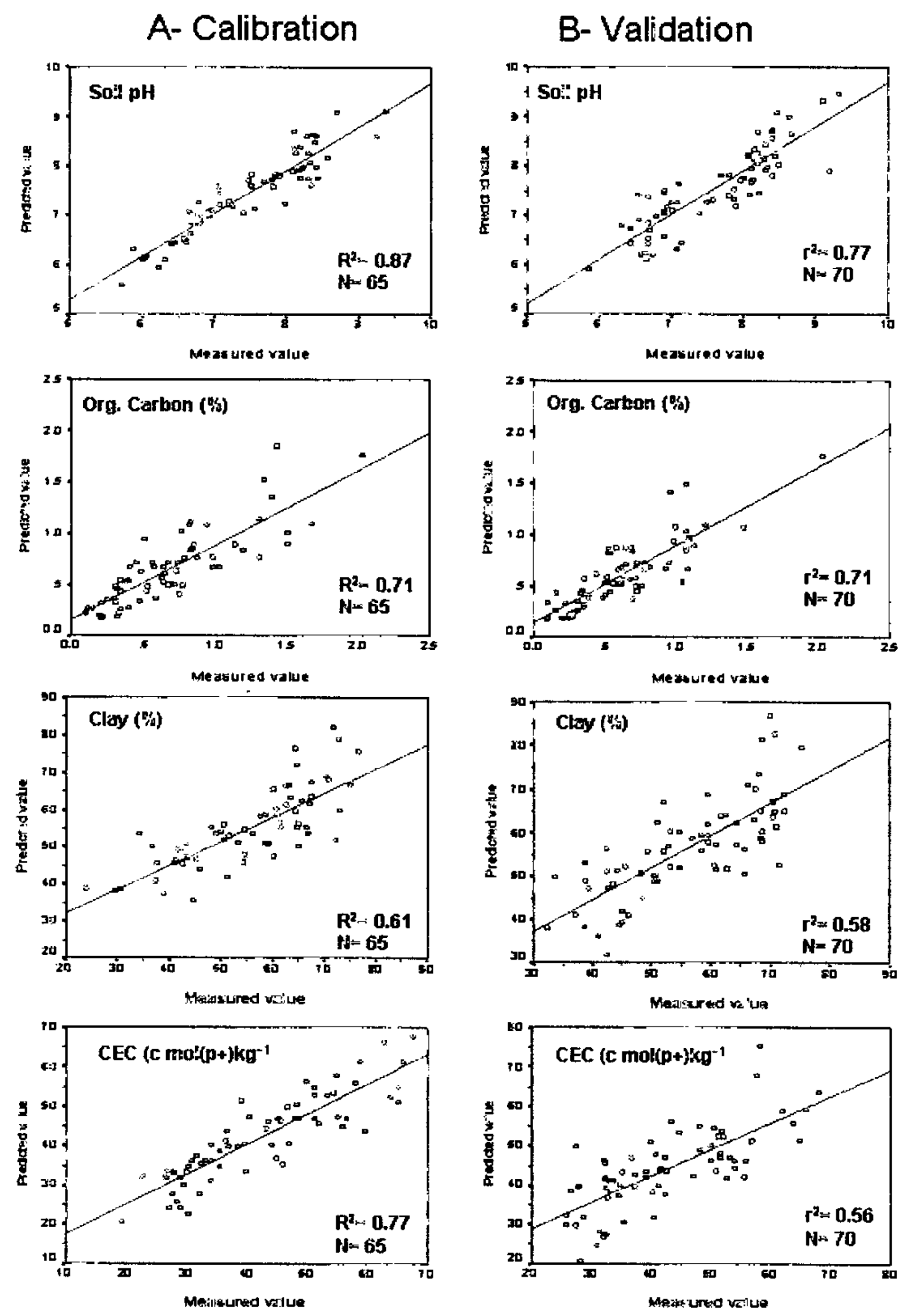

Fig. 6. Scatterplot comparison of measured and predicted values for different soil properties for calibration (A) and validation datasets (B)

any change in shape with depth. The results of the study open up a strong possibility to build roust model for prediction of soil attribute.

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