

Determination of soil activity from optical spectroscopy

P.C. Kariuki & F.D. van der Meer

International Institute for Geo-Information Science and Earth Observation (ITC) P.O. Box 6, 7500AA Enschede, Netherlands
kariuki@itc.nl

Keywords: soil activity, spectroscopy, absorption feature mapping

ABSTRACT: Soil activity in engineering terms is applied to the ratio between the plasticity index and clay content and reflects the type of clay mineral dominant in the soil. It is related to the specific surface area/charge resulting due to presence of clay minerals with a net negative charge to neutralize which, water and exchangeable cations are attracted to the mineral surface. Here we report on the findings in which we sought to establish the capability of absorption feature mapping to determine soil activity. We used the widely accepted Atterberg limits tests to obtain the soil activity and spectral measurements to identify diagnostic parameters to identify clay mineral type. We then used correlations between the soil activity and the diagnostic parameters to obtain a simple empirical model to estimate soil activity from the spectral indicators.

1 INTRODUCTION

The behavior of a soil depends on the composite effects of several interacting factors, which have been described to consist of compositional and environmental components (Mitchell, 1993). Compositional consist of the amount and type of clay minerals, the shape and size distribution of soil particles, adsorbed cations, and pore water. Environmental factors are basically moisture content, density, confining pressure, fabric, and temperature among others. The compositional factors determine the potential range of values for soil properties, whereas environmental factors dictate the actual value.

Soil activity is a term first introduced by Skempton (1953) and refers to the ratio between plasticity index and the percentage clay of a soil. Plasticity is due to the electrochemical behaviour of the clay minerals and is unique to soils containing clay mineral particles (Carter *et al.*, 1991). Thus activity is a function of the clay mineral type dominant in a soil. The order in which activity increases with the clay mineral type has been established to be kaolinite, illite and smectites respectively where each represents a group of clay minerals with similar engineering properties (Mitchell, 1993).

These minerals have distinct reflectance fingerprints in the Short wave infrared (SWIR) region, which has been extensively used for their qualitative identification (Goetz *et al.*, 1983). The precise wavelength position of the water and hydroxyl ab-

sorption features varies among the groups, depending on the details of the composition, structure, and associated atomic bonding characteristics. Smectite and kaolinite groups owe their absorption features to the presence of water where very strong molecular water bands at 1400nm and 1900nm are due to bound water typical of smectite and strong hydroxyl bands at 1400nm and 2200nm have been described as typical of kaolinite (Hunt and Salisbury, 1970). Mathews *et al.* (1973b) established illite to show low absorption intensities for the water and hydroxyl bands when compared to the other two.

Soil reflectance is a cumulative property that derives from a combination of inherent spectral behaviour of these and other minerals, organic matter and soil water (Mulders, 1987). Unsatisfied valences occur on the surfaces and at the broken edges of the clay mineral particles. The exposed oxygen's and the hydroxyls of silica and aluminium sheets act as negatively charged sites, which attract hydrogen ions and other cations. The hydroxyl groups formed at these edges cause most of the absorption features in soil reflectance spectra (Iron's *et al.*, 1989).

The discrete absorption bands allow unique identification of both the adsorbed water and clay minerals. However, the complexity of the interaction of materials making up the soil, make assessment of reflectance properties by physical theories or models very difficult (Liang and Townshed, 1996). Empirical quantitative approach has been found to be a bet-

ter alternative to derive the chemical/physical information from soil spectra (Ben Dor et al, 1999).

Here we use the clay mineralogy diagnostic absorption features parameters relationships with known soil activity (A_c) to derive a simple empirical model to estimate the soil activity from these spectral indicators.

2 MATERIALS AND METHODS

Synthetic mixtures of between 0-100% kaolinite and smectites were mixed quantitatively. These mixtures together with soil samples obtained from areas known to consist of kaolinitic and montmorillonitic soils were oven dried at 105°C for 12hours to eliminate free water prior to their use in spectral data acquisition. Spectra were obtained for both the mixtures and the soil samples using the Portable Infrared

Mineral Analyser (PIMA II) spectrometer. The results of the synthetic mixtures were used as a calibration to those of the soil samples.

Activity was determined by using the standard engineering methods of Atterberg limits and the particle size distribution analysis tests (see Head et al, (1992) and Nelson et al, (1992) for details).

The results from both the engineering tests and the absorption feature mapping were used to obtain an empirical model through the forward multiple regression analysis method where the parameters of the absorption features namely, position, depth, area, asymmetry and width were correlated with the obtained activity. Transformation of nonlinear relationships was done prior to their use in the search for the representative model. Figure 1 illustrates one of the relationships that required transformation prior to being used in the establishment of the final empirical model.

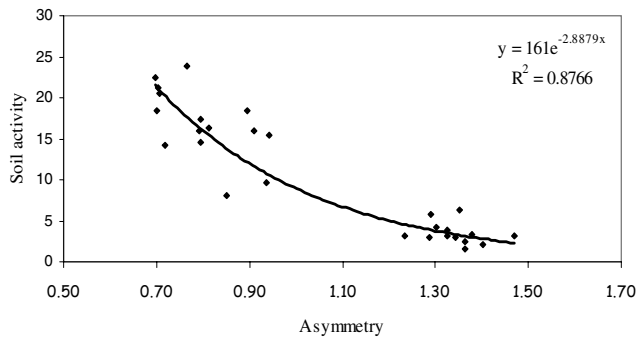


Figure 1. Decrease in asymmetry with increase in soil activity at 1400nm

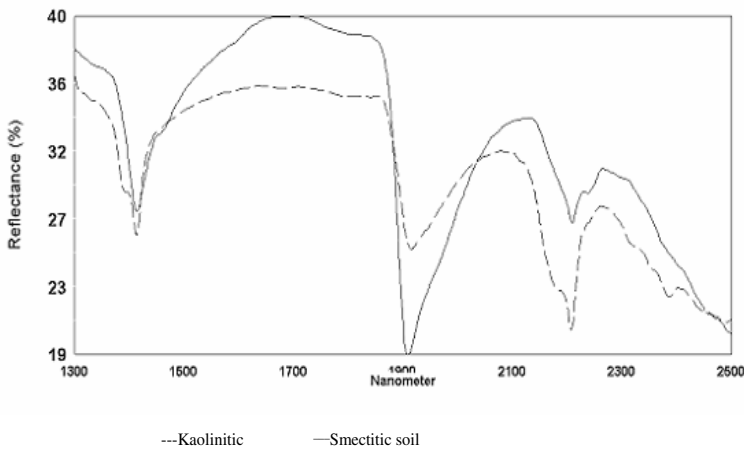


Figure 2. Spectra showing characteristic differences of two soil samples one rich in smectite and the other kaolinite

3 RESULTS

The absorption feature characteristics of both the synthetic mixtures and the soils were observed to vary with composition. Figure 2 gives an example of characteristic differences in the absorption feature parameters of the soils due to domination of particular a clay mineral. It shows clear differences between kaolinite and smectite rich samples.

There were finally four parameters determined to form part of the empirical model and included position and depth of the 1900nm molecular water feature and asymmetries at the lattice OH features of 1400nm and 2200nm.

The position at 1900nm and the asymmetries at both 1400nm and 2200nm gave negatively weighted coefficients whereas depth at 1900nm gave a positive coefficient in the model. Table 1 provides the coefficients of the obtained model. Thus,

$$\text{Soil activity} = f(\text{depth}_{1900}, \text{asy}_{1400\&2200}, \text{position}_{1900\text{nm}}) \quad (1)$$

Table 1 Model to predict soil activity

	Weighted Coefficients
Constant	31.8
Asymmetry (1400)	-0.323
Position (1900)	-0.016
Depth (1900)	0.017
Asymmetry (2200)	-0.092

4 DISCUSSIONS

The negative weight of the position at 1900nm can be attributed to increasing electrochemical forces on the structural water as activity increased (more smectites) thus vibrational processes of this water requiring more energy leading to the shift towards lower wavelengths. This agrees with the observations of Graham, (1964) whose Nuclear magnetic resonance (NMR) data results showed increasing attraction of inter-layer water with charge on clay surface. The feature's depth positive weight was attributed to increasing abundance of inter-lattice water as the surface area of the soil increased. This is in line with observations by Hauff (2000) who established depth at 1900nm as a good semi-quantitative estimator of smectite content.

Negatively weighted coefficients of the asymmetries at the two lattice OH (1400nm and 2200nm) features were attributed to the inverse relationship between increase in inter-layer water and order in the crystal structure and further confirms observa-

tions by Kruse (1991) of the significance of asymmetry at 2200nm in estimating the ratios between kaolinite and smectites in soil samples.

Thus we can describe soil spectra as greatly influenced by the dominant clay mineral type, which results in diagnostic absorption feature characteristics at the molecular water and cation hydroxyl wavelength positions.

Abundant kaolinite (representing low activity) results in soil spectra showing characteristics of order in the lattice OH (2200nm and 1400nm) features whereas abundant smectites results in the spectra showing characteristics of order in the molecular water features and disorder in the lattice OH features. The results also show that inter layer water has a different form from that of free water in whose absence the water absorption feature together with those of lattice OH can be used to estimate activity.

5 CONCLUSIONS

The results show that though soil is a complex material and in that case soil spectra, a remarkable amount of information on the clay mineralogy is available in the absorbed photons and under controlled conditions, can be retrieved. From the results it is evident that molecular water and lattice OH related features give reasonable information on the soil activity and thus can be used to give its estimation.

REFERENCES

- Ben-Dor E, J.R Irons, and G.F Epema., 1999. Soil reflectance In: Remote Sensing for the Earth Science, manual of remote sensing, 3rd Edition, Vol. 3 (New York: John Wiley & Sons).
- Carter M and Bentley S.P., 1991. Correlations of Soil Properties, (London: Pentech Press, UK).
- Goetz, A.F., and Rowan, B.N., 1983. Remote Sensing for exploration: an overview. *Economic Geology*, 78, 573-590.
- Graham, J., Walker, G.F., and West, G.W. 1964. Nuclear magnetic resonance study of interlayer water in hydrated layer silicates. *Journal of chemical physics*, 40(2), pp. 540-550.
- Hauff, P.L., 2000. Applied reflectance spectroscopy with emphasis on data collection and data interpretation using the pima-II spectrometer. Spectral international inc., Sydney, Australia.
- Head K H., 1992. Manual of Soil Laboratory Testing, 2nd edition, Vol.1 (London Pentech Press)
- Hunt, G.R., and Salisbury, J.W., 1970. Visible and near infrared spectra of minerals and rocks. I. Silicate minerals, *Mod. Geology* 1, 283-300
- Irons, J.R., Weismiller, R.A., and Petersen, G.W., 1989. Soil Reflectance. In: G. Asrar (Editor), Theory and Applications of Optical Remote Sensing. Wiley, New York. pp 66-106.
- Kruse, F.A., M. Thiry, and P.L Hauff, 1991. Spectral identification (1.2-2.5nm) and characterization of Paris basin kaolinite/smectite clays using a field spectrometer. In: *Proceedings of the 5th international colloquium on physical*

- measurements and signatures in remote sensing*, Courchevel, France, (pp. 181-184).
- Liang, S., and R.G. Townshend, 1996. A modified Hapke model for soil bidirectional reflectance, *Remote Sensing of Environment*, 55, 1-10.
- Mathews, H.L., R.L. Cunningham, and G.W. Peterson, 1973. Spectral reflectance of selected Pennsylvania soils, *Proc. Soil Sci. Soc. Am. J.*, 37, 421-424.
- Mitchell, J.K. 1993. *Fundamentals of Soil Behaviour*, John Wiley & Sons, New York
- Mulders, M.A., 1987. *Remote Sensing in Soil Science*, *Dev. Soil Sci.* 15, Elsevier, Amsterdam, 379pp.
- Nelson J.D and Miller D.J., 1992. *Expansive Soils: Problem and Practice in Foundation and Pavement Engineering* (John Wiley & Sons, Inc. New York, USA)
- Skempton, A.W., 1953. The colloidal activity of clays. *Proc. 3rd Int. Conf. Soil Mech. Found. Eng., Switzerland*. V.1: 57-61.