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NIR analysis as an integrated tool for the assessment of soil quality

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Abstract
Near infrared reflectance spectroscopy (NIRS) is a rapid, non-destructive, reproducible and cost-effective analytical method involving diffuse reflectance measurement in the near infrared region (NIR; 780-2500 nm). A NIR sensing device able to collect *in-situ* 3D spectral data through an entire soil profile, allowing a rapid and objective soil classification. A set of regression methods allows the prediction of many properties of unknown samples using calibration equations that relate spectral information to sample properties measured by conventional methods, within a calibration subset. soil quality (pH, organic C, total N, P, Ca, Mg, K, CEC, clay, silt) and developed ordinal soil condition classes (poor, average, good), which were used to identify spectral wavebands that could diagnose soil condition. They found that five wavelengths were related to their soil quality index: relative reflectance at 570, 1410, 2040 and 2390 nm were negatively correlated with soil condition class whereas relative reflectance at 1940 nm (which is almost certainly due to O–H bond of water) was positively correlated with soil condition class.

Keywords: Near infrared reflectance spectroscopy, soil profile, spectra, soil quality

Introduction

Soil is a major natural resource for the production of food and energy. Soil controls the movement of water in the landscape, working as a natural filter for metals and other contaminants that may leach into ecologically sensitive spheres of the environment. Soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation.

Near infrared reflectance spectroscopy (NIRS) is a rapid, non-destructive, reproducible and cost-effective analytical method involving diffuse reflectance measurement in the near infrared region (NIR; 780-2500 nm; Sheppard *et al*., 1985) [17]. Reflectance signals result from vibrations in C–H, O–H, N–H chemical bonds, and provide information about the proportion of each element in the analysed sample (Ciurczack, 2001) [9]. Although a qualitative interpretation of NIR spectra through visual analysis can be achieved (Stoner & Baumgardner, 1981) [19], direct quantitative prediction of soil characteristics is almost impossible because soil constituents interact in a complex way to produce a given spectrum. The quantification of the property of interest is therefore usually done with statistical models and is the subject of the discipline called *Chemometrics*. An overview of the use of chemometrics in spectroscopy, its history and main concepts has been published by Geladi (2003) [12]. The quantitative analysis of NIRS data may be conducted in two ways, both requiring the implementation of multivariate statistics (Burns & Ciurczack, 2001) [9]. Firstly, clustering techniques can be used to discriminate samples or to detect changes in sample properties (Albrecht *et al*., 2008) [2]. Secondly, a set of regression methods allows the prediction of many properties of unknown samples using calibration equations that relate spectral information to sample properties measured by conventional methods, within a calibration subset (Martens & Dardenne, 1998; Chang *et al*., 2001) [14, 7].

One can basically distinguish three types of NIRS measurements for soils (although other classifications are possible): (i) laboratory measurements, (ii) proximal sensing measurements and (iii) remote sensing measurements. The two latter techniques are able to collect spectral data *in-situ* and are therefore usually exploited to map soil properties (Barnes *et al*., 2003) [3]. Many authors report the development of spectral sensors mounted on tractors (Mouazen *et al*., 2007) [15]. These systems are generally used in precision agriculture to manage the quantity of nutrient inputs into soils (Adamchuk *et al*., 2004) [1]. Proximal sensing may also include hand-held measurement, which is used as a fast tool to monitor soil properties *in-situ* (Kooistra *et al*., 2001; Udelhoven *et al*., 2003; Stevens *et al*., 2008) [20, 18]. Ben-Dor *et al*. (2008b) [4] recently presented a NIR sensing device able to collect *in-situ*.

3D spectral data through an entire soil profile, allowing a rapid and objective soil classification. Remote sensing of soil properties has been attempted using aerial photographs (e.g. Chen *et al*., 2000) [8], multispectral (e.g. Galvão *et al*., 2001) [11] or hyperspectral images (also called imaging spectroscopy; e.g. Ben-Dor *et al*., 2002) [5]. Imaging spectroscopy differs from multispectral imaging in its greater number of wavebands, enabling precise recording of the spectrum and a detailed analysis of spectral properties of the soil surface.

Assessment of soil quality

Using a holistic definition of soil quality, Vågen *et al*. (2006) [21] aggregated ten commonly used agronomic indicators of soil quality (pH, organic C, total N, P, Ca, Mg, K, CEC, clay, silt) and developed ordinal soil condition classes (poor, average, good), which were used to identify spectral wavebands that could diagnose soil condition. They found that five wavelengths were related to their soil quality index: relative reflectance at 570, 1410, 2040 and 2390 nm were negatively correlated with soil condition class whereas relative reflectance at 1940 nm (which is almost certainly due to O–H bond of water) was positively correlated with soil condition class. The authors computed a soil fertility index (SFI), calibrating the membership of the three soil condition classes to reflectance spectra of soils using a proportional odds ordinal logistic regression model. Finally, the SFI was successfully applied to the spatial representation of global soil quality based on remote sensing satellite imagery

Diagnostics of specific soil quality

The application of laboratory spectrometry for the specific assessment of soil quality started in the 2000s. Cohen *et al*. (2005b) [10] presented the first application for the rough assessment of a specific soil threat. They showed that NIRS clearly outperformed a frequently used empirical model for classifying sites according to soil erosion status. They used classification trees to provide an objective definition of degraded and intact soil conditions and developed NIRS-based screening models calibrated with reliable visual observations of degraded sites. These NIRS classification models were found efficient in discriminating three degradation classes (intact, moderate and severe erosion). This rough assessment of a soil threat could be a useful tool for characterizing site conditions prior to irreversible degradation (Cohen *et al*., 2005b) [10].

Recent research has focussed on the quantitative prediction of specific and targeted soil quality indices with laboratory NIRS. Shepherd & Walsh (2007) [17] presented some preliminary tests of indices designed to assess particular soil functions or threats such as soil fertility, soil erosion rate, soil erodibility, soil infiltration capacity, and plant growth potential. Their specific spectral indicators were based on the Mahalanobis distance in the principal component space built using a library of soil reflectance spectra. Cécillon *et al*. (2009) [6] recently proposed a tentative approach based on the direct prediction of specific soil quality indices related to soil ecosystem services using laboratory NIRS. The accuracy of three soil quality indicators derived from the general indicator of soil quality (GISQ; Velasquez *et al*. 2007) [22] was tested on the impact of wildfire disturbance (time since last fire) and soil engineering activity of earthworms (topsoil *versus* casts samples). For each sample, conventional analyses related to three soil ecosystem services were performed. Organic matter storage was assessed through organic C and total and mineral N contents, nutrient supply through pH and exchangeable cations (Ca, Mg, K, Na, CEC), and biological activity through a set of microbiological parameters (microbial C, two extracellular enzymes, potential denitrification and microbial C to organic C ratio). Three specific indicators (SI) of soil quality, reflecting the provision of these soil ecosystem services, were then computed using the GISQ approach (Velasquez *et al*., 2007) [22]. Higher SI values indicate more ecosystem services produced, thereby an improved soil quality (Velasquez *et al*., 2007) [22]. Implementing this cost-effective strategy could have wide implications for the spatial coverage and the sampling frequency of soil monitoring networks (SMN). Existing SMN sites and data could be used for the regional calibration of soil quality indices. Then a quantitative assessment of soil quality could be performed at the field scale depending on the end-user or land manager's needs. The sampling frequency of SMN could also be increased enabling a seasonal assessment of soil quality, which is crucial for the early detection of changes in soil conditions.

Conclusion

Spectroscopy is an emerging technology having vast applications in different fields such as cereal industry, dairy industry, meat industry etc. Soil Nutrient content important for plant growth, the knowledge about soil available nutrient will be beneficial for farmer to improve crop production. There is widespread interest for using near infrared reflectance Spectroscopy and NIR analysis for soil analysis and to provide information for soil mapping.

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