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Mir spectroscopy: An innovative tool for soil quality evaluation

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Abstract
The demand for important soil quality indicators for evaluating and inspecting the impact and measuring the success of modern agricultural practices has increased. Hence studying of Soil quality with its different indicators like Physical chemical and biological is having its own importance. Soil physico-chemical and biological properties affect plant nutrient availability; measuring them by conventional laboratory methods is laborious and time-consuming. Diffuse reflectance spectroscopy provides a good alternative that may be used to enhance or replace conventional methods of soil analysis, as it overcomes some of their limitations. Spectroscopy is rapid, timely, less expensive, non-destructive, straight forward, sometimes more accurate than conventional analysis and do not use any toxic chemical. The methodology has sufficient accuracy across a range of soils for application to determine the effects of land-use on these key indicator soil properties.

Keywords: MIR spectroscopy, diffuse reflectance spectroscopy, soil quality

Introduction
The demand for important soil quality indicators for evaluating and inspecting the impact and measuring the success of modern agricultural practices has increased. Fertilizer use efficiency in India is very low, imbalanced, and is in favour of Urea. The injudicious use of chemical fertilizer has created problems like deterioration of soil quality and health as well as environment too. It has been observed in recent years that yield has reached a constant rate due to decline in factor productivity (Yadav *et al*., 1998) [1]. Hence studying of Soil quality with its different indicators like Physical chemical and biological is having its own importance. Soil properties based on biological have been shown to respond to small changes in soil conditions, thus providing information sensitive to subtle alterations in soil quality (García-Ruiz *et al*., 2008) [2]. However, determination of these soil quality indicators is usually quite time consuming. To be of practical use in assessing soil quality, bio-indicators should be easily measured by standardized methods, and reflect changes in management within a relevant time frame. Soil physico-chemical and biological properties affect plant nutrient availability; measuring them by conventional laboratory methods is laborious and time-consuming. Proximal soil sensing using diffuse reflectance spectroscopy (DRS) has been suggested as a possible alternative because measurements are rapid and inexpensive (Viscarra Rossel *et al*., 2011). Furthermore, the technique can produce simultaneous assessment of different soil properties, including soil texture and SOM. Diffuse reflectance spectroscopy uses the interactions of visible (vis., 400–700 nm), near-infrared (NIR 700–2500 nm) and/or mid-infrared (mid-IR, 2500–5000 nm) radiation to investigate the characteristics of the soil sample. Intense fundamental molecular frequencies related to soil components occur in the mid-IR part of the electromagnetic spectrum.

Mid Infra-red (MIR) Spectroscopy
Mid-Infrared spectroscopy (MIR) is a FTIR spectroscopy technique that is growing rapidly and providing exciting new experimental capabilities for soil quality studies. The combined contributions from the various soil components can result in a very complex spectrum, difficult to analyze visually, but multivariate calibration models can be built to derive useful qualitative and quantitative relationships or models between the spectral signatures and many soil properties.

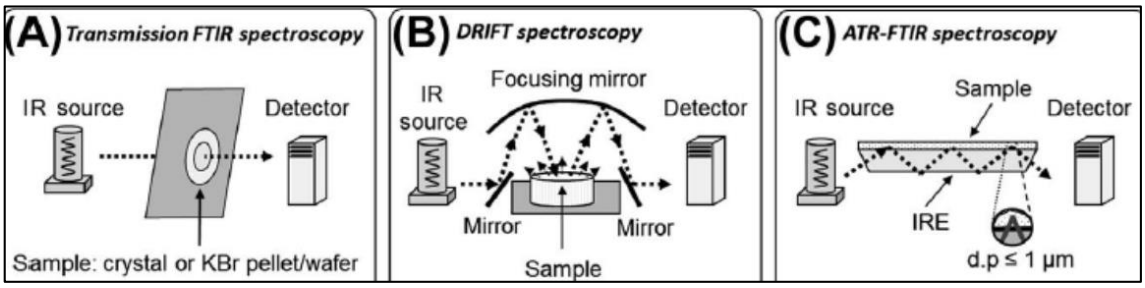

Fig 1: Representation of common FTIR sampling approaches like A) transmission, (B) diffuse reflectance infrared Fourier transform spectroscopy (DRIFTS), and (C) attenuated total reflectance (ATR)-FTIR (FTIR, Fourier transform infrared) Adapted from Parikh an Chorover (2005) [5].

Spectrometry is the combination of spectroscopy and chemometric (multivariate statistical) methods. Diffuse reflectance spectroscopy provides a good alternative that may be used to enhance or replace conventional methods of soil analysis, as it overcomes some of their limitations. Spectroscopy is rapid, timely, less expensive, non-destructive, straightforward, sometimes more accurate than conventional analysis and do not use any toxic chemical. Furthermore, a single spectrum allows for simultaneous characterization of various soil properties. Due to advances in spectrometer hardware, computing and statistical software, mid infrared reflectance (MIR) spectroscopy have shown great potential for fast, accurate and cheap soil analysis with particular application in the field and where high spatial density is needed.

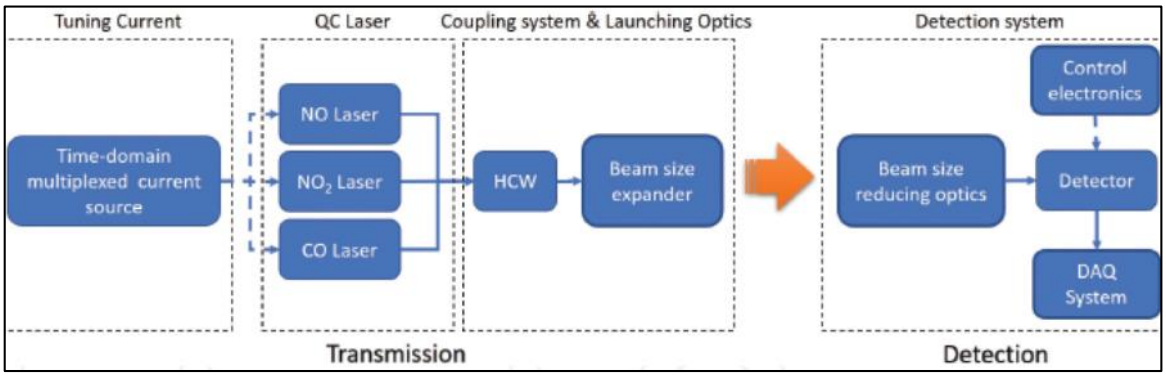

Fig 2: Simplified schematic representation of the Mid-IR spectroscopy system

Over the last two decades or so, the application of mid-infrared (mid-IR) spectroscopy has come under increasing investigation for the analysis of soils. The strength of Mid Infrared Spectroscopy (MIRS) lies in its ability to provide rapid and cost effective estimates of a number of physical and chemical properties of soil. Very less pre-treatment of soil samples i.e. drying and grinding of soil samples to less than 0.5 mm is required for obtaining MIR spectra. Internationally there is considerable research effort is going on for developing NIR and MIR calibrations for rapid estimation of soil parameters.

Prediction of soil physical properties using mid infrared spectroscopy

Evaluation of chemical and mineralogical properties from Diffuse Resonance Spectroscopy measurements is widely documented, studies on soil physical properties like, and aggregate stability, soil water retention etc. are less. The proportion of water stable aggregates larger than 0.25 mm (WSA), mean weighted aggregate diameter (MWD) and water dispersible clay (WDC) are good indicators of the risk of surface sealing, runoff generation and soil erosion by water. These aggregation indices are influenced by the contents in clay, iron oxides, calcium carbonate and organic matter, among other soil properties. Because these soil components possess specific spectral characteristics, one can use reflectance measurements to estimate the previous aggregation indices. Soil-water properties vary widely with soil composition and texture, but measurements are often time consuming and expensive to determine using traditional laboratory methods. Mid-infrared (MIR) spectroscopy is sensitive to soil composition, allowing multivariate calibrations to be derived between volumetric soil water retention and MIR spectra. Mid-infrared partial least squares (PLS) models can be derived from the spectra of soils and reference data, and can be used to predict the water retention solely from the MIR spectra of unknown samples.

Prediction of soil chemical properties using mid infrared spectroscopy

Chemical estimation of soil is an important thing to recommendation of fertilizers for supplying the plant nutrition. The prediction of chemical properties by using MIR spectra and can recommend the fertilizers for crop production.

Soil carbon and organic matter

The different carbon pools are be in command of aggregation, water holding capacity, retention of plant nutrients, pH etc. TOC (Total organic carbon) is considered as an indicator of sustainability and plant nutrients as well as control biological status also. IR (Infra-red) analysis is most important tool for the SOM (soil organic matter) which present in SOM. VIS-NIRs are frequently estimate of SOM. Whereas, MIR is used to determine organic and inorganic carbon pools in soil.

Cation exchange capacity (CEC)
CEC is an important parameter to evaluation of soil fertility and estimation of fertilizers doses. CEC of soil mostly controlled by SOM, surface area and clay type also. MIRs are gives peak of spectra with hydrated molecules of elements like Ca, Mg, K and Na due to much more susceptible to water content. This spectra peak depends on the layers of hydrated cations molecule (Monolayer / Double layer).

Prediction of soil biological properties using mid infrared spectroscopy
80-90 % of biological transformation of nutrients are depends on soil microbial biomass (SMB) and SMB is a carbon pool which central to cycling of C and other nutrients as well as energy flow in soil system.

Microbial biomass
5 % or less of TOC, represented by SMB in soil. Moderately successful prediction were originated for biomass C for MIR, NIR and vis-NIR region of spectra (R2 values; 0.82 to 0.84).

Soil respiration
The SMB is generally documented alongside substrate-induced respiration and basal soil respiration (BSR) rate or used to calculate the metabolic quotient (respiration per unit biomass) as an indicator of the efficiency of carbon utilization. In general, greater prediction success was reported for SMB-C and BSR, compared to prediction of the metabolic quotient (the respiration the size of microbial biomass to the rate of respiration.

Elemental analysis
Soil nutrients, such as N, P, K, C plays an important role in the development of agricultural crops and hence determination of their concentrations is crucial to the application of the precision agriculture concept. Soil carbon, and especially organic C, is the property most commonly determined, using DRIFT. Many studies reported very good results with correlation coefficients (R2) between the actual and estimated values higher than 0.90. Reeves and Smith (2012) hypothesized that wide range of soil uses was responsible for the poor performance of the regression models. Acceptable results were also reported for estimation of total nitrogen (R2>0.80), using either DRIFT or photo acoustic spectroscopy. The largest determination errors correspond to calcareous soils for which nitrate determination is hindered by the absorbance band of carbonate that overlaps the nitrate band. For potassium, phosphorous conflicting findings have been reported. Bertrand *et al*. (2002) reported that DRIFT could be used to estimate potassium concentration (R2=0.85).

Conclusion
Mid-IR range have lot of potential that this technique holds for rapid and inexpensive soil analysis. A major advantage of spectroscopy techniques in general and mid-IR in particular is that several properties can be determined from a single spectrum, which greatly reduces the costs of analysis compared to conventional laboratory techniques. In addition, the measurement is very rapid so that a large number of samples can be easily screened within a very short period of time. MIR analysis can provide low cost, rapid prediction of properties or indicator level analyses. MIR spectra are acquired in less than one minute and simultaneous prediction of soil properties takes only a few seconds more.

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