Measurement of soil attributes using NIR spectroscopy: A review

BabanKumar S. Bansod¹, RitulaThakur², Vikash², Neha Kamboj²

¹CSIR- Central Scientific Instruments Organisation, Sector 30-C, Chandigarh, (India)
²NITTTR- National Institute of Technical Teachers Training and Research, Chandigarh, (India)

ABSTRACT
Soil fertilizer management is important to adjust the soil fertility by supplying fertilizers at optimum level to achieve maximum yield at minimum environmental risks. Precision agriculture demands to develop better cost and time efficient methodologies for analysis of soil properties. Besides conventional techniques, sometimes spectroscopy is more accurate, fast, non-destructive and inexpensive analytical technique. Diffused reflectance measurement in the NIR region (780-2500 nm) is involved in NIRS (near infrared reflectance spectroscopy) and this is highly sensitive to both inorganic and organic phases in soil. Quantitative analysis for prediction of various soil properties and components involves NIR spectra calibration against some reference value by using some prediction model (e.g. ANN (Artificial neural network) or MPLS (Modified Partial Least Square Regression)). The goal of this paper is to review the results, modelling methods, hardware and software involved to measure various attributes of soil using NIR spectroscopy.

Keywords- NIRS, Precision Agriculture, Soil properties, Spectroscopy.

I. INTRODUCTION
Measurement of soil properties by means of conventional methods is expensive, time consuming and complex when large numbers of samples are needed. Perhaps a possible substitutes to improve the conventional laboratory methods for analysis of soil properties are the spectroscopic techniques (e.g. nuclear magnetic resonance (NMR), near-infrared (NIR), mid-infrared (MIR), visible (VIS) spectroscopy and mass spectroscopy)[1]. Spectroscopic techniques preserve the integrity of the soil system due to their non-destructive nature. Near infrared reflectance spectroscopy (NIRS) having electromagnetic spectrum region from 780-2500nm wavelength is highlighted in Fig.1. Simultaneous characterisation of multiple soil attributes, in particular with infrared spectroscopy is permitted by a single spectrum. Less time consuming, in expensive and need for a little or no sample preparation are some other advantages of NIR spectroscopy over conventional techniques of soil analysis [2]. NIR spectra of soil consists of tones and combinations of fundamental bands for N-H, C-H and O-H bonds and results from stretching, twisting, scissoring or bending of different chemical bonds [3]. Near-infrared (NIR) spectra is also influenced by the physical as well as the chemical properties of a material. The length of transmission of light through a sample is affected by the shape, size, arrangement and the voids between particles of the sample under observation and hence it influences the reflectance[4].
II. QUANTITATIVE ANALYSIS OF SOIL SPECTRA

It is impossible to interpret the NIR spectra directly. A statistical treatment is required for each NIR data[5]. A mean centring technique is used to normalize the spectral data and it can be variance scaled. 1st and 2nd derivative of spectra is computed to reveal information hidden in spectral data. Derivative filters (e.g. Savistky-Golay or Norris) can be used for smoothing the optical signal. It helps to reduce spectral noise and scattering corrections like MSC and SNV [6]. Statistical tools are implemented for spectral data analysis after pretreatment.

Various Statistical Techniques to relate the spectral data with the soil properties

There are lot of techniques used by the researchers to relate soil attributes to spectra obtained from soil. For e.g., MRA (multiple regression analysis) was used by Ben-Dor Banin (1995)[7] to relate various properties of soil to specific bands in NIR. SMLR (stepwise multiple linear regression) was used by Shibusawa et al. (2001)[8] for estimating a number of soil properties from the NIR spectra obtained from the soil by an on-the-go field installed sensing system. MARS (Multivariate adaptive regression splines) was used by Shepherd and Walsh (2002) [9] for estimating soil properties from available soil libraries. RBFN (radial basis function network) was employed by Fidencio et al. (2002) [10] to detect OM contents of soil from the spectra obtained in near infra-red region. ANN (artificial neural network) was used by Daniel et al. (2003) [11] to evaluate soil OM, P and K from the VIS-NIR spectra. However the most widely used prediction techniques or spectral calibration technique are PCR (principal components regression) and PLSR (partial least square regression) used by Chang et al. (2001) [12] and McCarty et al. (2002) [13] respectively. BP-NN( back propagation neural network) was used by XiaofeiAn et al. (2013) [14] to estimate soil attributes from a NIR spectra.

A local methodology for calibration of NIR prediction has attracted attention recently [15] [16] [17][18]. Within spectral classes, a local calibration is predicted and defined either directly upon soil texture groups, land use or soil type or on Mahalanobis distances (statistical distance among spectra). The Mahalanobis distance of an
observation \( \mathbf{x} = (x_1, x_2, x_3, \ldots, x_n)^T \) from a set of observations with mean \( \mathbf{\mu} = (\mu_1, \mu_2, \mu_3, \ldots, \mu_n)^T \) and covariance matrix \( S \) is shown by (1):

\[
D_n(\mathbf{x}) = \sqrt{\left( \mathbf{x} - \mathbf{\mu} \right)^T S^{-1} \left( \mathbf{x} - \mathbf{\mu} \right)} \quad \text{Equation 1 [27]}
\]

Assessment of the quality of NIR prediction model can be done with various indices \([5], R^2\) (the coefficient of determination), SEP (standard error of prediction) and RPD (ratio of performance to deviation), where \( R^2 \) - the coefficient of determination is as shown by (2):

\[
R^2 = \frac{\left( \sum_{i=1}^{n} (y_i - \bar{y})^2 \right) \left( \sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2 \right)}{\left( \sum_{i=1}^{n} (y_i - \bar{y})^2 \right)} \quad \text{Equation 2}
\]

Where,

dx is the standard deviation of x

dy is the standard deviation of y

III. INFERENCE AND DISCUSSION

NIRS (Near infra-red diffuse reflectance spectroscopy) technology is a good tool to detect various soil attributes with a considerable accuracy by using various prediction techniques. TABLE 1 shows the value of \( R^2 \) obtained while measuring various soil properties by using different prediction models. The study shows that various methods of pre-processing the data are employed to enhance the robustness, reliability and performance of the prediction model. Spectroscopic analysis of soil properties in laboratory is simple, non-destructive and accurate method which does not require a complex procedure to prepare soil samples for testing. The only disadvantage is that the whole testing system consists of a very costly set-up and it is lab based only. Keeping in view the small farmers who have small and scattered land for farming and their ignorance towards bringing soil samples to laboratory for testing, there is a need to develop a cheap on-the-go system based on the above said technology to detect soil macro-nutrients, so that Indian farmers can be benefitted in order to improve the crop production.

Table 1- A detailed study of prediction techniques and hardware used to detect various soil attributes by means of NIRS.
## Table

<table>
<thead>
<tr>
<th>Device Used</th>
<th>Software used</th>
<th>Prediction Model used</th>
<th>r² values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foss NIR Systems 5000 Spectrophotometer (Silver Spring, MD, USA)</td>
<td>Win ISI III V.1.61 Software (Inf rasoft Intl, LCC, PA, USA)</td>
<td>PCA, PLS Method</td>
<td>C=0.97, N=0.93</td>
</tr>
<tr>
<td>NIR Spectrophotometer (Oceanoptics)</td>
<td>OPUS QUANT2 Software (Bruker Optics GmbH, Germany)</td>
<td>PLSR, BRT</td>
<td>0.99</td>
</tr>
<tr>
<td>FieldSpec Pro FR (350-2500nm)</td>
<td>Unscambler 8.5 software Package (CAMO, ASA, Norway)</td>
<td>Partial Least Square Regression, Least Square method</td>
<td>0.99</td>
</tr>
<tr>
<td>Foss NIR Analyzer (spectral measure range 781-2779 nm)</td>
<td>Unscambler 8.0 (CAMO, ASA, Norway)</td>
<td>Principal Component Analysis, PLS Method</td>
<td>0.97</td>
</tr>
<tr>
<td>Perkin Elmer Spectrum One NTS, FT-NIR Spectrometer (Laurel, MD, USA)</td>
<td>Unscambler 8.0 (CAMO, ASA, Norway)</td>
<td>Principal Component Analysis, PLS Method</td>
<td>0.97</td>
</tr>
<tr>
<td>Device Used</td>
<td>Software used</td>
<td>Prediction Model used</td>
<td>r² values</td>
</tr>
<tr>
<td>------------</td>
<td>----------------</td>
<td>----------------------</td>
<td>-----------</td>
</tr>
<tr>
<td> </td>
<td> </td>
<td> </td>
<td> </td>
</tr>
</tbody>
</table>

## REFERENCES

