Near Infrared Spectroscopy Based a Portable Soil Nitrogen Detector Design

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Abstract— **Spectroscopy is an emerging technology, having vast applications in food industry and agriculture. The unique quality of Spectroscopy to characterize material from the reflection or absorbance has been used in the current paper to measure soil Nitrogen content. Taking into account the advantages of Near Infrared (NIR) region over other regions of electromagnetic spectrum, NIR Spectroscopy was decided to be employed for Soil Nitrogen measurement. An expensive, bulky, non-portable Spectrometer was successfully replaced by a small, portable assembly consisting of six LEDs (940, 1050, 1100, 1200, 1300, 1550) corresponding to six Nitrogen sensitive wavebands and six photo-detectors. The detailed structure design and experimental procedure has been described in the paper. Device was calibrated using the most commonly used Partial Least Square Regression (PLSR) analysis which acquired a calibration coefficient of determination (R^2) 0.875 and Validation R^2 0.803.**

Keywords— **Spectroscopy, Near Infrared (NIR), Spectrometer, Partial Least Square Regression (PLSR), coefficient of determination (R^2)**

I. INTRODUCTION

For increasing crop production, soil testing is helpful for recommending the type of fertilizer and its quantity to be added to the soil. This leads to an efficient fertilizer use, Environment protection, product quality enhancement and increase in yield. The conventional soil testing methods, namely laboratory analysis methods are time consuming, expensive and require expert operator in chemical analysis. At the same time these methods won't be helpful in on-line monitoring processes. Thus, there is an insistent demand for investigating a reliable and cost effective method for instantaneous analysis. Overcoming these disadvantages, Spectroscopy has shown promising results for estimation of soil constituents.

Spectroscopy is a rapid, timely, less expensive, non-destructive analytical technique which can be reliably used to estimate different soil properties without the need of chemicals [14]. It is an analytical technique that characterizes the materials according to their absorbance or reflectance in the specific wavelengths. The estimation of constituents is achieved from the soil spectrum, obtained by directing radiation containing all relevant frequencies in the particular range to the sample. Depending on the constituents present in the soil, the radiation will cause individual molecular bonds to vibrate, either by bending or stretching, and the light absorption will correspond to a specific energy quantum equivalent to the difference between two energy levels. Because of its particular bonds and molecular structures, each chemical species produces a unique IR absorption spectrum, which can be used for analytical purposes [15].

Near infrared reflectance (NIR) spectroscopy, with electromagnetic spectrum region from 780-2500nm wavelength, has been used for analysis of minerals, forages, plant material and grains as well as for some soil materials. The NIR region is dominated by weak overtones and combinations of fundamental vibrations due to the stretching and bending of N-H, O-H and C-H groups [14]. NIR is well supported commercially, is well suited to field portability, remote sensing, copes better with moist samples and can deal with larger bulk soil samples because of its more intense sources and sensitive detectors.

The main reason for sensing nitrogen in the farm fields is to determine the amount of fertilizer applied to meet the needs of the crops and to prevent over-applying so as to diminish nitrate leaching down in groundwater reservoirs. Nitrogen is said to be a best indicator of soil fertility. Nitrogen is an essential element of all amino acids, which are the building blocks of proteins. It is also a key component of nucleic acids and chlorophyll. A plant receiving sufficient nitrogen will typically exhibit higher photosynthesis rate and vigorous plant growth. From the surveillance, it is inferred that NIR region of the spectrum is most suitable for predictions of soil Nitrogen contents [14].

In recent decades, Spectroscopy technique has been increasingly used in agricultural and food industries. Many experiments and research has been done to develop spectroscopy based reliable, portable and cost effective device. Felipe et al. [6] developed a low-cost IR absorption spectroscope based on linear variable filter (LVF) technology for the automated detection of gases and vapours, and the semi-automated detection of liquids. Sudduth and Hummel et al. [16] used a portable near infrared spectrophotometer for estimation of soil organic matter with an R^2 of 0.89 and a standard error of prediction of 0.40%. Similarly, NIRS has been used for soil total Nitrogen detection by Dalal and Henry et al. [5] using MLR calibration with correlation coefficient R^2 of 0.92 over 1100-2500. Reeves and McCarty (2001) used PLSR with R^2 of 0.94 in wavelength range 1100-2300. They all employed various spectrophotometers for estimation of soil nutrients through the spectra obtained. But, use of spectrophotometers made the device bulky and very expensive. Replacing the spectrophotometers with LEDs and detector, An et al. (2011) suggested six wavelengths (1550, 1300, 1200, 1100, 1050, and 940 nm) as the sensitive wavebands for soil Nitrogen [16]. The estimation

model was obtained using the FT-NIR analyzer with calibration R^2 of 0.85, and the validation R^2 of 0.77. Further, XiaofeiAn et al. [18] developed the BP-NN estimation model having soil TN content R^2 0.88 and the validation R^2 0.75. As, these estimation models had a very good accuracy, the six LEDs are used in the present design.

II. OVERALL STRUCTURE DESIGN

To make the system design more compact and simple, structure is designed as shown in fig. It consists of six LEDs (having wavelengths 1550, 1300, 1200, 1100, 1050, and 940 nm) [18], six photo-detectors and a test tube with low refractive index and a mirror for total internal reflection. LEDs and photo-detectors are placed vertically parallel to the axis of test tube. The whole assembly is enclosed into a black box so as to have zero interference due to atmospheric light.
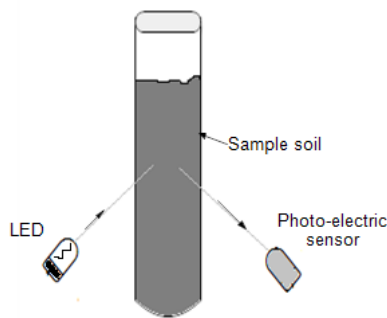

Fig. 1.   Structure of Nitrogen detector module

Microcontroller controls LED switching. First LED is turned on for 1 second. In the intervening time, light reflected from the soil is transferred on the photo-electric sensor which converts optical signal into electrical signal. Consequently, the electrical signal is digitized and the value is stored for further processing. Similarly, all the digitized values corresponding to all six LEDs are stored and finally the estimated value of Nitrogen (%) is displayed on LCD.

III. MATERIALS AND METHODS

The soil samples used in this study were collected from the farm with clean soil in which no cultivation, fertilizer application was performed. 30 different soil samples were prepared by adding Urea in the soil samples in increasing proportion to simulate soils with varying Nitrogen concentration. Since Urea is the highest concentration dry nitrogen fertilizer available, containing 46% Nitrogen, it was decided to be used for preparing soil samples.

Water incorporated into the lattice of soil absorbs strongly near 1400 and 1900 nm. This is due to overtones and fundamentals of the three fundamental vibration frequencies of H_2O come in NIR region [15]. Thus Soil Moisture Content is the major negative factor affecting NIR spectroscopic calibrations adversely. Similarly, other influencing factors include soil particle size, soil colour, type of detectors and calibration methods [15]. Thus soil preparation procedure is necessary to minimize these noise effects on calibration accuracy. It includes following steps.
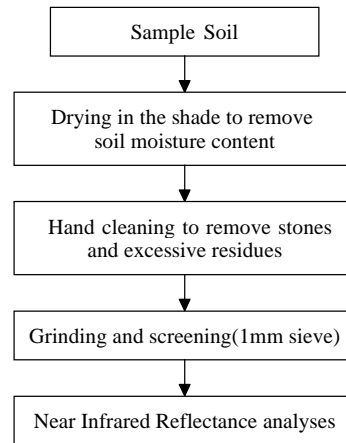

Fig. 2.   Sample preparation steps for NIR analysis

Soil sample is air dried to equalise its water content to atmospheric moisture. The dry soil is hand cleaned to remove unwanted particles from soil and then it is grinded and screened with a sieve of 1mm diameter. Thus, prepared soil can be used for NIRS analysis.

Depending on the Soil Nitrogen quantity, the reflectance will vary. Absorbance is selected as the spectral parameter. From the reflectance value absorbance can be calculated as [18]

$$A_x = \log\left(\frac{1}{R_x}\right)$$

where, x indicates 1550, 1300, 1200, 1100, 1050 and 940 nm;

The soil TN content of each soil sample was measured using conventional chemical analysis by Kjeldahl method. These results were used to calibrate the device using Partial least squares (PLS) analysis. Partial least squares (PLS), also called the factor method, is a soft modelling technique in which the data are decomposed into principal components (PC) that are linear combinations of the original data. Total 30 soil samples were divided into 20 samples of Calibration set and 10 samples of validation set randomly. Every sample was scanned 3 times at different locations. The average was taken as a final reading for calibrating the model.

Model accuracy is described by the coefficient of determination (R^2), root mean square error of calibration (RMSEC), and root mean square error of prediction (RMSEP). Considering 'x' as the Soil TN value measured using chemical method which are reference values for calibrating the device; 'y' as the TN value predicted by the device; and 'n' as the number of soil samples used for calibration, the formulae for R^2, RMSEP and RMSEC are defined in equations below.

1. Coefficient of determination (R^2)

$$R^2 = \frac{\left(\sum_{i=1}^{n} d_{xi}\, d_{yi}\right)^2}{\sum_{i=1}^{n} d_{xi} \sum_{i=1}^{n} d_{yi}}$$

Where,

$d_x d_x$ is the standard deviation of x;

$d_y d_y$ is the standard deviation of y.

2. Root Mean Square Error of Calibration (RMSEC):

$$RMSEC = \sqrt{\frac{\sum_{i=1}^{n}(x_i - y_{ci})^2}{n_c}}$$

Where,

y_{ci} is the soil TN content predicted from the calibration group;

n_c is total number of soil samples in calibration group.

3. Root Mean Square Error of Prediction (RMSEP):

$$RMSEP = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - y_{pi}\right)^2}{n_p}}$$

Where,

y_{pi} is the soil TN content predicted from the validation group;

n_p is total number of soil samples in prediction group.

IV. RESULTS AND DISCUSSIONS

Three different soil samples with different Nitrogen content are collected and analysed by the designed detector to observe absorbance at six wavelengths i.e. 940, 1050, 1100, 1200, 1300 and 1550nm.
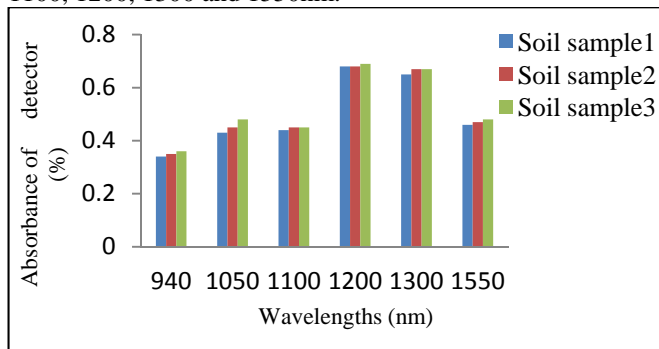

Fig. 3.   Absorbance for various Soil samples

From the graph shown above, Absorbance is more found at 1200nm and 1300 nm. Thus, Nitrogen absorbance is highest near wavelength 1200 and 1300nm.

In this experiment, partial least square regression analysis was used to relate the near infrared reflectance data to the known concentrations of nutrients, which were obtained by the chemical analyses. Coefficient of determination (R^2) for calibration set of 20 Soil samples obtained by partial least square regression analysis method was found to be 0.875.
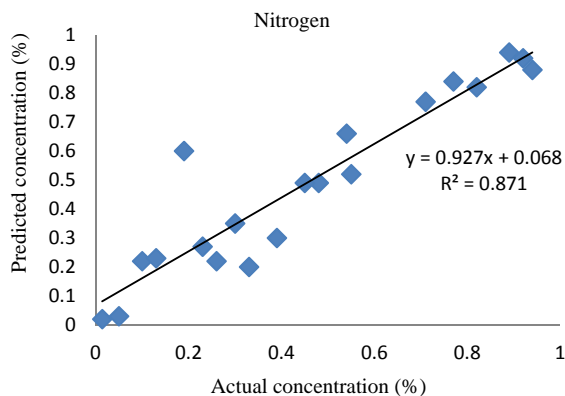

Fig. 4.   Calibration curve of Total Nitrogen

Validation R^2 obtained for remaining 10 samples was 0.803. The RMSEC and RMSEP values obtained using the designed model, were 0.044 and 0.052. Thu the present model and the Partial Least Square calibration method can be reliably applied for developing the Total Nitrogen detector.
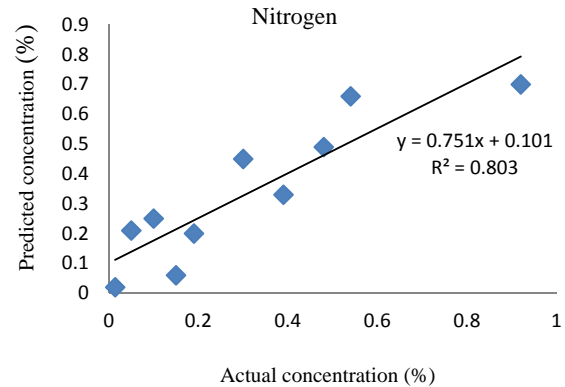

Fig. 5.   Validation curve of Total Nitrogen

Even though, the device has high accuracy, its prediction may vary at different environmental conditions and due to various noise factors including such as Soil texture, color, atmospheric moisture, temperature. Soil preprocessing minimized these noise factors to a great extent. Eliminating Soil preprocessing steps, the device may be used as an on-the-go sensor for measuring field TN.

V. CONCLUSION

The spectroscopy technique is practicable, as analysis is possible from the IR absorption spectrum, which is unique for every species, chemical or material. Instead of examining the wide range of NIR spectra, Total Nitrogen concentration has been successfully predicted by investigating only six wavelengths. Use of LEDs corresponding to these six Nitrogen sensitive wavebands (940, 1050, 1100, 1200, 1300, 1550), has resulted in designing a compact, portable, very cost effective and rugged TN detector device. Soil sample pre-processing steps improved the prediction accuracy by eliminating the noise parameters, such as Moisture, Soil structure, etc. Though, the current device is not useful for in-situ applications, it can be further advanced for real time field use, without the need of Soil pre-processing. Most commonly used Partial Least Square method was used for calibrating the device which acquired Calibration R^2 0.875 and Validation R^2 0.803. Very less RMSEC and RMSEP were obtained, in particular, 0.044 and 0.052 respectively. Thus, the device can reliably be used for Soil Nitrogen measurement, with optimum accuracy.

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BIBLIOGRAPHY

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