REVIEW OF OPTOELECTRONIC DETECTION METHODS FOR THE ANALYSIS OF SOIL NUTRIENTS

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Abstract:
It is required to give proper ratio of nutrients to the crop for their growth through the fertilizers. The fertilizers required to add in the soil should be known. Many researcher are working to determine primary soil nutrients Nitrogen (N), Phosphorous (P) and Potassium (K). This paper gives review of sensing technology and other portable methods used to determine the soil nutrients NPK.

Keywords: Soil nutrients NPK, LED, optical detector, near infrared

I. Introduction:

Soil efficiency can be achieved by giving proper ratio of fertilizers to the soil. These fertilizers plays important role by giving essential soil nutrients to the crop land that are required for nourishing and growth of crop. But sometime farmer give the additional fertilizers to the soil which becomes the fatal situation that directly affect the crop productability. If they know in advance, what is a proper concentration of soil nutrients in the crop land, then it will be beneficial to the farmers.

We can determine these soil nutrients in the soil by various methods. Many researchers tried to invent the method that give the information regarding the soil nutrient contents. There are various method to determine soil nutrients such as electrochemical methods, spectroscopy methods and optical methods [1]. These all methods are important to determine the soil nutrients like nitrogen, phosphorous, potassium, iron, magnesium, calcium, manganese, boron, minerals, soil organic matter, soil water content.

Optical reflectance method with visible infrared and mid infrared frequencies gives the great result including soil organic matter soil minerals and some soil nutrients. Optical sensor plays important role in determination of soil nutrients. With the help of the sensor we can estimate proper ratio of nutrients in the soil, and then accordingly farmers can use ratio of fertilizers.

II. Related work:

Adamchuk et al. [1] proposed various on the go soil sensors for precision agriculture. Various attempts are taken to develop on-the-go soil sensors. The development of sensors is expected to increase the effectiveness of precision agriculture. They proposed the various sensors namely electrical and electromagnetic sensors, optical sensors, mechanical sensors, acoustic sensors, pneumatic sensors and electrochemical sensors to determine various soil micro-components. All these sensing methods are useful, but most widely used method is

electrical and electromagnetic method. Due to electrical nature of the soil in the form of electrical resistivity or electrical conductivity, electrical and electromagnetic methods are very useful in determination of soil texture, salinity, organic matter, moisture contents and other soil parameter. Soil surface reflects energy of particular spectral range. This reflected energy can be calculated using optical sensor. Soil reflectance can be measured at 660 nm for organic matter having $r^2 = 0.71$. Visible and NIR spectroscopy can be used to determine organic carbon and total nitrogen having $r^2 = 0.65$ and $r^2 = 0.87$.

W.S. Lee et al. [2] proposed various sensing technology that are very useful for determination of various soil physical and chemical information and properties. They proposed various sensing system like field-based electronic sensors, photospectro meters, machine vision, remote sensing, satellite imagery, thermal imaging, RFID, and machine olfaction system. These all sensing technologies are useful for detection of soil nutrients, crop water content, crop detection, weed and biomass detection. So they discussed the factors that are need to be researched for precision agriculture including soil properties, soil nutrients, water contents and pest conditions.

Bah A. et al. [3] discussed the potential of various on the go sensor like electrochemical sensors, optical and radiometric sensors, acoustic sensors and mechanical sensors and they can play an important role for nondestructive and rapid characterization of soil nutrient variability and various soil nutrients. Precision agricultural based on modern agricultural technologies plays important role for efficient management of soil nutrient and crop management. Optical soil sensors have a high potential for estimation of soil organic matter content based on soil color. In optical sensing of soil, the visual and near-infrared spectral reflectance can potentially estimate texture, moisture, CEC and other soil parameters, if proper data analysis techniques are applied. Intensive grid sampling is the most popular method for deciding the variability of crop and soil attributes but this method is time consuming and expensive so neglected. They proposed various sensors that are solely applicable to determine one or two soil attributes. Acoustic sensors are useful to differentiate the physical and mechanical characteristics of soil. These sensors senses the sound waves that are useful to determine the soil compaction layers. Mechanical sensors are useful to determine the soil strength that is required for plant growth.

Hak-Jin Kim et al. [4] discussed the two sensing technologies for determination of soil macronutrients like nitrogen, phosphorous and potassium. Accurate determination of soil nutrient is required for efficient crop production including site specific crop production. Two sensing approaches i.e. electrochemical method and optical diffuse reflectance sensing are the most promising methods. On the go vehicle based sensing system also has the ability to efficiently and rapidly characterizing variability of soil nutrients in the field. The NIR absorbance data in conjunction with fast fourier transform [FFT] and partial least squares regression [PLSR] is used to determine soil nitrate NO_3-N over the range of 0 to 300 mg/kg. In electrochemical method
nitrate ion membranes and electrodes gives the best response to the nitrate in the soil.

Sinfield et al. [5] discusses various methods for determination of soil micronutrients. The micronutrients like nitrogen (N), phosphorous (P), potassium (K) are the most powerful nutrients required for the plant growth and are the prime ingredients in fertilizers. The use variable rate of application of fertilizer for the crop growth is impractical and economically challenging. For the nitrogen determination they discussed nitrate ion selective electrode and nitrate ion selective field effect transistor methods. For phosphorous determination they discussed the raman scattering and reflectance spectroscopy methods. This method give the good result of total phosphorous content in the soil having the r^2 value nearly about 0.63 to 0.68. For potassium determination they discussed the reflectance spectroscopy and potassium ion selective electrode methods giving r^2 value nearly about 0.7. Chemical analysis for the

detection of soil nutrients involves intensive and complex laboratory testing. Optical analysis is the most efficient and reliable method for the detection of the soil nutrients and this method gives the accurate result giving the accuracy (r^2) = 0.92 but need site specific calibration.

Jose M. Soriano-Disla et al. [6] proposed three methods for spectroscopy and they are compared for the determination of physical, chemical and biological properties of soil. The three methods namely Visible-Near infrared [Vis-NIR], Near infrared [NIR] and Mid infrared [MIR] spectroscopy methods are used for performance measurement of soil properties. MIR spectroscopy method is useful for determination of other soil components like quarts, clay minerals and carbonates. They have the frequency range of 2500-25000 nm. Spectrum obtained by mid infrared spectroscopy is complicated by the presence of inorganic material including Si-O group in quartz and C-O group in carbonates. Median R^2 value is known as degree of determination used for the prediction of various soil chemical properties. Soil organic matter properties are mostly predicted by Vis-NIR spectroscopy method. Frequency range for visible range is between 400-700 nm and frequency range for near infrared region is between 700-2500 nm. For prediction of determination of nitrogen [N], phosphorous [P] and potassium [K] nutrients R^2 value takes into consideration. Table I shows the comparison in terms of R^2 value.

Table I: Comparison of various spectroscopy methods in terms of R^2 value [6]

Method / Soil nutrients	Mid infrared [MIR] method	Near infrared [NIR] method	Visible-near infrared [Vis-NIR] method
N (total)	0.90	0.86	0.86
P (total)	0.58	0.84	0.75
K (total)	0.70	0.50	0.75

Hari Prasad Reddy Aenugu et al. [7] discussed the use of near infrared spectroscopy for various applications. For the optical analysis various spectroscopy methods including raman spectroscopy, near and mid infrared spectroscopy methods are used. Near IR spectroscopy method uses IR rays having spectral range of 700-2500 nm. The most important source of infrared light is Light Emitting Diodes (LED) which consists of Gallium arsenide used as semiconductor for near infrared light emission that produces the radiation at particular wavelength. They require less power to transmit radiations, hence they can be used in the formation of portable device. They discussed the various NIR instruments including scanning spectrometers, fourier transform spectrometers, acoustic optical tuneable filter spectrometers and photodiode array spectrometers. The silicon photo diode array [PDA] are very useful in NIR spectroscopy they include InGaAs detector material makes the PDA more powerful for NIR analysis. They cover the spectral range between 900-2200 nm. The detector that used in NIR spectroscopy is given in Table II.

Yubing Wang et al. [8] suggested the potential of VIS/NIR soil sensors and also discussed the various prediction models. Soil organic matter contents is predicted using VIS/NIR soil sensor. Various regression methods are used namely Direct Linear Regression, Principle Component Regression and Back Propagation Neural Network to construct the prediction model which provide appropriate result for the estimation of organic matter content in soil. Principle Component Regression and BP-ANN have given the

favorable result which straightforward denotes the VIS/NIR sensor is good tool for detection of organic matter in soil.

Table II: Detectors used in NIR spectroscopy [7]

Detector	Wavelength range (nm)	Region	Responsivity/detectivity	Remark
PbS	1100-2500 400-2600 1100-4500	NIR UV-NIR NIR-MIR	Intermediate/intermediate	Pbs sandwiched in silicon photodiode, are often used for VIS-NIR
PbSe	1100-5000	NIR-MIR	Fast /high	The detector must be cooled with liquid nitrogen
InGaAs	700-1700	NIR NIR Raman	Fast / very high	Linear array high sensitivity, dynamic range, signal to noise performance and stability FT-NIR diode arrays spectrometers
InSb/InAs	1000-5500	NIR MIR IR	Fast / very high	High quality detector Detector photodiodes
CCD	800-2200	NIR	Fast / high	High performance detectors applied in cameras Diode arrays spectrometers

Table III: summary of methods used for sensing technology [1] [3] [5] [9]

References	Proposed sensing technologies	Merits/demerits
Adamchuk et al. [1]	Electrochemical and optical method	Chemical method is time consuming
Bah A. et al. [3]	Various sensing technologies including optical, mechanical	Optical method has a potential to estimate soil organic matter contents
Sinfield et al. [5]	nitrate ion selective electrode, reflectance spectroscopy	Chemical analysis requires complex laboratory testing
Masayuki Yokota et al. [9]	Optical method including LED's and color developing reagents	Efficient and low power consumption

Hu Xue et al. [9] conducted experiment to analyze and predict the total phosphorous in the soil. A model is developed to determine the total soil phosphorous using chemical reference method and using visible/infrared spectral method. It uses partial least square regression algorithm and r^2 values for evaluation and validation. The r^2 and logarithmic total phosphorous [logTP] are calculated having values 0.69 & 0.65

respectively. So this method is suitable and robust to predict TP in wide soil samples.

Masayuki Yokota et al. [10] developed a system using optical devices. They used particular wavelength LED light as a source of transmitter which can transmit IR rays. They determined the soil nutrients at a particular wavelength. They developed portable optical detector which can detect the soil nutrients optically using the LED light source. This detector is able to determine the ammonium nitrate, nitrate nitrogen, phosphorous, iron, manganese and calcium in the soil. The soil samples are developed by using color developing reagents that are acquired by using commercially available soil analyzer. NH_4-N is determined using Indophenol method. The soil sample containing color solution becomes green having the absorption peak at 650 nm. The nitrate nitrogen is determined using the Azo dye and soil sample solution becomes magenta giving the absorption peak at 540 nm. The phosphorous is determined using Murphy-Riley method. Sample solution becomes blue having the absorption peak between spectral ranges of 700 nm to 900 nm. The iron and manganese are determined using tripyridyl-triazine method and a periodic oxidation method using sodium periodate respectively. The color solution of iron becomes purple having the absorption peak at 600 nm and for manganese it becomes pink giving the absorption peak at 530 nm. For calcium the soil sample solution becomes pink using the o-cresolphthalein complexone (OCPC) method .

giving the absorption peak at 570 nm. For this experiment they used three LED's having the central wavelength of 524 nm, 632 nm and 849 nm. For detection purpose one silicon photodiode is used having the detection area of 10 * 10 mm^2. The absorbance A can be calculated by the following equation.

$$A = \log_{10} (I_{in} / I_{out}) \text{ …… (1)}$$

where I_{in} is the incident light and $I_{out\ is}$ reflected light from the soil sample.

Vagner B. dos Santos et al. [11] proposed a system for potassium determination. This system is low cost, portable and low power consumption. It is microcontroller based nephelometer. This system is constructed using two LED's having radiation intensities at 465 nm and 880 nm. For detecting purpose two photodiodes are used. Various solution are formed for experiment. These solution can be reacted with coconut solution to determine the available potassium in the sample. Potassium chloride, sodium tetraphenylborate and polyvinyl alcohol is prepared as formation of samples

Conclusion:

We have reviewed various methods which are useful in the determination of soil nutrients. Optical methods are studied for the determination of soil nutrients which uses optical LED's and VIR-NIR methods. In the future we wanted to develop a hand electronic sensor for determination of micronutrients in the soil

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