Detection of NPK nutrients of soil using Fiber Optic Sensor

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Abstract: Measurement of N (nitrogen), P (phosphorus) and K (potassium) contents of soil is necessary to decide how much extra contents of these nutrients are to be added in the soil to increase crop fertility. This improves the quality of the soil which in turn yields a good quality crop. In the present work fiber optic based color sensor has been developed to determine N, P, and K values in the soil sample. Here colorimetric measurement of aqueous solution of soil has been carried out. The color sensor is based on the principle of absorption of color by solution. It helps in determining the N, P, K amounts as high, medium, low, or none. The sensor probe along with proper signal conditioning circuits is built to detect the deficient component of the soil. It is useful in dispensing only required amount of fertilizers in the soil.

Keywords - Nitrogen , phosphorus, potassium(NPK) sensor; colorometric measurement; nutrient; fiber optic sensors,

1. INTRODUCTION

To fulfil increasing demand of growing population over the years there is a need of increase in food production. To increase crop yield fertilizers containing predominantly nitrate (N), phosphate (P), and potassium (K) are essential. Improper use of fertilizers in turn results into poor quality in fruits, vegetable lagging in color, size, test and even quantity. In China over-application of fertilizers has caused low fertilizer usage efficiency (~35% in average) resulting in low agricultural product quality, serious environmental pollution, etc. [1] Quantity of NPK is dependent on crop type and on plant growth status. How much quantity of fertilizer to be used is further dependent on present contents of NPK nutrients in the soil. Researchers in agriculture are looking for ways to optimize plant yield while minimizing the consumption of fertilizer. Since these macro-nutrients vary even on a small scale throughout a cultivated field, numerous researchers have attempted to develop the sensors to map these nutrient contents. Integrated crop management systems have been designed to study spatial and temporal behavior of NPK [1,2]. Continuous monitoring of these along with humidity and pH of soil is leading to an automation in agricultural areas to improve crop productivity [3,4].
The present study deals with the actual detection of NPK values of the soil using multimode plastic fiber optic sensor. Aqueous solution of soil under test is illuminated by different light colors. Light gets reflected from solution depending upon its absorbent coefficient of soil. Reflected light is received by another optic fiber which is converted into electrical signal. Further using threshold values stored in database of microcontroller one can determine NPK levels. This helps in detecting the deficient component of the soil. Thus undesired dispensing of the fertilizers can be controlled which in turn reduces deterioration of soil.

2. NPK SENSORS

2.1 Available sensors: A key in soil testing for formulated fertilization is to determine the amount of soil nutrients, followed by recommendation of nutrient needs and site-specific fertilization. Conventional soil NPK testing methods have been generally performed by three steps: soil sampling, sample pretreatment and chemical analysis. To date, soil sampling is manually carried out in a field to obtain representative soil samples at a proper depth (~20cm below ground level). Chemical analysis i.e. actual measurement of NPK is carried out by three techniques viz. conductivity measurement, optical method, and electrochemical methods.
In Conductivity measurement technique two or three electrodes of same material are immersed in soil samples. Materials used can be steel, silver, platinum,

graphite or copper. As per concentration of NPK in soil, conductivity of electrode change. The change in conductivity is converted into electrical signal for further electronic control system [5].

Electrochemical sensors constitute Ion Selective Electrode (ISE) and Ion Selective Field Effective Transistor (ISFET). ISE and ISFET selects particular ion from samples using sensor cocktail. ISEs/ISFETs uses different membranes, extraction solutions, and a multi-target system with coated wire field-effect transistor [6,7].

The principle of optical NPK sensors is based on the interaction between incident light and soil surface properties, such that the characteristics of the reflected light vary due to the soil physical and chemical properties. Laser Induced Florescence Spectroscopy (LIFS) [8,9] or Near InfraRed spectroscopy (NIR) technique [10] or UV spectroscopy [2] is very widely used for experimental as well as commercial purpose. These optical methods are reliable, but time-consuming, complex and high cost per test (~150 Yuan/Sample). This resulted in the limitation of the number of soil samples tested for characterizing the spatial variability of soil nutrients in a field or fields.

2.2 Developed sensor and its working: During the work NPK sensor is built using multimode, plastic optical fibers. The designing of fiber optic NPK sensor probe is a critical job. Various sensing configurations have been reported for chemical sensing [10]. The fiber configuration used by us is shown in Figure 1. A sensor probe consists of seven fibers arranged in concentric configuration with central fiber acting as receiving fiber and surrounding six fibers acting as transmitting fibers.

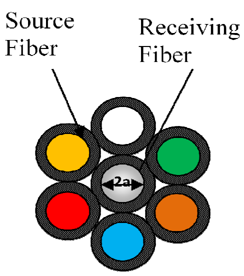

Figure 1. Sensor probe

Each fiber is a multi mode plastic fiber of 488µm core diameter with numerical aperture of 0.47. The length of each fiber is 90 mm. The fiber tips are polished with zero emery paper. These fibers are enclosed in a brass cylinder. To the sensing tip end of fiber bundle a round cut glass plate is press fitted in order to avoid damage of polished tip due to interaction with chemical under test. At one end of fiber a circular brass disc is attached which holds six high bright LED's in a circular fashion and one photodiode at center.

The developed sensor works on colorimetric principle. Colorimetry deals with the measurement of colored intensity. The color of a substance is due to the absorbance of light waves of certain wavelengths. The absorption of light by solution results in excitation of electrons in its molecule [11].

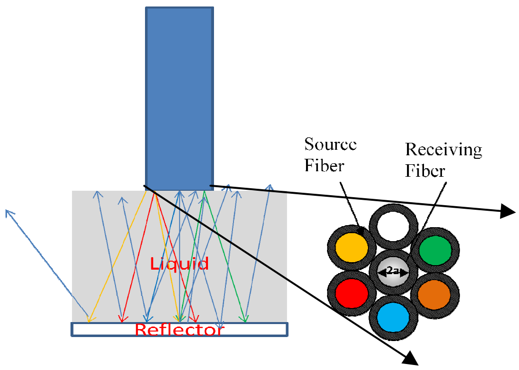

Figure 2. Working principle of Optic fiber based NPK sensor

The working of fabricated NPK sensor is illustrated in Figure 2. The different colored LEDs emit colored light of same intensity. Through multimode optic fibers light is incident on the liquid. At a optimized distance a reflector is placed. When light travels through the solution from the probe towards the reflector and back, depending on the color of absorption characteristics of the solution, different intensities will be received for different colors. The reflected intensities can be plotted against the wavelength of the source to obtain a fairly simple absorption spectrum at discrete wavelengths. From the obtained spectrum for the different soil sample aqueous solutions a simplified detection mechanism is developed.

3. SYSTEM OF NPK MEASUREMENT OF SOIL:

Figure 3 shows the block diagram of NPK detection system. It consists of fiber optic NPK sensor probe, colored light sources with driver circuits, detectors and signal conditioning circuits and display. The high brightness 5mm LED's of different colors are used as light sources and is coupled with each peripheral transmitting fiber. LED's emit relatively narrow wavelength bands. They are also amenable to direct intensity modulation, so that a mechanical chopper is not necessary. The desire to use these devices in design of fluorescent sensors has therefore often been stated in the literature. The laser diodes also can be used in place of LED's however, because of the requirements of large drive current, required additional heat sinks are considered to be difficult to handle. The driving circuit of LED consists of voltage to current converter, buffers and a subtractor.
The colored light passes through the aqueous solution of soil sample. Depending upon NPK values of soil light of particular wavelength and strength gets absorbed by the solution and remaining gets reflected back. Reflected light is collected by receiving fiber of probe and then converted to electrical signal using phototransistor. The sensor output is calibrated in terms of deficient component values as per the standard color chart. The electrical output of the sensor varies as per the color of the solution. Further the signal conditioning circuit consists of buffers, inverting amplifier with variable gain and a subtractor for zero setting designed with opamp. Comparing current values obtained with the microcontroller data base values of NPK deficient component is predicted. LCD displays the name of the deficient component and the amount required in the soil. Thus user can select the fertilizers accordingly for dispensing in the soil.

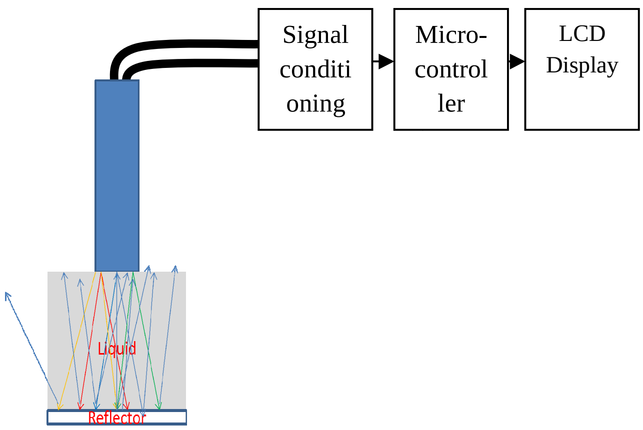

Figure 3 Block diagram of Experimental Setup

4. EXPERIMENTAL PROCEDURE:

Preparation of solutions:

Aqueous solutions of soil samples whose NPK values are known are prepared by adding water to soil and precipitating the soil. The NPK values are varified by using the standard kits available in the market (Greenfield soil tester) along the universal indicator and standard color charts. The aqueous solution remained above the precipitated soil is the solution used for the measurement. The color of the aqueous solutions for three samples shows pink, orange and gray colors indicating deficiency of phosphorous in sample 1, deficiency of potassium in sample 2 and deficiency of nitrogen in sample 3. This color is detected by the system described in previous section.

Measurements:

Initially the distance between the probe and reflector is varied and the output for each distance is noted. The results obtained are as shown in Figure 5. It is observed that at the probe to reflector spacing of about 2mm separation between the curves corresponding to different values of NPK is optimum. It is therefore decided to carry out all further experiments by keeping the separation fixed at 2 mm.

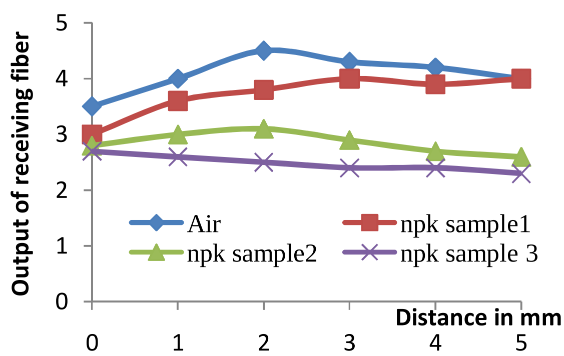

Figure 5 Optimization of distance between the sensor probe and reflector as 2 mm.

The experimentation is then carried out with the other soil samples. The fiber optic NPK probe is dipped into the chemical cell filled with aqueous solutions of different soil samples. Since the color of the solution depends on the NPK values, the final readings are in turn giving information about NPK values.

5. RESULTS AND DISCUSSION:

The response of the sensor is as shown in Figure 6 for different soil samples. It indicates remarkable variation at the output of the sensor. This sensor output shows that as the sample changes output of the sensor changes. The data obtained is then compared with the values stored in the look up table in the microcontroller. In this three threshold levels are set for each component viz. nitrogen, phosphorous and potassium.

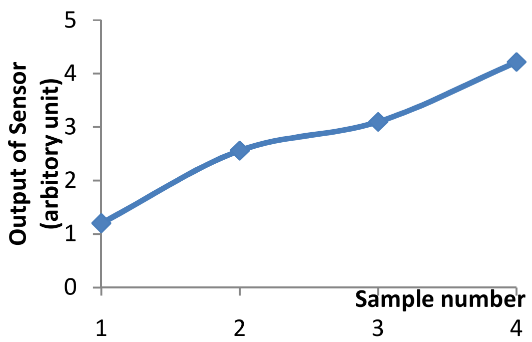

Figure 6 Sensor output as function of sample solution

These threshold values decide the deficiency of the components. Table 1 shows these threshold values for three components. (x is color sensor output)

Component	LOW	MEDIUM	HIGH
Nitrogen	$x \leq 15$	$15 < x \leq 20$	$20 < x \leq 25$
Phosphorous	$16 < x \leq 20$	$20 < x \leq 35$	$35 < x \leq 50$
Potassium	$20 < x \leq 25$	$25 < x \leq 40$	$50 < x \leq 60$

Sample 1 of agricultural land of reference [12] is tested and results are produced here. Following results are obtained for pH of soil = 7 i.e neutral or good soil.

a) For Nitrogen test : x value obtained is 14. Threshold value for LOW Nitrogen in the program is 15. Colour of the comparator matches with the value of 420 kg/hectare which is low medium for this soil sample. This means that there is need of Nitrogen to be dispensed in the field.

b) For Phosphorus test: x value obtained is 33. Threshold value for MEDIUM Phosphorus in the program is 20 to 35. Since $20 < x \leq 35$ enough Phosphorus is in the soil.

c) For Potassium test: x value obtained is 55. Threshold value for HIGH Potassium in the program is 50. Potassium content in soil is very high. It indicates that there is no need to put the potassium fertilizer any more.

6. CONCLUSION:

Fiber optic sensor is thus developed to detect the deficiency of the nutrients N, P or K in the soil. The sensor is fabricated which has concentric arrangement of source and receiving fibers. It is based on the colorimetric principle where absorption of light by a solution results in variation in the output of the sensor. Aqueous solutions of the soil samples are prepared for testing and then calibrated using proper signal conditioning circuit and microcontroller. The system thus designed is advantageous as it reduces the undesired use of fertilizers to be added in the soil. One can properly select the fertilizer quantity to be used for reducing the deficiency in the soil at a particular field. Fiber optic sensors are widely used in various industrial applications as well as in agriculture etc for their inherent advantages such as light weight, immunity to EMI and RFI, economical etc.

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