Automatic Soil Nutrient Detection and Fertilizer Dispensary System

Amrutha A, Lekha R, A Sreedevi
Department of Electrical and Electronics Engineering
R V College of Engineering
Bangalore, India
amruthaananth1994@gmail.com, lekha24r@gmail.com, sreedevia@rvce.edu.in

Abstract— **Soil fertility is an important factor to measure the quality of the soil as it indicates the extent to which it can support plant life. The fertility of soil is measured by the amount of macro and micronutrients, water, pH etc. Soil nutrients are depleted after every harvest and hence must be replenished. To maintain nutrient levels in the soil in case of deficiency, fertilizers are added to soil. Most of the farmers choose to approximate the amount of fertilizers and add them manually. However, addition of fertilizers in right amount is a matter of great importance as excess or insufficient addition can harm the plant life and reduce the yield. Use of modern trends and technology promises to provide a solution to the above problem. Though automated techniques for seeding, weeding, harvesting the crops etc. have been proposed and implemented, none of the techniques target at maintaining soil fertility. The proposed research aims at restoring the levels of Nitrogen, phosphorous, potassium in the soil by the measuring the amount of nutrients present. The presence of nutrients is determined by chemical processes and quantified using sensors. An automated system has been developed for the controlled addition of fertilizers in order to avoid excess/ deficient fertilizers in the soil.**

Keywords— automatic fertilizer dispenser; primary macronutrients; soil fertility; sensor; microcontroller

I. Introduction

Agriculture contributes nearly 18.1% to the Indian annual gross domestic product (GDP). It faces a number of unique social, economic and environmental challenges, including increasing globalization and international competitiveness, climate variability, shortages in labor, urban pressure on farmland. Increasing population requires food production to be increased to meet the demand which requires better cultivation in the form of proper utilization of seeds and fertilizers with minimum labor work [1].

Techniques for automatic seeding, weeding, herbicide spraying, harvesting the crops has been proposed and implemented. Use of advanced techniques like automatic systems for irrigation and modern crop varieties reduced the dependence on manual labor and increased the yield obtained at the same time. Though much advancement in the field of agriculture has reduced the reliability on manual labor, there is a strong need to look into modern methods to maintain soil quality. This is because soil serves as a growth medium for all the crops. Agricultural soil quality is a measure of the ability of the soil to function as a suitable growth medium for plants, by providing required amounts of water and nutrients necessary for plant growth [2]. The process of soil testing that is adopted typically involves chemical tests conducted in laboratories, which takes at least a few days [3]. The farmer estimates the quantity of fertilizers based on the area of field, crop to be grown and amount of nutrients present, which is a cumbersome task [4]. The intelligent control system used in the project addresses the difficulties incurred by farmers by automating the process [5-6]. Hence, provide a solution to the above problems by reducing the labor required [7-8].

Plants extract nutrients that they need for their growth from the soil, which are classified as macronutrients and micronutrients. Macronutrients are those that are needed in large amounts, while those needed in small amounts are called micronutrients. Nitrogen, Potassium and Phosphorous (NPK) are primary macronutrients. Secondary macronutrients include Calcium, Sulphur and Magnesium. The primary goal of soil testing is to ensure efficient and effective management of available fertilizers, and to decide optimum dosage levels necessary to obtain maximum produce, which is achieved by soil testing [7].

Nitrogen is a very important nutrient to ensure proper plant growth. It is present in the soil as either Nitrate ion (NO_3^-) or as Ammonium ion (NH_4^+). Deficiency can result in yellow coloring of the leaves and reduction in the flowering and fruiting. Phosphorous in the soil present as phosphate, provides plants a means of using the energy obtained by process of photosynthesis to carry out activities as a part of its metabolism. Deficiency of this nutrient can lead to impaired vegetative growth, low quality of fruits and seeds, reduced yield of crop and weak roots. However, excess Phosphorous is harmful to the quality of surface water. Potassium is the other macronutrient apart from nitrogen that is absorbed in large quantity by plants and is present as cation K^+. If the amount of Potassium is found to be scarce, then plants are generally incapable of utilizing the available water efficiently and are highly prone to diseases [7-8]. When a nutrient is to be supplied by externally by means, a suitable fertilizer is used.

Fertilizers may be classified as:

1) *Single nutrient fertilizers* – they provide single nutrient to the soil.

2) *Multi nutrient fertilizers*

a) Binary fertilizers – these fertilizers provide two nutrients to the soil.

b) NPK fertilizer – these fertilizers provide all the 3 primary macronutrients (in certain fixed ratio) when added to the soil.

In the proposed system, single nutrient fertilizers namely urea (containing 26% of N), MOP (containing 50% of K); TSP (20% of P) is used [9-11].

II. Design and Development of the System

Block diagram of the proposed system is as shown in Fig. 1.

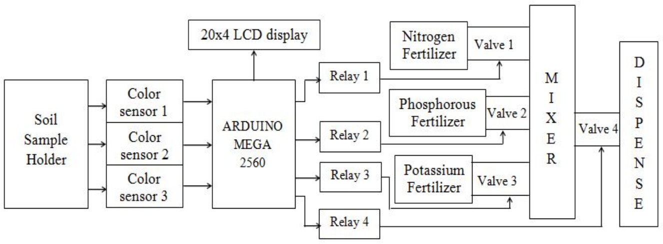


Fig. 1. Block Diagram

It consists of three main parts: sensor system, microcontroller, dispensary system. The designed and developed system is divided into two subsystems: Development of a Sensor system for estimation of nutrients present in the soil and Development of an intelligent system for estimation and control of flow of required amount of fertilizers. The design procedure to realize each of the above steps is discussed below.

A. Development of a Sensor system for estimation of nutrients present in the soil

The principle used for the identification of the NPK nutrients in the soil is 'colorimetry'. By this principle, as the concentration of the element or compound in a solution increases, its color intensity increases linearly. In order to estimate the amount of nutrients present from the colored solution a color sensor is used.

This color sensor is used to identify different colors and its shades. It consists of an LED (emitter), a photodiode (receiver), and microcontroller. The output of the sensor contains red, green and blue values for each color which is used to determine its shade. The sensor was calibrated by testing with results obtained from various soil samples using a microcontroller. The results obtained were verified by interfacing the sensor with the PC and comparing the values.

B. Development of an intelligent system for estimation and control of flow of required amount of fertilizers

The control system estimates the amount of fertilizers to be added based on the results of soil test as illustrated in section 1. The dispensary system controls the flow of fertilizers to the soil as explained in section 2.

1. Estimation of fertilizers to be added

Depending on the amount of nutrient present, the fertilizer is estimated and added accordingly. 'Maintenance dosage' is the quantity of fertilizer that is added as a supplement when the nutrient present is absorbed by the crops during various stages of its growth to maintain balance i.e. when the nutrient levels are within the optimum levels.

The optimum nutrient levels for primary macronutrients for Indian soil are shown in Table I.

TABLE I. Optimum nutrient levels for Indian soil

Soil nutrients	Soil fertility rating in kg/acre		
	Low	Medium	High
Nitrogen	<280	280-570	>570
Phosphorous	<10	10-25	>25
Potassium	<108	108-280	>280

The flowchart shown in Fig. 2 describes the algorithm implemented for estimation of nitrogen, and subsequent addition of urea by controlling the turn ON time of the valve, where 't_0'is the valve opening time in seconds to add maintenance dosage of urea i.e. when the nutrient levels are within the limits; 't_0-t_1' is the reduced valve opening time in seconds corresponding to high Nitrogen levels, 't_0+t_2' is the increased valve opening time in seconds corresponding to very low Nitrogen levels.

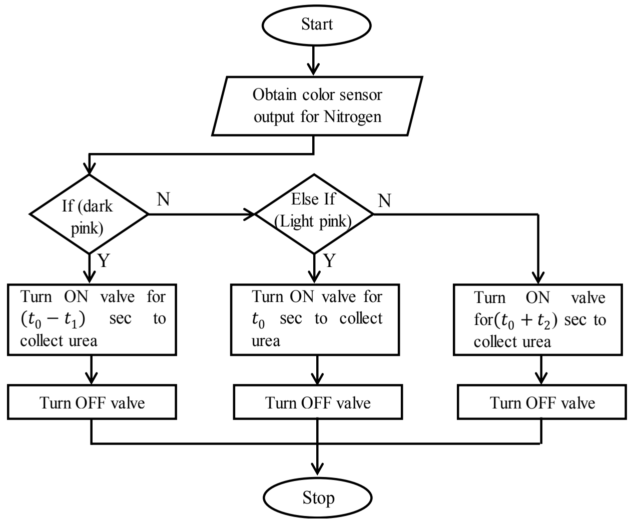


Fig. 2. Control algorithm for estimation of nitrogen and addition of urea

Similar control algorithm is implemented for estimation and addition of MOP and TSP fertilizers.

The dosage levels of nitrogen, potassium, phosphorous for rice, wheat and maize are as shown below in Table II.

TABLE II. MAINTENANCE DOSAGE FOR VARIOUS CROPS

CROP	Optimum nitrogen (kg/ha)	Optimum phosphorous (kg/ha)	Optimum potassium (kg/ha)
Rice	100	50	50
Maize	150	75	40
Wheat	100	40	40

The following sample calculations indicate the estimation of the fertilizers to be added after determining the nutrient levels by soil test. Consider that the crop to be grown is rice and fertilizer solutions prepared with fixed concentration, typical calculations for addition of urea and TSP fertilizer to restore the level of nitrogen and phosphorous respectively are discussed below.

a) Addition of urea (to supplement Nitrogen)

Allowing for the amount of Nitrogen indicated by the soil test as 40 kg/acre, the determination of the amount of fertilizer to be added is as shown:

The Nitrogen present in one hectare is 40kg/acre ≡ 98.84 kg/ha. For a field of area 1ha, the lower threshold level for N = 280 kg (from Table I). Hence, it can be said that Nitrogen is deficient. The equation to estimate Nitrogen to be added is described by (1).

$$\begin{matrix}\text{amount of nitrogen}\\ \text{to be added}\end{matrix} = \begin{matrix}\text{maintenance}\\ \text{dosage}\end{matrix} + \begin{matrix}\text{25\% (to compensate}\\ \text{for deficiency)}\end{matrix} \quad (1)$$

In the above scenario, it can be estimated to be 100 + 0.25×100 = 125 kg of nitrogen. Urea contains 46% N, hence weight of urea to be added to avail 125kg of available nitrogen is found to be 271.74kg

b) Addition of TSP (to supplement phosphorous)

Allowing the amount of phosphorus indicated by the soil test as 20 kg/acre, the determination of the amount of fertilizer to be added is as follows:

For the field of area 1ha, the amount of phosphorous present is 49.42 kg. For a field of area 1ha, the upper threshold level for P = 25 kg (from Table I). Hence, it can be seen that phosphorous is higher than the threshold value. Equation (2) describes estimation of the amount of phosphorous required.

$$\begin{matrix}\text{amount of phosphorous}\\ \text{to be added}\end{matrix} = \begin{matrix}\text{maintenance}\\ \text{dosage}\end{matrix} - \begin{matrix}\text{25\% (to compensate}\\ \text{for excess present)}\end{matrix} \quad (2)$$

In the above scenario, it can be estimated to be 50 – 0.25×50 = 37.5 kg of phosphorous. TSP contains 20% of phosphorous. Therefore, 187.5 kg of TSP is necessary for obtaining 37.5kg of available phosphorous.

2) Dispensary System

The dispensary system consists of containers to store fertilizers, a mixer compartment to collect them, valves and relays. Urea, MOP and TSP fertilizers are stored separately. Flow of fertilizers from storage compartment to the mixer, and then from mixer to the soil are controlled using solenoid valves, which are operated using relays.

Fig. 3 and Fig. 4 show the different views of the robot with the various components including microcontroller, relays, solenoid valves, LCD display, motor drivers etc.

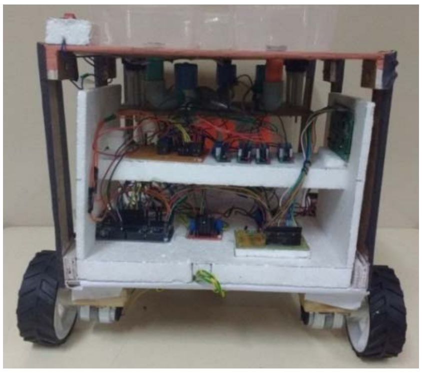


Fig. 3. Arrangement of circuit components in the rear end of the robot

Fig. 4. Side view of the robot

The fertilizers are stored in liquid form in three separate containers at the top section. The middle section houses the solenoid valves that control the flow of the fertilizers. The bottom section contains the sensor setup, mixer compartment and other electronic control equipment like relays, motor driver etc. The system is an all-wheel drive, driven by high torque motors placed at all the wheels.

III. WORKING OF THE SYSTEM

The working of the system comprises of three steps: Preparation of soil sample, Estimation of results from soil sample and dispensing estimated amount of fertilizers to soil.

A. Preparation of soil sample

Soil sample of the field whose nutrients need to be determined is prepared manually. Representative samples are collected from different areas of the field and mixed together to obtain a homogenous mixture. The resultant soil sample is used for testing. For the purpose of testing, a soil solution is first prepared by dissolving known quantity of soil in distilled water. Subsequent addition of reagents to the soil solution

978-1-5090-3342-3/16/$31.00 ©2016 IEEE

results in a color change, corresponding to the amount of nutrient present [12].

Estimation of nitrogen is based on the Griess Ilosvay reaction, in which Nitrate present in the soil is first reduced to Nitrite, using a suitable reducing agent such as zinc dust. It then reacts with Sulphanilic acid and α-Naphthylamine to form a colored azo dye [13]. Nitrites already present in the soil are removed using Sulphamic acid. Estimation of Phosphorous is based on the fact that the Phosphates present in the soil react with Ammonium Molybdate to form Ammonium Phosphomolybdate, which is then reduced with a suitable reducing agent [14]. Estimation of Potassium is by the reaction of K^+ with Tetrapheylborate to form a complex [15].

B. Estimation of results from soil sample

For each nutrient (NPK) a colored soil solution is obtained from the above mentioned manual process. These solutions are placed in respective soil sample holders. Color sensor detects the intensity of color present in the soil solution and gives three readings simultaneously corresponding to red, green and blue. This reading is read by the microcontroller, analyzed and then displayed on LCD as low/medium/high as an indication of the nutrients present in the soil.

C. Dispensing estimated amount of fertilizers to soil

An algorithm is developed to estimate and operate the valve based on the calculation performed as mentioned in section II.B. Readings from all three color sensor are sent to microcontroller. Then, valves for each compartment are operated individually for a predetermined amount of time so as to collect the fertilizers in the mixer compartment which is subsequently dispensed to the soil by operating the mixer valve.

IV. Results and Discussions

The solenoid valve, color sensor, relay and motor were tested individually for their functionality and then integrated in the system.

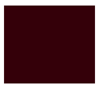
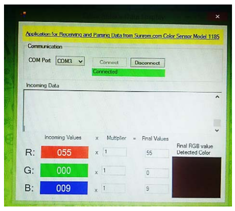
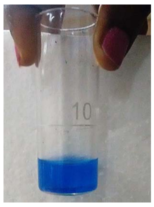
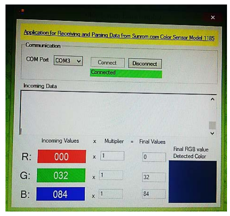
Addition of reagents to the soil solution results in a colored complex which is quantitatively estimated using sensors. Estimation of Nitrogen is based on the estimation of the intensity of the azo complex formed at the end of diazotization reaction. Phosphates are estimated by determining the intensity of blue colored Molybdenum Oxide. Potassium is estimated by measuring the intensity of Potassium Tetraphenylborate complex.

The following points were considered while calibrating color sensor with various solutions obtained after chemical reactions:

- The proximity of the test tube with the sensor decides the quality and reliability of the output.
- It has also been observed that when left unenclosed, the presence of external light sources affects the reading.
- The size of the test tube which contains the solution under test is crucial to obtain accurate output, because the light emitted by the sensor needs to be completely detected by the receiver after striking the surface of the test tube.

The results obtained from color sensor are as shown in Table III.

TABLE III. RESULTS FROM COLOR SENSOR

Sl. No	Object	RGB output displayed on LCD	RGB output displayed on PC
N test		 Corresponding colour: 	
P test		 Corresponding colour: 	

The pink complex obtained during testing of nitrogen was tested by integrating the sensor to controller and comparing the value to that obtained by integrating with PC directly. Similar procedure was adopted for phosphorous and potassium results as well. This procedure was carried out multiple times using many test results, to ensure the exact calibration of the sensor and to check consistency in the output obtained. It has been observed that the results obtained by both methods are consistent as illustrated in Table III. The distinction between various shades of the same color is a very crucial step in the project, as it decides if the nutrient present in the soil can be categorized as High/Medium/Low.

The soil test results obtained were compared with those by chemical analysis provided by Gandhi Krishi Vignana Kendra, Bangalore. It was found to be within permissible limits.

Furthermore, the valves and relays were tested for their functionality when integrated with the entire system. The control system was programmed such that the timing for valve opening is proportional to the amount of fertilizer required by the soil.

V. CONCLUSION

While the time taken for soil testing by chemical methods in a laboratory takes a few days, in the proposed system the results are obtained within 30 minutes. The results obtained from the soil test are fed to sensors and the results are analyzed using a microcontroller which in turn needs a few seconds. Hence, whole process of soil testing for all the measurement of the macronutrients requires a maximum 30-40 minutes after which the field can be fertilized.

From the above results, it can be seen that the proposed system addresses the issues faced by farmers. The system determines the available NPK nutrients in the soil, estimates the fertilizers to be added. In addition, it automates the process of addition of fertilizers thereby reducing the time and manual labor required.

The complete algorithm for the estimation of nutrients in the soil and control of fertilizer addition to the soil has been designed and implemented. However, the system is a prototype as the containers to hold the fertilizers are small. If the system is to be scaled for use in larger farms, containers of appropriate size are to be designed with a capacity of a few quintals.

Acknowledgment

We would like to thank M.N. Thimmegowda (Gandhi Krishi Vignana Kendra, Bangalore) for providing us soil samples and analyzing our results.

References

[1] B.S. Shivaprasad, M.N. Ravishankara, and B.N. Shoba, "Design and Implementation of seeding and fertilizing agriculture robot", Int. J. Application or Innovation in Engg & Mgmt, vol. 3, no. 6, pp. 5073-5081, June 2014.

[2] J. Spargo, T. Allen, and S.Kariuki, "Interpreting Your Soil Test Results" UMass Soil and Plant Tissue Testing Laboratory, revised July 2013.

[3] Methods Manual – "Soil Testing in India", Dept. of Agriculture & Co-op, Ministry of Agriculture, Govt of India, New Delhi, Jan. 2011.

[4] V.A. Kulkarni, A.G. Deshmukh, "Advanced Agriculture Robotic Weed Control System", Int. J. Adv. Research in Electrical, Electronics and Instrumentation Engg, vol. 2, no. 10, pp 5073-5081, Oct. 2013.

[5] A. Singh, A. Gupta, A. Bhosale, and S. Poddar, "Agribot: An Agriculture Robot", Int. J. Adv. Research in Comp. Comm. Engg, vol. 4, no. 1, pp. 317-319, Jan. 2015.

[6] G. Bhanumathi, B. Subhaker, "Smart Herbicide Sprayer Robot for agriculture fields", Int. J. Comp. Sci. and Mobile Computing, vol.4, no. 7, pp. 571-574, July 2015.

[7] M.H. Ko, K.C. Kim, B.S. Ryuh, A. Suprem, and N.P. Mahalik, "Development of Autonomous Traveling for Agricultural Robot Drive Platform by Using a Single Camera", Proc. World Congress on Engg. and Comp. Sci., San Francisco, USA, 23-25 Oct. 2013, vol. I

[8] A. Gollakota, M.B. Srinivas, "Agribot — A multipurpose agricultural robot", Annual IEEE Ind. Conf., Hyderabad, Dec. 2011, pp 1-4.

[9] https://www.ipni.net/publication/nss.nsf/0/5FE74632D6D80872852579AF00706626/$FILE/NSS-01%20Urea.pdf

[10] https://www.ipni.net/publication/nss.nsf/0/8FBD66599EAB433F852579AF00741710/$FILE/NSS-03%20PotassiumChloride.pdf

[11] https://www.ipni.net/publication/nss.nsf/0/35039C5F78D8740C852579AF0076567A/$FILE/NSS-14%20Triple%20Superphosphate.pdf

[12] G. Svehla, Vogel's textbook of macro and semimicroqualitative analysis, Longman Inc., 5th edition, 1979

[13] G.H. Jerffery, J. Bassett, J. Mendham, R.C. Denney, Vogel's Textbook of Quantitative Chemical Analysis, 5th Edition. Longman. p. 702.

[14] Mahadevaiah, M.S. Yogendrakumar, M.S. Abdul Galil, M.S. Suresha, M.A. Sathish, and G. Nagendrappa, "A simple spectrophotometric determination of phosphate in sugarcane juices, water and detergent samples", E-journal of chem., vol. 4, no. 4, pp. 467-473, Oct 2007

[15] Engelbrecht, R. M, McCoy F. A, "Determination of Potassium by Tetraphenylborate Method", Anal. Chem, 1956