Effective Implementation of Automated Fertilization Unit using Analog pH Sensor and Arduino

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***Abstract*—Unplanned use of fertilizers leads to inferior quality of crops. Excess of one nutrient can make it difficult for the plant to absorb the other nutrients. To deal with this problem, the quality of soil is tested using a pH sensor that indicates the percentage of macronutrients present in the soil. Conventional methods used to test soil quality, involve the use of Ion Selective Field Effect Transistors (ISFET), Ion Selective Electrode (ISE) and Optical Sensors as the sensing units which were found to be very expensive. The prototype design will allow sprinkling of fertilizers to take place in zones which are deficient in these macronutrients (Nitrogen, Phosphorous and Potassium), proving it to be a cost efficient and farmer-friendly automated fertilization unit. Cost of the proposed unit is found to be one-seventh of that of the present methods, making it affordable for farmers and also saves the manual labor. Initial analysis and intensive case studies conducted in farmland situated near Ambedkar Nagar, Sarjapur also revealed the use of above mechanism to be more prominent and verified through practical implementation and experimentation as it takes lesser time to analyze the nutrient content than the other methods which require soil testing. Sprinklers cover discrete zones in the field that automate fertilization and reduce the effort of farmers in the rural areas. This novel technique also has a fast response time as it enables real time, in-situ soil nutrient analysis, thereby maintaining proper soil pH level required for a particular crop, reducing potentially negative environmental impacts.**

***Keywords*—pH sensor, in-situ, macronutrients, over-fertilization, automated, soil testing, NPK, soil**

I. INTRODUCTION

Over-fertilization is a serious issue faced by farmers globally. Unplanned use of fertilizers leads to inferior quality of crops, various environmental problems like leaching, water pollution, soil contamination, soil salinity, bio magnification resulting in contamination of ground water and poor food quality. Also, the present day soil analysis techniques are time consuming and expensive since they are ex-situ techniques and are carried out in laboratories. Having known the fact that India's major economy is from Agriculture, it is important to consider the needs for smarter ways of farming by getting rid of ex-situ techniques that increase the production cost. Paper [1] makes use of a wireless network of sensors to determine the crop yield. It makes use of real time field data like temperature, moisture content, rain fall etc. to determine the changing soil characteristics and hence can be implemented with this project to give a real time analysis of the amount of nutrients present in the soil and the amount of fertilizer needed to be sprinkled.

Similarly, another project [2] makes use of Raspberry Pi and few other sensors to detect pH, Humidity, Electrical Conductivity and Temperature to analyze the nutrient content of the soil and save the data on a local server. These methods are sure to give good results but the cost factor has not been dealt with carefully. Also, the data is being stored in the database and not being used to perform an action. This data could instead be used to make the system automated and more convenient for the farmer.

The present day soil analysis techniques include ISE, ISFET and Fiber Optic Sensors. Fiber optic sensor technology is the most widely used soil analysis technique. ISE and ISFET makes use of the ion-selective microelectrode technology, where an ion-selective membrane responds selectively to one analyte in the presence of other ions in a solution[3]. Even though the ISE and ISFET exhibited fast response time, the ion selective membranes in ISE and ISFET showed interference with foreign ions which lead to the lack of accuracy[4]. Hence it is suggested to use a method that has a fast response time and a technique which enables real time, on-site soil nutrient analysis. The use of pH sensor for the analysis of nutrient content of soil has been recommended, since the pH of the soil depends on the macronutrient content in the soil[5].

Recent field experiments in Philippines[6] implemented the use of color sensors that converts light to digital data with MCU to determine the NPK content of soil. Color detection is possible but involves detailed study of the soil and the color is detected for a threshold value, which is achieved by vermicast fertilizer after various trials for Nitrogen and Phosphorous detection. Uneven farm terrain is difficult to be covered by a rover[7] to distribute the fertilizers depending on the area suffering from deficiency of nutrients. Keeping these points into consideration, the Automated Fertilization Unit is designed in a way to keep the farmer at ease by performing precision agriculture at an affordable price.

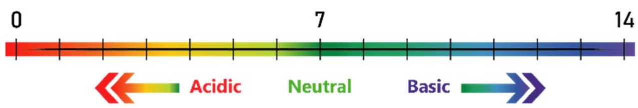

Fig. 1. pH scale (pH 0-14)

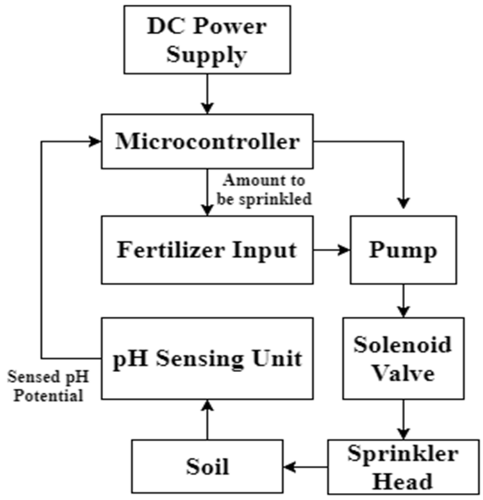

Fig. 2. Proposed Automated Fertilization Unit

It has been proven that, use of this novel, in-situ (on-site) method is cost effective and robust. Further, it gives farmers an essential weapon to tackle the unfavorable conditions and better the yield for the future. pH stands for power of Hydrogen ion in the solution. *Fig. 1* depicts the pH scale that varies from being alkaline to acidic for different values of pH. As the concentration of Hydrogen ion (H+) increases, the pH decreases, leading to less availability of much required macronutrients (NPK concentration reduces)[8]. The farm near Sarjapur, Bengaluru that was visited for the soil analysis, had access to various off-site soil-testing measures, but there are other farmlands that are often located in remote villages without any access to lab equipment. Devices like ISFET and ISE demand frequent maintenance and Optical Sensors provide only field specific data. The use of Analog pH Sensor will not only allow for in-situ soil testing but will also prove to be cost effective, more accurate and have a fast response time.

II. METHODOLOGICAL OVERVIEW

The work that was carried out has been classified into different sections. Section II.**a.** Hardware Implementation, which will briefly explain the topographical block diagram of the Automated Fertilization Unit, and II.**b.** Analytical Modelling, which will deal with the mathematical calculations involve and II.**c.** Software Implementation which will discuss the software aspect of the model through an algorithmic flow chart of the basic programs the system operated on.

A. Hardware Implementation

Arduino and pH sensor serve as the vital part of this proposed automated fertilization technique and pH monitoring system along with solenoid valve for flow control. A pH meter is a voltmeter, that quantifies the electric potential in the solution whose acidity is to be found, then analogizes with a known potential, and uses the difference between them to deduce the difference in pH [9].

System Block Diagram in *Fig. 2* illustrates the application of Analog pH Sensor to attain the pH value from the soil and also determines how the setup will run for a particular pH found from the present soil content. Power is supplied to the microcontroller that receives a pH value from the pH Sensing Unit. The pH value of the soil indicates the percentage of macronutrient present in the soil as shown in Table II. It is periodically interrogated and the pH of the soil is obtained based on the relationship between the voltage and the pH of the soil. A threshold value of pH is stored in the database of the microcontroller. Table II suggests a pH value of '7' for a perfect NPK content of soil and hence, threshold value of '7' is set for comparison. The obtained pH is then compared with threshold pH and a difference value is found. If the tested pH value is greater than the threshold, the program directs the fertilizer to be sprinkled on to the fields. If not, the steps are repeated so that there is a continuous vigil. The relationship between the pH value and the macronutrient content in the soil, serves as the guideline by which we find the difference between the ideal pH and tested pH value and an equivalent deficient amount of fertilizer is provided to the soil. Now, if the ideal threshold pH value stored, is greater than the tested pH value, the exact value of fertilizer requirement is calculated by the controller and the simultaneous opening and closing of the solenoid valve is done by the controller to control the flow of the fertilizer. When the Arduino detects a pH change, it triggers the solenoid valve. The solenoid valve controls the amount of the fertilizer solution that is to be pumped and sprinkled. Arduino monitors the switching operation of the solenoid valve with respect to time at regular intervals in order to control the amount of fertilizer solution to be sprinkled with respect to the change in pH. A switching circuitry is also installed for the smooth functioning of the same.

The motor pump, driven by the Arduino, pumps the fertilizer solution to the sprinkler head at a high pressure,which is then sprinkled at a radius. *Fig. 3* demonstrates the on-field setup of the system for the reader's understanding. The pH sensing Unit is installed in the ground to measure the NPK nutrient content of the soil. This data is sent to the Controller for further computation that will determine the amount of fertilizer that should be provided to restore the necessary NPK content of the soil.

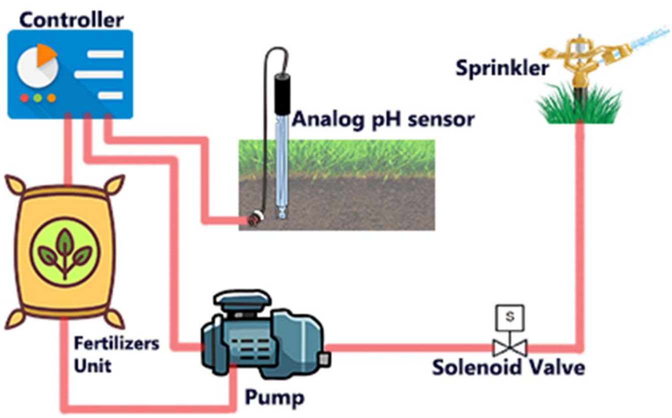

Fig. 3. Proposed model of Irrigation Layout

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The pump is installed between the fertilizer unit and the solenoid valve. The required amount of fertilizer will be pumped out of the unit and will be given to the valve so as to be sprinkled on to the fields. Fertilizers used in the unit are some commonly used fertilizers like Urea, Di-ammonium Phosphate (DAP) and Muriate of Potash (MOP). These fertilizers help the crop meet the precise NPK requirements and therefore help in better nutrient content of the yield and longer shelf life of the crop. With every minute change in the concentration of the macronutrients determined from the change in pH value, the installed circuitry will act upon the solenoid valve to open and close, thus, letting the sprinkler determine whether the crops need to be sprinkled with fertilizers.

The working of a pH sensor is closely identical to that of a battery[10]. The positive terminal is the measuring electrode, which develops a potential directly related to the hydrogen ion concentration, while the negative terminal is the reference electrode, which provides a stable potential against which the measuring electrode potential can be compared. With an accuracy of about 0.02 pH, the unit is able to determine slight changes in macronutrient concentration in a lesser time. Refer to Table I for more details of the pH sensor used in the system. The pH value changes with temperature and hence there is a temperature sensor used in the pH measurement loop to correct the change in values.

TABLE I. Technical Specifications of pH Sensor

Characteristics	Value
pH Range	0 to 14 pH
pH Resolution	0.01 pH
pH Accuracy	0.02 pH
Temperature Range	-5.0 to 60.0 deg. Celsius
Response Time	<=1 minute

Table II denotes the relation between the pH and the macronutrient content of the soil. Over-fertilization causes an imbalance in the macronutrient content of the soil. Presence of acidic media can severely affect the plant growth, as the condition affects the microorganisms that form symbiotic relationships with plants [11]. The system also comprises of a Driving Circuit and a Switching Circuit. The pH sensor generates a voltage due to ionic reactions in millivolts, which is not significant enough to be read by Arduino. Hence, a driver circuit with an instrumentation amplifier is used to amplify the voltage so that the controller can read it.

B. Analytical Modelling:

The measure of hydrogen ion concentration in a given solution is defined as the pH of that solution.

$$pH = -\log([H+]) \quad (1)$$

Equation (1) implies that for each unit decrease in pH, there is ten times increase in acidity.

From Fig. 5, we infer that the pH and voltage relationship is linear. Hence, we use the equation of line to calculate pH value from the analog voltage value as shown in (2),

$$y = mx+c \quad (2)$$

Where m is the slope of the line, c is the intercept that is considered as the offset pH in the calculations. Equation (3) gives the slope of the line.

$$m = \frac{y_2 - y_1}{x_2 - x_1} \quad (3)$$

Where (x_1, y_1) and (x_2, y_2) are coordinates in the pH-voltage graph. Fig. 5 exhibits the characteristic dependence of the voltage on pH value and its direct proportionality signifies how the voltage detected by the pH sensor helps to realize the pH value of the soil.

TABLE II. pH Relationship With Macronutrients

pH value	*Nitrogen content*	*Phosphorus content*	*Potassium content*
4.5 (extremely acidic)	30%	23%	33%
5 (very strong acid)	53%	34%	52%
5.5 (strong acid)	77%	48%	77%
6 (medium acid)	89%	52%	100%
7 (neutral)	100%	100%	100%

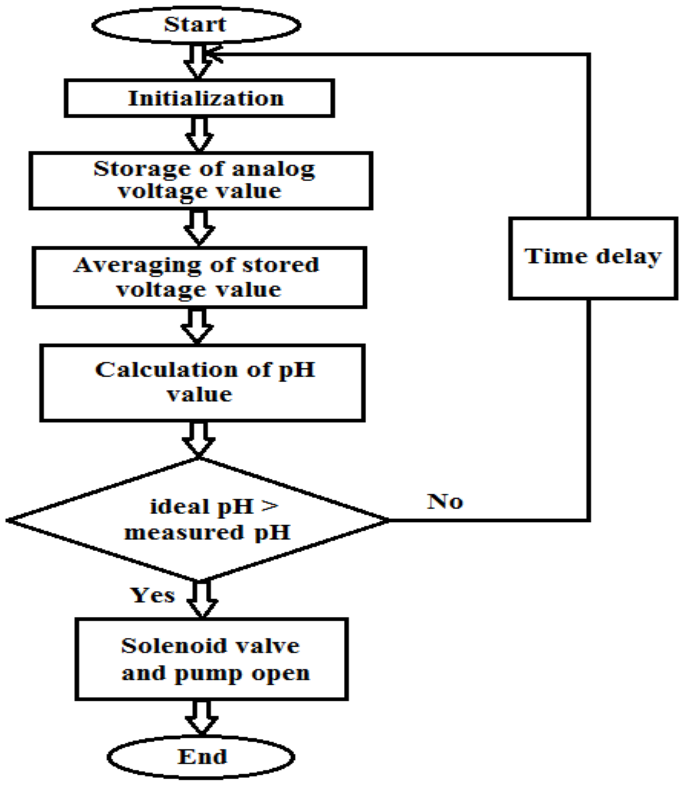

Fig. 4. Flowchart of Main Program

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C. Software Implementation:

The pins of the Arduino Uno are initially defined in the algorithm. As shown in *Fig. 4*, the algorithm begins with the initialization of the sampling rates and calculation of intervals. It also assigns specific locations for storage of the sampled values, i.e. in arrays, and also assigns a definite length of storage. The next step involves the sampling of analog input from the analog pH sensor whose running average is taken for better accuracy.

III. DISCUSSIONS AND RESULTS

The pH of the soil is obtained based on the relationship between the voltage and the pH of soil. Now, if the ideal pH value stored is greater than the tested pH value, the program directs the fertilizer to be sprinkled on to the fields which is time regulated. If not, the steps are repeated so that there is a continuous vigil. There is a relationship between the pH value and the macronutrient content in the soil, based on which we find the difference between the ideal pH and tested pH value and an equivalent deficient amount of fertilizer is provided to the soil. Equations (2) and (3) prove that the pH is linearly related to voltage from which the corresponding pH value can be obtained. From the graph shown in *Fig. 5*, at a temperature of 303K, the pH-Voltage graph is linear with a slope(m) of -2.1 and intercept (c) is found to be 8.3. Hence a pH equation is deduced by substituting the values in (2) where 'y' is the pH value of the soil and 'x' is the voltage found by the analog pH sensor in mV. After detailed study, it is evident that most crops grown in Ambedkar Nagar, Sarjapur like Ragi, Potato and Rice require neutral soil i.e. pH value almost equal to 7. The proposed unit can measure a pH range from -4 mV (for Alkaline soil) to +4 mV (for Acidic soil). It is also noted that the moisture content is adequate but after fertilizers are sprayed manually, an additional amount of water needs to be added so that fertilizers can easily seep into the soil. An accurate nutrient and water content is hence required for better crop growth, which can easily be achieved by the implementation of an analog pH sensor unit along with other components while making the whole process automated.

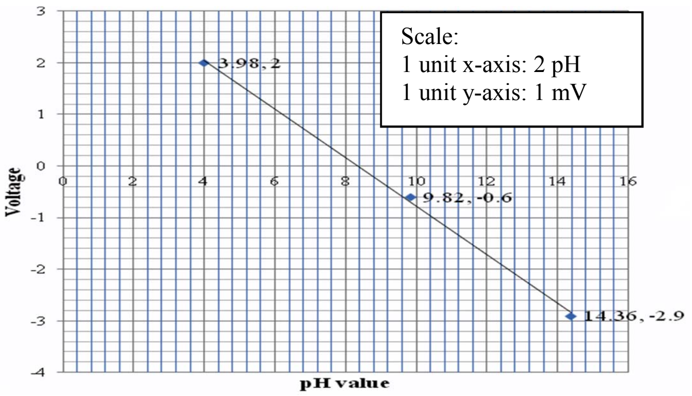

Fig. 5. pH-Voltage relationship

Considering other applications to find the NPK concentration of the soil, *Fig. 6* determines the cost effectiveness of the proposed idea using the Analog pH sensor by plotting the Price (INR) of the setup against the Hardware Unit used. Unit 1 makes use of three different Ion selective Glass Electrodes for NPK measurement[12]. Unit 2 makes use of an even compact ISE that determines the NPK values. Unit 3 makes use of an ISFET. Unit 4 comprises of the pH Measurement Kit (inclusive of reference electrode, Analog front-end, AD Convertor and USB Interface) using another ISFET . Optical sensors are another means of detecting the NPK composition in the soil, but due to complexity, time-consumption and high cost per test, it is difficult to implement the same[13]. The automated fertilization unit costs an estimated amount of 6903 (INR) and is an easy replacement to any pre existing techniques in the field of precision agriculture. The same unit can be implemented for different kinds of soils and for the cultivation of different crops by just varying the variables that are stored in the controller. A larger area can be covered within less time by using a higher power rated motor where the force of fertilizers to be sprayed will be more.

More development can be achieved in the field of precision agriculture by incorporating the climatic factors of temperature variation and moisture content within the system to analyze macronutrient content of the soil and its dependance on the variation factors. Hence, the proposed unit, that comprises of an analog pH sensor driven by an Arduino is proven to be cost-effective, reliable and farmer friendly. This uplifts the concept of precision farming and hence helps in keeping a check on excessive fertilizer usage.

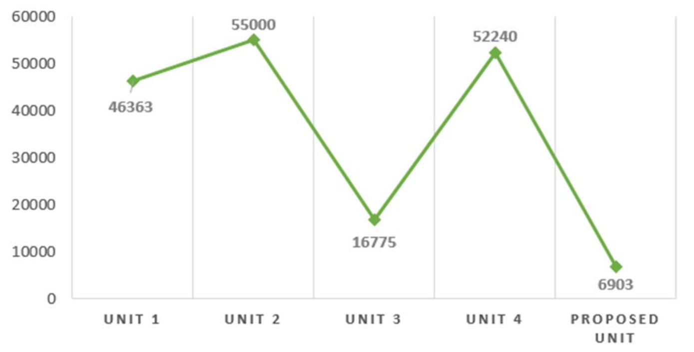

Fig. 6. Price Comparison with other Hardware Units

IV. CONCLUSION

On detailed investigation of the proposed method, it has been found that, the soil pH could be monitored and with the aid of the pH-macronutrient relationship, the deficient amount of the macronutrient can be provided to the soil effectively. On study and successful implementation in the farms spread across 3 acres in Sarjapur, Bengaluru, the soil quality and durability of the crops is uplifted and hence, several environmental issues are curbed due to the idealization of the pH values of the soil samples. There is a check on consumption of chemical fertilizers that are to be used and hence over-fertilization is reduced, which leads to precision agriculture. In addition to this, the time for analysis is minimized by the implementation of in-situ soil testing methods. Hence, the project proves to be beneficial to the farmers as it is cost-effective, reliable,

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automated and farmer-friendly that leads to a better yield of crops with better nutritious content.

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