SoilMac.pH: Arduino-Based Automated Soil Macronutrients and pH Level Analyzer Using Visible-Near Infrared Spectrometer

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SoilMac.pH: Arduino-Based Automated Soil Macronutrients and pH Level Analyzer Using Visible-Near Infrared Spectrometer

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***Abstract*— This study aimed to improve efficiency and reduce costs associated with soil nutrient analysis for farmers. A device called SoilMac.pH, utilizing an Arduino Mega 2560 microcontroller and TOSHIBA TCD1304AP CCD Linear Sensor, was developed to measure soil macronutrients (Nitrogen, Phosphorus, and Potassium) and pH levels. Spectroscopy and the Beer-Lambert law were employed to classify these parameters accurately in Philippine farmlands. The results were presented in a printed form, including nutrient and pH level calculations, along with fertilizer recommendations. This project particularly benefits farmers in remote areas, providing rapid results within one to two hours, eliminating the need to visit regional soil test centers and endure lengthy waiting periods. The study focused on identifying soil macronutrients and pH levels for rice crops, achieving a 95% accuracy rate.**

Keywords*— *Soil, Arduino, Spectrometer, Absorbance, Transmittance, Macronutrients, pH Level

I. Introduction

One of the fundamental functions of soil is stowing and providing minerals and nutrients that are essential for plants. It gives the plants protection against extreme temperatures and protects the roots from direct sunlight. Soil quality is significant for plants health and the humans and animals that eat the plants. Nitrogen, phosphorus and potassium, known as the plant's macronutrients, are very important for plant's normal growth and increasing yields. The application of N, P and K fertilizers provide great increase in the number of agricultural crops that provide the needs of the world's population. Nevertheless, too much use of these fertilizers can cause infection of the surface and ground water. Preferably, application rates should be modified based on the requirements for the best production at each location. Nitrogen is vital because it is a main component of amino acids, which is known as the building blocks of protein. It is also composed of chlorophyll, the element that converts the energy from the sunlight to produce sugar. Phosphorus plays the role in capturing and converting the sun's energy into useful plant compounds. Phosphorus also helps the root growth. Potassium affects the physical quality of the plants such as its shape, size, color, and taste. Lack of potassium can cause defects in plants.

This study aims to develop an Arduino-based soil macronutrients and pH level analyzer using Visible-Near Infrared (Vis-NIR) spectrometer and MATLAB Simulink. It aims to meet the following objectives needed for the development of a soil macronutrients and pH level assessment for inbred rice plant: (1) to design a visible – near infrared spectrometer that can analyze soil macronutrients and pH level, (2) to develop an Arduino program that can analyze the soil's macronutrients and pH level, (3) to develop a program that can show the spectral waveform of the soil macronutrients and pH level using MATLAB Simulink, (4) to display and print the qualitative data of the soil macronutrients and pH level and fertilizer recommendation thru the TFT LCD and portable printer, and (5) test and validate the device for accuracy and ease of use by comparing with soil test kits and laboratory testing.

II. Related Works

Using color processing, a soil-testing device was constructed [1]. Their system includes a microprocessor, color sensors, and data storage. By indicating pH and nutrient content, they recommended plants for every soil test kit. They employed a set distance from a given origin to eliminate lighting and distance effects. Eliminating color comparison and plant advice sped up soil sample analysis.

Fiber optics was used for detection of NPK nutrients of the soil in this study [2]. The device detected the actual values of NPK of the soil using multimode plastic fiber optic sensor. Different light colors illuminated aqueous solution of soil under test. Light got reflected from solution depending upon the absorbent coefficient of soil. A fiber optic-based color sensor receives the reflected light then converted into electrical signal. One can determine NPK levels using the threshold values stored in database of microcontroller. This helps in the detection of the deficient soil component. Thus, undesired dispensing of the fertilizers can be controlled which reduces the deterioration of soil.

This research [3] uses near infrared spectroscopy to identify soil nutrients, especially organic matter and accessible N, P, K, for precision fertilization. FieldSpec3 spectrometer measured soil organic matter, available nitrogen (N), available phosphorus (P), and available potassium (K). Randomly partition 54 samples into 40 prediction and 14 validation sets. Main component analysis retrieved the eight principal components of smoothed spectra (PCA). Prediction models of soil organic matter, available nitrogen (N), available phosphorus (P), and potassium (K) were created using the eight primary components as input and soil nutrients as output. The 14 validation samples were predicted.

Analyzing soil parameters helped map basic nutrients [4]. They sampled soil at Pune's Agriculture College. Using UV Spectroscopy, they built a multi-parametric analytical device to detect soil nutrients on-field. They reviewed sensor technologies for detecting basic nutrients in soil and showed UV Spectroscopy approach for on-the-go soil sensor.

SoilMATTic was designed for quicker and more accurate soil analysis than current methods to help farmers determine crop compatibility and boost farm productivity and crop production [5]. Arduino-based prototype automates macronutrient and pH soil analysis from testing to fertilizer suggestion. Stepper motors and pumps automate the chemical interaction of soil with chemical reagent during testing, and an on-board printer prints fertilizer recommendation. It employs digital image processing to determine Philippine agriculture nitrogen, phosphorus, potassium, and pH. The system includes automated soil testing, picture capture, image processing, training, and recommendation. AI image processing was rapid and accurate. 70% of the 356 collected photos are for training, 15% for testing, and 15% for validation. This research exhibited 96.67 accuracy in recognizing soil macronutrient and pH level and delivers fertilizer recommendations.

In this work [6], digital image processing was utilized to determine the macronutrients and pH level of Philippine agriculture soil: Nitrogen, Phosphorus, Potassium, and pH.

Image capture, image processing, training system, and outcome make up the system. This research used an artificial neural network for its rapid and precise image processing capabilities. The system will use 448 images for training, testing, and validation. The application prints a report based on the outcome. This research determines soil macronutrients, pH, and fertilizer recommendations for inbred rice plants. It was 98.33% accurate.

III. System Architecture

The composition of the system is composed of four sections: (1) Color Acquisition (2) Training System, (3) Application of the Beer's Law and (4) Recommendation as shown in Fig. 1.

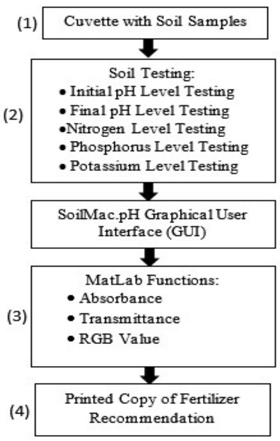

Fig. 1. Block Diagram

A. Color Acquisition

The color acquisition is responsible for obtaining color coming from the light that passed through the soil sample then was bend by the mirror that enters the linear CCD sensor.

B. Training System

For the training system section, based on the principle of spectrometry the absorb light by measuring the intensity of light that passes sample cell that will be converted to its RGB equivalent will serve as the input. The soil's macronutrients and pH level will be derived based from the color standards given by the authorized laboratory institution. Fig. 2 shows the spectrum scale, the transmittance vs. wavelength graph and absorbance graph of the acquired pH level result from the sample. It also shows the RGB equivalent together with its approximate color, which is 255 for red, 71 for green and 11 for blue in this soil sample. In the right part of the figure shows the breakdown of the results. Fig. 3 shows the spectrum scale, the transmittance vs. wavelength graph and absorbance graph of the acquired nitrogen result from the sample. It also shows the RGB equivalent together with its approximate color, which is 75 for red, 0 for green and 0 for blue in this soil sample. In the right part of the figure shows the breakdown of the results.

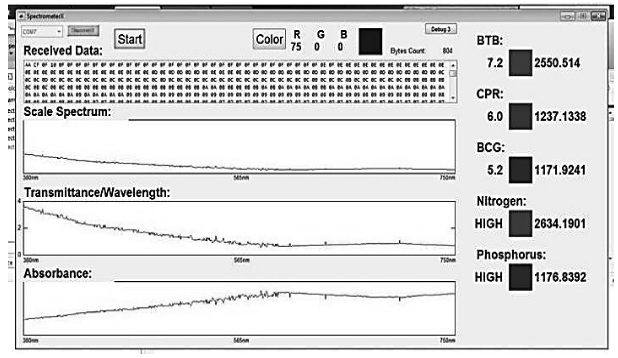

Fig. 2. pH Level Curve

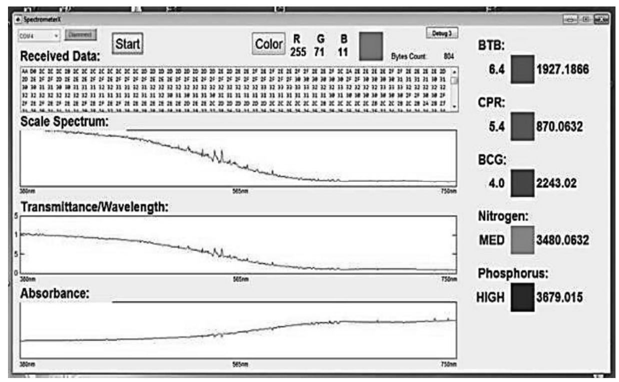

Fig. 3. Nitrogen Level Curve

Fig. 4 shows the spectrum scale, the transmittance vs. wavelength graph and absorbance graph of the acquired phosphorus result from the sample. It also shows the RGB equivalent together with its approximate color which is 0 for red, 0 for green and 31 for blue in this soil sample. In the right part of the figure shows the breakdown of the results.

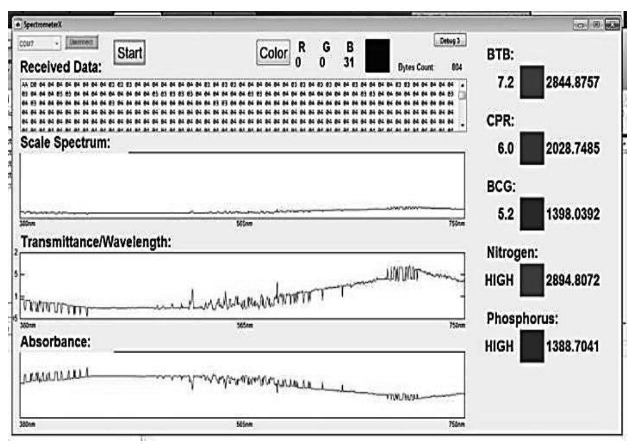

Fig. 4. Phosphorus Level Curve

Fig. 5 shows the spectrum scale, the transmittance vs. wavelength graph and absorbance graph of the acquired potassium result from the sample. It also shows the RGB equivalent together with its approximate color, which is 255 for red, 88 for green and 11 for blue in this soil sample. In the right part of the figure shows the breakdown of the results.

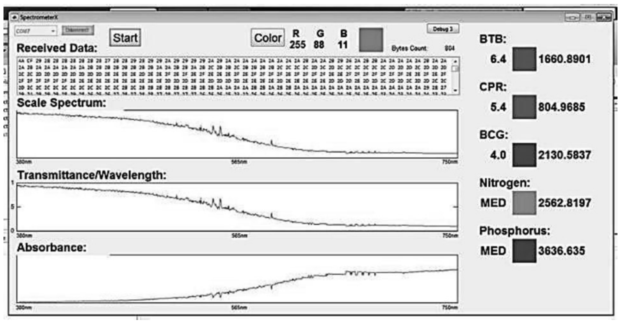

Fig. 5. Potassium Level Curve

C. *Application of the Beer's Law*

Light attenuation is a function of a material's characteristics, which may be described by the equation Beer's Law. According to the rule, absorbance is proportional to concentration in a chemical solution. You may express Beer's Law as:

$$A = \varepsilon \cdot b \cdot c \quad (1)$$

Using molar concentration units, we may write this as: where A is the absorbance measurement, ε is the molar absorptivity, b is the route length, and c is the analyte concentration.

The spectrometer records the intensity of the light entering the reference cell at various wavelengths. The common name for this is "I_o."

For that wavelength, we also measure the intensity of the light that enters the sample cell, denoted by the letter I. The two intensities as shown in Fig. 6 is given by:

$$A = \log10\ (Io / I) \quad (2)$$

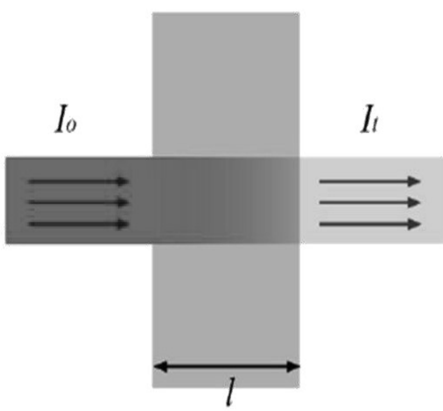

Fig. 6. Beer's Law

D. *Recommendation*

The recommendation section will produce printed report as shown in Fig. 7 established from the analysis of the system and will contain the following: Qualitative results of Macronutrients (Nitrogen, Phosphorus and Potassium) and pH level, Suitable amount of fertilizer to use per hectare, and when to apply.

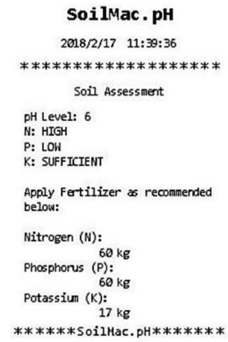
SoilMac.pH
2018/2/17 11:39:36
****
Soil Assessment
pH Level: 6
N: HIGH
P: LOW
K: SUFFICIENT
Apply Fertilizer as recommended below:
Nitrogen (N):
60 kg
Phosphorus (P):
60 kg
Potassium (K):
17 kg
******SoilMac.pH*******

Fig. 7. Sample Printed Report

IV. Design Considerations

A. *Using Arduino Mega 2560 as the systems microcontroller*

The ATmega2560 is the foundational microcontroller for the Arduino Mega 2560. Among its many features are 54 digital I/O pins (15 of which may be used as PWM outputs), 16 analog I/O pins, 4 Universal asynchronous receiver-transmitter (UART) connections, a 16 MHz crystal oscillator, USB port, a power jack, an ICSP header, a reset button, and an onboard reset circuit. Everything required to run the microcontroller is included. The CCD Linear Sensor and Thermal Printer each need four pins, bringing the total number of pins required by the TFT LCD to fifty.

B. *Software Development*

The program is to be done using Arduino IDE and Matrix Laboratory (MATLAB). The Arduino IDE will be used to make the GUI of the TFT Touchscreen LCD, for the programming of the Arduino Mega 2560 and the application of the beer-lambert's law and colors distance formula that will control the process of soil nutrient analysis.

The MATLAB will be used as the IDE for the conversion of color transmitted from the soil sample to its RGB equivalent and for the spectral waveform of the soil sample.

The step-by-step process and construction of the whole project is shown in Fig. 8. The soil sample will be placed in a cuvette, which would be inserted in the device. The device will use a LED light as a source of white light, a lens focuses the light that strikes the mirror that will separate the light into its component wavelength. The mirror is slanted in such a way that only light of the desired wavelength enters the cuvette and interacts with the sample. The sample's transmittance and absorbance are evaluated by the amplifier, a photodiode. Transmittance measures how much light can go through an object before being intercepted by a detector. The amount of light absorbed by a sample is known as its absorbance. Using the LCD as a display medium, the microcontroller measures the amount of light passing through the sample.

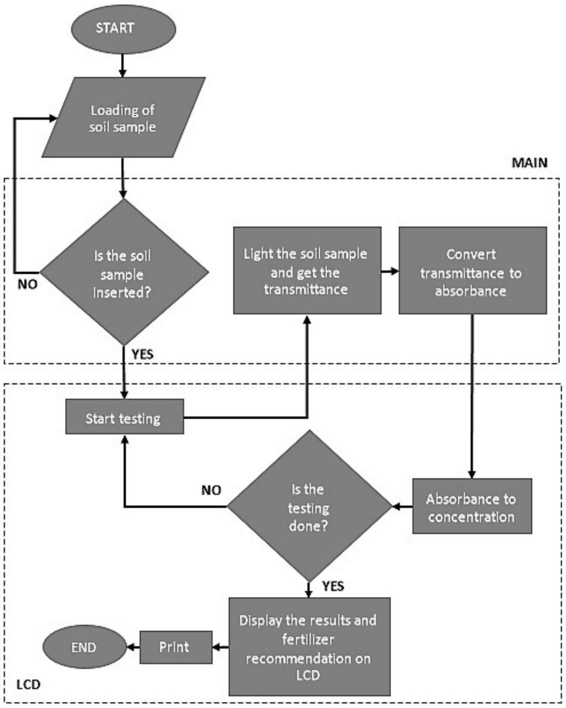

Fig. 8. Process Flowchart

Once the program starts up, as shown in Fig. 9, the user can analyze the initial pH of the soil, whether it is below 5.0, above 6.0 or in between. Upon acquiring the color from the soil sample, click on the Analyze button dedicated for the pH level and wait for the initial result that will be used for the final test of the pH level.

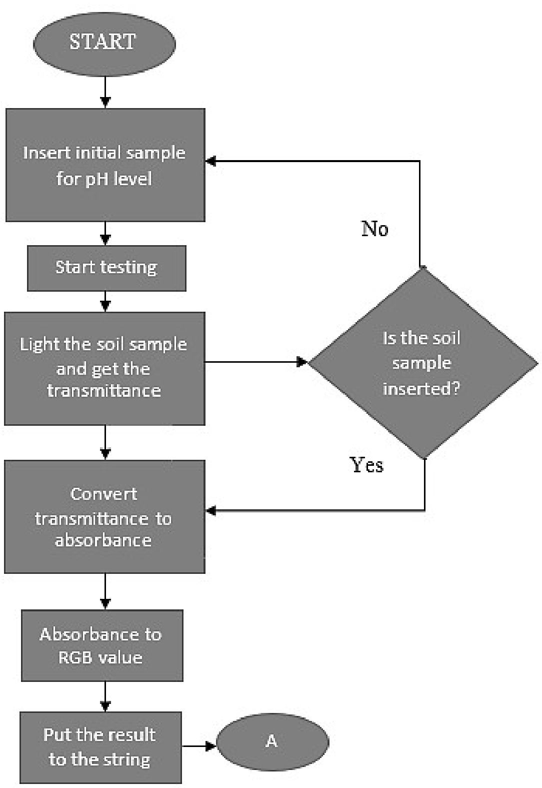

Fig. 9. Arduino GUI Basic Flowchart

After analyzing the initial pH, the user can now analyze the Macronutrient level and final pH level of the soil, as shown in Fig. 10. Final pH depends on the result of the initial result of pH. One sample consists of pH, Nitrogen, Phosphorus and Potassium cuvette will be used. Upon obtaining the samples, click on the Analyze button (for pH, Nitrogen, Phosphorus and Potassium) and the program will analyze the captured color. After analyzing the results, the farmers will be asked to identify what type of soil it is then the device will provide necessary information to guide the farmer with the amount of fertilizer, click on the Submit button. Recommendations can be viewed in the LCD screen and can be printed using the thermal printer.

C. Hardware Development

The spectrometer as shown in Fig. 11 will be consisted of a light source, an aperture, a monochromator, cuvettes, and a photodiode array. An Arduino MEGA 2560 will be utilized as the microcontroller of the prototype and the quantitative output will be displayed through the TFT LCD.

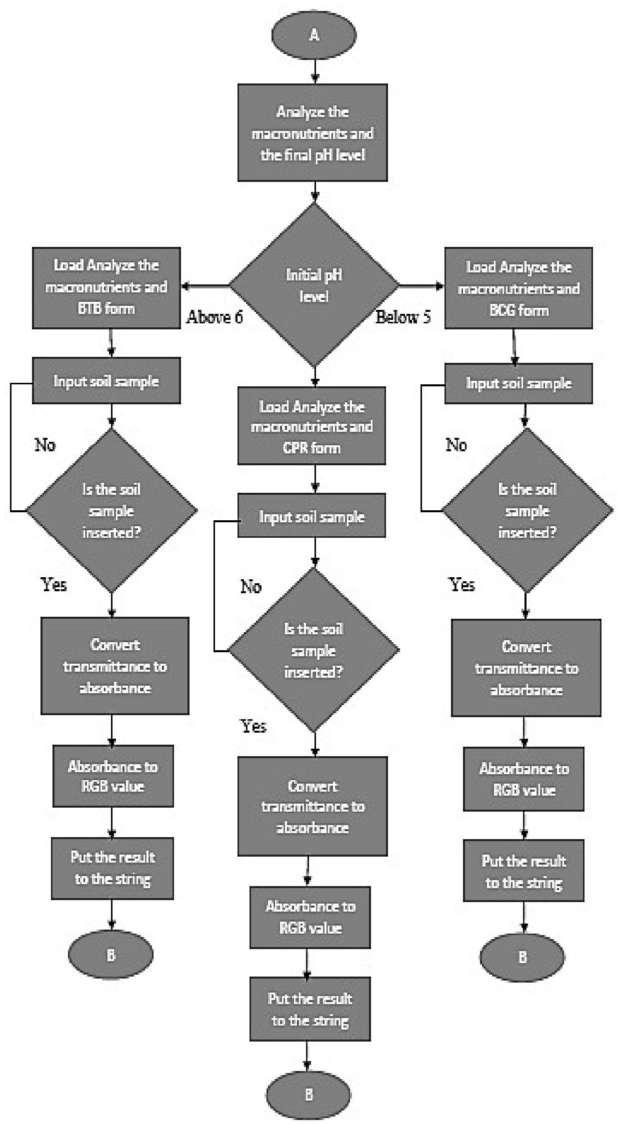

Fig. 10. Arduino GUI Basic Flowchart

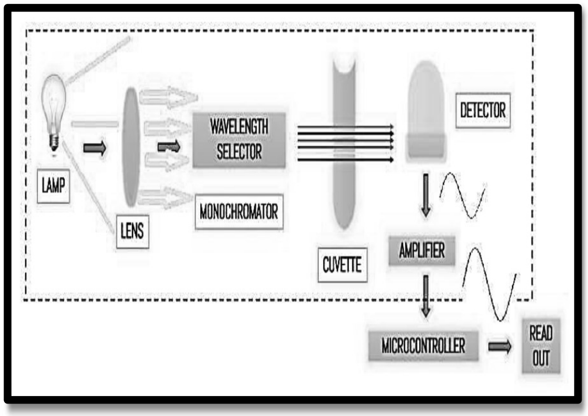

Fig. 11. System of the Spectrometer

D. Design and Assembly

Fig. 12 and 13 shows the internal and external hardware design of the device including the cuvette holder.

E. System Flow

The soil sample is inserted in the device cuvette slot and will be analyzed by the spectrometer. The data gathered from the spectrometer will then be transmitted to the microcontroller. The microcontroller will convert the data through a program. Finally, the result will be displayed through the LCD.

Fig. 12. External Design of the Device

Fig. 13. Internal Design of the Device

F. Implementation of MATLAB Software for Soil Macronutrient and pH Level

The flow of the program in distinguishing the level of the soil's nitrogen, phosphorus, potassium and pH level is as follows: The beam of light from a visible near infrared light source that is reflected by a mirror will serve as the input of the system. Using the Beer Lambert's Law the results will then be uploaded into the Arduino. Based on the results, the program will generate a printed report.

G. Importing the results from Graphical User Interface (GUI) to the MATLAB for Checking

A GUI as shown in Fig. 14 was made using Arduino IDE. The complied Arduino functions will be called to perform the analysis. After the process, a printed copy of the report with the recommendation will be produced.

V. RESULTS AND DISCUSSION

A. Results of Soil Macronutrients and pH Level Identification

Fig. 15 shows that out of 30 different types of soil sample tested and validated simultaneously by conventional method (Soil Test Kit -STK) and SoilMac.pH with 93.33% (28 out of 30) percent accuracy for pH level, 100% (30 out of 30) percent accuracy for nitrogen level, 90% (27 out of 30) percent accuracy for phosphorus level and 96.67% (29 out of 30) percent accuracy for potassium level.

Fig. 14. Graphical User Interface

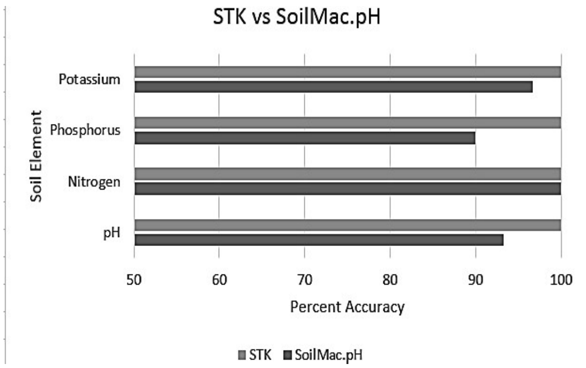

Fig. 15. STK vs SoilMac.pH

Thirty soil samples with different nutrient content were used for the assessment of the program. The samples were manually tested and compared to the Soil Test Kit color charts. The proponents simultaneously do the tests between the Soil Test Kit (STK) and SoilMac.pH was done with certain samples. The system was used to test the same soil samples whether the result of SoilMac.pH where the same with the conventional and visual testing and evaluation. Table I summarize the results of soil macronutrients and pH level testing.

The study's comparison with previous research in soil analysis is summarized in Table II. Notably, [5]-[6], and [9]-[10], achieved high accuracies by utilizing images of soil mixed with standard test chemicals commonly employed in traditional soil testing methods. In contrast, our proposed approach employed the TCD1304AP Linear CCD sensor and VIS-NIR Spectroscopy, which have been demonstrated to be effective in NPK and pH analysis, resulting in superior accuracy outcomes.

TABLE I. RESULTS OF SOIL MACRONUTRIENTS AND PH LEVEL TESTING

Macronutrients and pH	Accuracy
pH Level	28 out of 30 samples 93.33%
Nitrogen Level	30 out of 30 samples 100.00%
Phosphorus Level	37 out of 30 samples 90%
Potassium Level	29 out of 30 samples 96.67%

TABLE II. PERFORMANCE COMPARISON OF THE PROPOSED WORK VERSUS PRIOR WORKS

	This work Soilmac.pH	**Sensoil [7]**	**[8]**	**[9], [10]**	**Automated Soil Nutrient Monitoring [11]**	**SoilMATTic [5]**	**Crop Prediction [12]**	**SoilMATe [6]**
Year	2023	2023	2023	2021	2018	2018	2017	2017
Sensors	TCD1304AP Linear CCD sensor (one at a time)	ISFET pH sensor, Soil moisture, RGB color sensor	-	digital single-lens reflex (DSLR) camera	Carbon, pH, NPK sensor	1080p Full-HD Webcam	NPK sensor	1080p Full-HD Webcam
Parameters	NPKpH	NPKpH	NPK	NPKpH	NPKpH and moisture	NPKpH	NPK	NPKpH
Recommendation	Fertilizer	Fertilizer	-	Fertilizer	Fertilizer	Fertilizer	Crop and Fertilizer	Fertilizer
Software / Algorithm	VIS-NIR Spectroscopy	Random Forest, NB, KNN, SVM	Sample Datasets, Enhanced Genetic Algorithm	Image Processing, OpenCV	SVM	Image Processing, ANN	Agro Algorithm	Image Processing, ANN
Microcontroller	Arduino Mega	Arduino Mega	-	-	Arduino Uno	-	Raspberry Pi	-
Data Display	Printed result	Web Application	-	Mobile application	Website interface	Printed result	-	Printed result
Database	None	Yes	None	None	Yes (SQLlite)	None	Yes	None
Accuracy	**95%**	**93.33%**	**20 - ~90%**	**88-98%**	**90%**	**96.67%**	**-**	**98.33%**

VI. CONCLUSION

The development of a system that would determine the Soil Macronutrients and pH level for rice crops through the principle of spectrometry was successfully instigated using MATLAB. The trial validated the project's utility and accuracy at the 95% level. Nonetheless, we hope the following suggestions for the project's enhancement would be helpful. To improve the device's accuracy, (1) collect additional soil samples from a variety of crops to add to the existing data sets. (2) Use a more advance and highly wrought linear CCD sensor for better results. (3) Use a bigger and higher resolution TFT LCD screen for better viewing of results. (4) Add more variety of crops to be studied. (5) Add a database so that historical data can be stored.

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