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SOTES A Smart Soil Testing Device with Web and Mobile Integration for Precision Agriculture

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ABSTRACT

Soil analysis is an important process to determine the available plant nutrients in the soil. Plants absorb the major nutrients through soil. In addition to soil, there are various major factors like rainfall, precipitation, fertilizer, etc that affect plant growth. Our aim is to create a prediction device for most suitable crop for a particular soil. As a first phase, we concentrated on predicting the user's accurate crop production by analyzing soil minerals such as phosphorus, potassium, and nitrogen. The pH level, temperature, and humidity of the surrounding area must also be entered into the webpage.

1. INTRODUCTION

Soil analysis is an important process to determine the available plant nutrients in the soil. Plants absorb the major nutrients through soil. In addition to soil, there are various major factors like rainfall, precipitation, fertilizer, etc that affect plant growth. Our aim is to create a prediction device for most suitable crop for a particular soil. As a first phase, we concentrated on predicting the user's accurate crop production by analyzing soil minerals such as phosphorus, potassium, and nitrogen. The pH level, temperature, and humidity of the surrounding area must also be entered into the webpage.

Na et.al (2016) talked about a smart phone based application that can measure PH value of the soil, temperature and humidity in real-time which are some really important aspects in crop cultivation. They have used many blocks like microcontroller blocks, sensing blocks and communication blocks. Moreover, it also uses the wireless sensors networks for the purpose of making notes of the soil properties and environmental factors seamlessly.

Satish Babu discussed the requirements and planning needed to build a successful software model to ensure precise farming in his paper. The model they proposed is named as Precise Agriculture (PA). Aakunuri Manjula, Dr. G .Nar- simha emphasized crop yield prediction by developing a framework called extensible Crop Yield Prediction Framework (XCYPF). Rakesh Kumar, M.P. Singh, Prabhat Kumar and J.P. Singh discussed the necessity of crop selection in their paper. The main factors behind selecting any crops are production cost, government policies and market price. The author proposed a model named Crop Selection Method (CSM) which will suggest the best crop to cultivate on a particular land depending on some criteria like season, weather, waterfall, soil type, crop type etc.

Salo et.al discussed eleven types of crop simulation models which can be used in prediction of crop yield. These models were tested for three years based on various nitrogen fertilizer rates. The widely used 11 crop simulation models are APSIM, CERES, CROPSYST, COUP, DAISY, EPIC, FASSET, HER- MES, MONICA, STICS and WOFOST. This paper happens to come out as the best paper to make a standard crop model in comparison to different levels of nitrogen supply.

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Dipto, Iftekher, Ghosh, & Reza discussed that Bangladesh is a country having an area of 1, 47,570 square kilometers in which a significant part is agricultural lands. As an agricultural country, we are mostly dependent on a cultivation which is dependent on the soil type. There are 3 most important nutrients in any soil, it's known as the primary macronutrients: Nitrogen (N), Phosphorus (P), and Potassium (K). Each of the primary nutrients is very essential in plant nutrition, serving a critical role in the growth and reproduction of the plant. We propose and demonstrate Crop Suggesting System based on N.P.K. values by using machine learning which will determine the best crop to grow in a particular soil based on some major criteria. This model will play a vital role in our agricultural sectors to fulfill the needs of our country by reaching the highest level of efficiency and ensure the best use of our arable lands. We have used four different machine learning algorithms named SVM, Adaboost, Random Forest and Logistic Regression and achieved a maximum of 98% accuracy using SVM.

Barangay Carolina Eastern Samar land consists of non-heritable spread of soil varieties like loam soil, black soil, muddy soil and in some regions clay soil. These completely different soil varieties possess different properties and different fertility levels. Soil fertility is measured by considering the quantity of Nitrogen(N), Phosphorous(P) and Potassium(K) and hydrogen ion concentration in the soil which are needed in comparatively huge quantities. N is a very important element of all super molecules, therefore is an integral to the plant. P may be a minor element of super molecule, however, is integral to the molecules that manage energy flow among the plant and maybe an element of genetic material. The role of K appears to be in maintaining the proper salt concentration within the plant sap. Plant growth is also influenced by soil pH because it determines the availability of nearly all essential plant nutrients. The most nutrients are available for plant use when the soil pH is 6.5. The temperature and humidity of the area are also important factors in plant growth because when the temperature is high and the humidity is normal, more stomata open, allowing carbon dioxide to enter the plant for active photosynthesis. When the air becomes too dry and the plant begins to wilt, the stomatal openings close, reducing photosynthetic activity and, eventually, plant growth. Several studies showed that ancient strategies of crop prediction could lead on to poor crop assessment and inaccurate crop space appraisal. Additionally, these strategies usually depend on rigorous field information assortment of the crop that is a costly and time consuming. So, the researchers aim is to come up with a device that can be used to determine the soil-appropriate. In this paper, the researchers will use the dataset provided by Ingle (2000) which focused only in twenty two (22) different types of plants. The researchers will develop a website and a mobile application which will serve as the evaluation tool for the soil property values.

Objectives:

1. Develop a website and mobile application that can recommend suitable plant in a soil in terms of Nitrogen, Phosphorous, Potassium, Temperature, Ph Level and humidity values.
2. Develop an Arduino based device that can retrieve soil Nitrogen, Phosphorous, Potassium, Temperature, Ph Level and humidity properties of the soil.
3. Conduct an evaluation of the developed device using the System Usability Scale.

2. METHOD

The study employed Research and Development method .This method consists of (1) development of an Arduino-based device, (2) development of a website, (3) development of a mobile application and (4) testing of the developed hardware and software.

Hardware

Arduino is a free and open-source platform for creating electronic projects. Arduino is made up of a physical programmable circuit board (which is also known as a microcontroller) and a piece of software called an IDE (Integrated Development Environment) that runs on your computer and is used to create and upload computer code to the physical board (Retrieved from: https://learn.sparkfun.com/tutorials/what-is-an-arduino/all, March 3, 2025). Arduino is the microcontroller used in the development of the device. Several sensors were also integrated in the device to be able to capture all the variables needed in the website and mobile application in determining what plant suits to the tested soil. Fig 1 shows the Schematic diagram of the device. It includes the different sensors and modules used in the development. The description of each module is shown in Fig 2.

A. Schematic Diagram

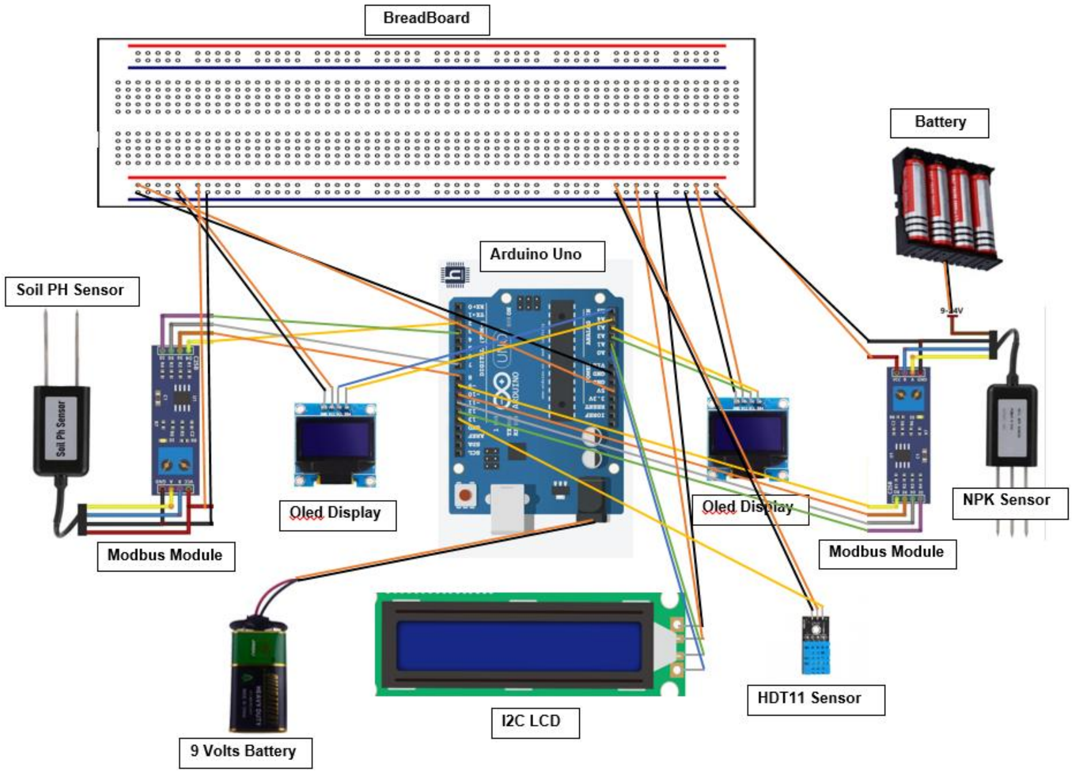

Fig 1. Schematic Diagram

B. Device Design

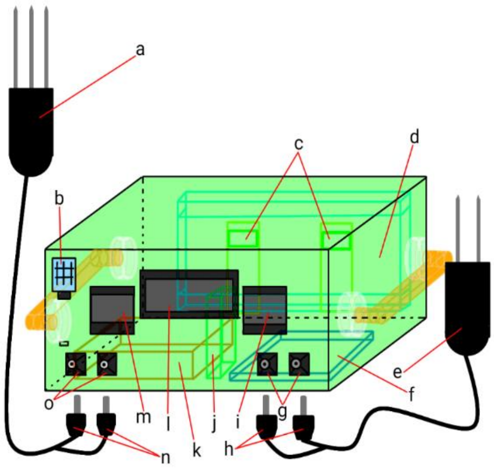

Figure 2 Device Design

Legend

a. Soil NPK sensor - measures the nitrogen, Phosphorus, and Potassium values of the soil
b. Humidity & Temperature sensor - measures the temperature and humidity value
c. RS485 Modbus Module - reads the soil NPK and pH sensors
d. Bread Board - helps on the connections of the pins and circuits into the device.
e. Soil pH - measures the pH value of the soil.
f. Arduino Uno - reads the code inputs of the sensors and activates the overall systems of the device.
g. DC jack ports, female - this side of the device are the jack ports for the soil pH sensor.
h. DC jack ports, male - these jack ports are attached to the soil pH and are to be connected to the female jack ports of the soil ph.
i. 0.96 inches OLED display monitor - the monitor of this side shows the measured values for the soil pH sensor.
j. 9 volts Battery - primary power supply of the device which powers up the Arduino, humidity/temperature and soil pH sensor.
k. 3.7 volts Batteries (3x) - secondary power supply of the device which powers up the NPK sensor.
l. LCD Display - the monitor which shows the measured values for the humidity and temperature sensor.
m. 0.96 inches OLED display monitor - the monitor of this side shows the measured values for the soil NPK sensor.
n. DC jack ports, male - these jack ports are attached to the soil NPK sensor and are to be connected to the female jack ports of the soil NPK sensor.
o. DC jack ports, female - this side of the device are the jack ports for the soil NPK sensor.

Software

The dataset retrieved from Atharva Ingle's Crop Recommendation Dataset were stored in an online database platform by the researchers which is the Firebase Database. This data can be retrieved and compared to the data from the SOTES device through the use of a website and a mobile application. Both website and mobile application will use the same database. The database will consist of data such as the plant, Nitrogen, Phosphorous, Potassium, Temperature, Ph Level and humidity values. A mobile application will also be developed to be used as another platform in evaluating the data retrieved from the soil. Using the application requires internet connectivity to access the database online. This application is limited to evaluating the data entered for analysis. Therefore, using the SOTES device is highly recommended in retrieving soil properties before using this application.

Data Requirement

To be able to analyze the data and recommend suitable in a specific soil based on the retrieved variables, the following soil properties must be entered in the system.

- *Nitrogen (N)* – Nitrogen is the primary electrolyte in soil. Having an adequate supply of electrolytes corresponds very closely with plant growth (Retrieved from: https://www.ecofarmingdaily.com/, 2022) to retrieve Nitrogen property of the soil, NPK sensor was utilized in the device.
- *Phosphorous* - constitutes about 0.2 percent of a plant's dry weight, where it is primarily a component of tissue molecules such as nucleic acids, phospholipids, and adenosine triphosphate (ATP). After nitrogen (N), phosphorus (P) is the second most limiting nutrient. It can reduce plant growth and development and potentially limit crop yield. (Retrieved from: https://www.aces.edu/). NPK sensor was used to measure the Phosphorous level in the soil.
- *Potassium*- Normal plant growth requires large quantities of potassium. In fact, throughout growth most crops contain more potassium than any other nutrient including nitrogen (N). (Retrieved from: https://www.pda.org.uk/, 2022)This data variable can be retrieved by the sotes device through the NPK sensor.
- *Temperature* – Soil temperature is the measurement of the warmth in the soil. RS485 Modbus Module was used to read the temperature value of the soli.
- *Ph Level*- DHT11 was used to determine the Ph Level of the soil.
- Soil humidity- is the water stored in the *soil* RS485 Modbus Module was used to read the Soil humidity value.

Crop Recommendation Dataset by Atharva Ingle
(Retrieved from: https://www.kaggle.com/datasets)

Fig 5 shows a partial screenshot of the dataset uploaded in the database. This dataset serves as the basis in determining appropriate plants that suits in the soil tested. Data in the dataset includes Nitrogen (N), Phosphorous (P), Potassium (K), Temperature, Ph Level (ph) humidity values and the suggested plants (plant).

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N	P	K	temperature	humidity	ph	plant
90	42	43	20.879744	82.0027	6.50299	rice
85	58	41	21.770462	80.3196	7.0381	rice
60	55	44	23.004459	82.3208	7.84021	rice
74	35	40	26.491096	80.1584	6.9804	rice
78	42	42	20.130175	81.6049	7.62847	rice
69	37	42	23.058049	83.3701	7.07345	rice
69	55	38	22.708838	82.6394	5.70081	rice
94	53	40	20.277744	82.8941	5.71863	rice
89	54	38	24.515881	83.5352	6.68535	rice
68	58	38	23.223974	83.0332	6.33625	rice
91	53	40	26.527235	81.4175	5.38617	rice
90	46	42	23.978982	81.4506	7.50283	rice
78	58	44	26.800796	80.8868	5.10868	rice
93	56	36	24.014976	82.0569	6.98435	rice
94	50	37	25.665852	80.6639	6.94802	rice
60	48	39	24.282094	80.3003	7.0423	rice
85	38	41	21.587118	82.7884	6.24905	rice
91	35	39	23.79392	80.4182	6.97086	rice
77	38	36	21.865252	80.1923	5.95393	rice
88	35	40	23.579436	83.5876	5.85393	rice
89	45	36	21.325042	80.4748	6.44248	rice
76	40	43	25.157455	83.1171	5.07018	rice
67	59	41	21.947667	80.9738	6.01263	rice
83	41	43	21.052536	82.6784	6.25403	rice
98	47	37	23.483813	81.3327	7.37548	rice
66	53	41	25.075635	80.5239	7.77892	rice
88	46	42	22.683191	83.4636	6.60499	rice
93	47	37	21.533463	82.14	6.50034	rice
60	55	45	21.408658	83.3293	5.93575	rice
78	35	44	26.543481	84.6735	7.07266	rice
65	37	40	23.359054	83.5951	5.33332	rice
71	54	16	22.6136	63.6907	5.74991	maize
61	44	17	26.100184	71.5748	6.93176	maize
80	43	16	23.558821	71.5935	6.65796	maize
73	58	21	19.97216	57.6827	6.59606	maize
61	38	20	18.478913	62.695	5.97046	maize
68	41	16	21.776893	57.8084	6.15883	maize
93	41	17	25.621717	66.5042	6.04791	maize
89	60	19	25.191924	66.6903	5.91366	maize
76	44	17	20.416831	62.5542	5.85544	maize
67	60	25	24.921622	66.7863	5.75025	maize
70	44	19	23.316891	73.4542	5.85261	maize
90	49	21	24.840167	68.3585	6.47252	maize
62	52	16	22.275267	58.8402	6.96706	maize
92	44	16	18.877514	65.7682	6.08297	maize
66	54	21	25.190087	60.2002	5.91905	maize
63	58	22	18.254054	55.2822	6.20475	maize
70	47	17	24.612912	70.4162	6.60083	maize
61	41	17	25.142061	65.2619	6.0219	maize
66	53	19	23.093481	60.1159	6.03355	maize
74	55	19	18.050337	62.8937	6.28887	maize

Fig 3. Partial Screenshot of the dataset

To determine the plant suitable to the variables inputted in the application, all the variables of least one (1) plant should be all variables must be equal to the inputted variables. Fig 4 shows a flowchart on how the data are evaluated.

Legend:

Dataset

- N[] = Nitrogen
- P [] = Phosphorous
- K [] = Potassium
- tmp[] = Temperature
- ph[] = ph level
- SM[] = soil humidity

Inputs

- iN = Nitrogen
- iP = Phosphorous
- iK = Potassium
- itmp = Temperature
- iph = ph level
- isM = soil humidity

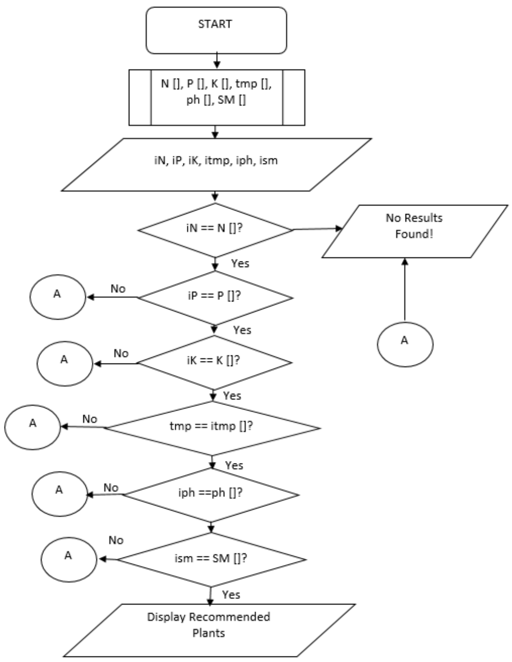

Fig. 4 System Flowchart

Evaluators

The evaluators of the study will be the twenty (20) members of the agricultural community in Barangay Carolina, Eastern Samar. These individuals are directly engaged in farming and soil management, making them qualified to assess the functionality and usability of the Soil Testing Device with Browser-Based and Mobile Application Soil Quality Analyzer Software (SOTES). Their feedback will provide critical insights into the effectiveness of the device in soil assessment, crop suitability recommendations, and ease of use.

Evaluation

The evaluation process will focus on assessing the usability, accuracy, and efficiency of the SOTES device in providing real-time soil analysis. The evaluators will use the **System Usability Scale (SUS)** to rate the system based on key usability factors, including ease of operation, accuracy of soil data retrieval, and the effectiveness of the browser-based and mobile application interface. The evaluation will be conducted using a **5-point Likert scale**, where respondents will rate their experience with the device. The collected responses will be analyzed to determine the overall usability score and identify potential improvements to enhance its functionality and user experience.

Scoring

The System Usability Scale is a Likert scale consisting of 10 questions that device users will respond to. Research Respondents rate each statement on a scale of 1 to 5, where 5 indicates strong agreement with the statement and 1 signifies strong disagreement. Table 1 shows the scoring method for the System Usability Scale (SUS), which uses a Likert scale with 10 questions. Respondents rate each question on a scale from 1 to 5, reflecting their level of agreement with the statement. A score of 5 indicates "Strongly Agree," while a score of 1 indicates "Strongly Disagree." The table provided clarifies the qualitative descriptions corresponding to each score, ranging from strong agreement (5) to strong disagreement (1). This method is designed to quantify users' subjective assessments of a system's usability, providing a consistent way to measure user satisfaction of the website.

Table 1 METHOD OF SCORING

Rating Scale	**Qualitative Description**
5	Strongly Agree
4	Agree
3	Slightly Agree
2	Slightly Disagree
1	Strongly Disagree

Computation

Step 1: Convert the scale into numbers for each of the 10 questions:

1. Strongly Disagree: 1 point
2. Disagree: 2 points
3. Neutral: 3 points
4. Agree: 4 points

5. Strongly Agree: 5 points

Step 2: Calculate:

- X = Sum of the points for all odd-numbered questions – 5
- Y = 25 – Sum of the points for all even-numbered questions
- SUS Score = (X + Y) x 2.5

Interpretation

SUS score will be able to tell the website's usability performance in the aspects of effectiveness, efficiency, and overall ease of use. Although each response yields a score on a scale of 0–100. The interpretation is shown in Table 2.

Table 2 Survey Result Interpretation

SUS Score	Grade	Adjective Rating
> 80.3	A	Excellent
68 – 80.3	B	Good
68	C	Okay
51 – 68	D	Poor
< 51	F	Awful

Retrieved from (https://uiuxtrend.com/measuring-system-usability-scale-sus/)

3. RESULT AND DISCUSSION

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Discussion

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4. CONCLUSION

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5. ACKNOWLEDGE

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