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A Review on Detection of Nutrients of Soil Using NPK and Moisture Sensors

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Abstract*: With an emphasis on the combination of NPK (nitrogen, phosphorus, and potassium) and moisture sensors, this review paper explores the critical role that contemporary sensor technology plays in identifying soil nutrients and moisture levels. Precision agriculture, which seeks to optimize irrigation and fertilization techniques based on real-time data, depends on accurate measurement of these parameters. The study looks at different kinds of moisture and NPK sensors, describing how they operate and how they are used in agricultural settings. There are various advantages to incorporating these sensors into farming operations. One of the biggest benefits is increased agricultural yields since optimal plant growth is ensured by accurate fertilizer and moisture management. Another important advantage is cost effectiveness; farmers can save input costs and boost profitability by eliminating excessive fertilization and irrigation. Additionally, efficient resource usage promotes sustainable farming methods, which improve soil health and lessen environmental deterioration. The content of vital nutrients in the soil can be determined using NPK sensors. These sensors allow farmers to customize their fertilization plans to match the unique requirements of their crops by giving them real-time information on the levels of nitrogen, phosphorus, and potassium. This accuracy guarantees that plants get the appropriate quantity of nutrients at the right time, leading to improved crop yields and reduced environmental impact. This paper identifies the need for developing superior systems for soil monitoring to strengthen precision agriculture, crop production, and sustainable farming.*

Keywords: NPK Sensors, Moisture Sensors, Soil Nutrient Detection, Real-Time Data, Crop Yield Improvement, Soil Health Monitoring, Sensor Technology in Agriculture

I. INTRODUCTION

With a projected global population of 98 billion for the year 2050 it is clear why countries such as india must ramp up their food production and other agricultural products a country like india is one of the most crowded in the world however despite this challenge on the way to producing rising demands on food fuel and other agricultural products sustainable agri- culture is one way the challenges are being approached in sus- tained agriculture long-term soil health environmental quality and economic viability comprise its practice they depend on soil health to enhance crop productivity and quality and the im- portance of this cannot be underrated in sustainable agriculture of the macronutrients nitrogen n phosphorus p and potassium k significantly promote plant growth for instance nitrogen promotes chlorophyll production and amino acid synthesis which are contributing factors in vegetative growth phosphorus promotes the synthesis of dnarna and root development while potassium regulates nutrient and water flow inside the cell for blooming and fruiting in a plant healthy growth of the plant requires that npk be present with an ideal ratio which an optimum ratio recommended for is 421 the only problem with maintaining such a balance is that over-fertilization and under- fertilization are two very common problems in india the farm- ers often indiscriminately apply fertilizers to their fields due to lack of time and proper soil health information traditional soil testing methods are time consuming and labor intensive hence the information cannot be readily obtained this calls for the development of rapid on-the-go soil nutrient measurement tools advanced in situ sensors have been developed by research for measuring soil macronutrients among the several methods explored are optical sensing ion-selective electrodes chemical methods and techniques using inductively coupled plasma icp spectroscopy along with fluorescence spectroscopy the latter appears to be pretty promising among these which also is portable low in cost and simple to utilize this method uses the optical property of the soil as a basis for the measurement of nutrient concentrations non-destructive with high sensitivity and selectivity soil health monitoring has undergone a change due to the integration of advanced technologies like iot and automated systems iot-enabled sensors can provide in situ real-time data for soil nutrient levels microclimate conditions and more critical parameters for example soil probes that can take all the measurements in the soil can be incorporated with the ability to detect npk levels soil moisture ph and air temperature and humidity using optical detection the systems are equipped with components that consist of leds for light emission ldrs for the detection of light and microcontrollers like nodemcu for the acquisition and transmission of data data can be presented in a digital form and uploaded on locally held web pages in order for farmers to get access as well as analyze easily this elaborates on the benefits of including spectroscopic colorimetric and imaging techniques for the analysis of soil nutrients these methods measure the reflectance absorption or transmittance spectra of the soil samples to yield a precise estimate of the concentration levels of the nutrients optical sensing is non-destructive and can be very efficient for real-time on-field use cases the paper further enhances the use of arduino as an adaptable tool for developing and programming electronic sensors in this regard the arduino uno platform allows users to design and develop the device hence customizing them into low-cost devices which can test soil is possible these devices may be interfaced with any input sensor and through this its output components ensure that it exhibits high precision while controlling and acquisition of data for agricultural applications this paper will utilize the novel innovative approaches to guide the development toward effective and sustainable systems for the detection of soil nutrients with respect to agricultural productivity and the capability to practice precision farming in contributing toward efficient food production and care for the environment.[1] [2]

A. Methods and Materials Used

Such total nitrogen levels and soil NPK will generally be approached under the following three methods: electric conducting tests, optical techniques, as well as electrochemical procedures.

Electrical Conductivity Testing: In electricity testing, assessing the conductivity of the solution in any given soil indicates the available quantity of dissolved nutrients through the soil via estimation.

Spectroscopy and Colorimetry Methods: These incor- porate spectroscopic and colorimetric methods for measuring soil particle-light interaction to procure nutrient information in the least-destructive and time-friendly way. 3. Electrochemical Methods: Sensors, mainly ISEs, provide the measurement of soil concentration by specific ions and are thus highly sensitive and very responsive in real-time. All of these allow for successful on-the-go measurements of the nutrients present in soils to optimize fertilizer usage and facilitate farmers' resource management practices.[3]

II. STANDARD LABORATORY TESTING PROCEDURE IN INDIA

The standard procedure for laboratory testing in Indian soil is through collection, preparation, and analysis of the sampled soil. This includes the determination of the macronutrients Nitrogen (N), Phosphorus (P), and Potassium (K) levels. The procedure involves a step-by-step analysis to ensure accuracy and reliability in the interpretation of results regarding soil fertility levels.

Collection of Soil Samples:

Soil samples are taken from various locations in a field to obtain a representative sample. This is done by taking soil cores at different depths and mixing them to form a composite sample.

Preparation of Soil Sample

The soil samples obtained are air-dried and sieved to remove debris and larger particles. The prepared samples are then homogenized to ensure uniformity.

Chemical Analysis:

Nitrogen Measurement The Kjeldahl is the most com- monly used method to measure soil nitrogen. A process of digestion, distillation, and titration gives the total amount of N.

Phosphorus Measurement Extracting phosphorus using a sodium bicarbonate solution, and its concentration by spec- trophotometry is an Olsen method that is highly common.

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Potassium Measurement: Potassium levels are usually measured using the flame photometry method, where the soil sample is extracted with a neutral ammonium acetate solution and the potassium content is determined by measuring the emitted light intensity. Soil Fertility Level Classification These can be broadly categorized into soil fertility levels on Nitrogen, phosphorus, and potassium with reference to concentrations in kilograms per hectare. This serves to provide interpretation of soil test result information and aid fertilizer applications that ensure better crop yields. Soil Fertility Explanation This classification of soil fertility levels provides an essential un- derstanding of how and when fertilizer application decisions are best made. The following breaks down each level further and clarifies what each entails.

Very Low:

This term describes a soil with extremely low Nitrogen (N), Phosphorus (P), and Potassium (K) levels. Its level of these critical nutrients is considered very deficient.

Implication: Such crops grown on such soils are likely to face stunted growth, low yield, and general unhealthy condition due to the lack of the critical nutrients needed for their growth.

Action: There should be substantial fertilization that would replenish these nutrients to make them grow healthily. Farmers need to apply more amounts of NPK fertilizers to raise the levels up to a more adequate range.

Low:

Definition: Soil with low nutrient levels has some of the required nutrients but not enough to support optimal plant growth.

Implication: Plants may exhibit mild deficiencies, such as yellowing leaves (chlorosis) caused by a deficiency in nitrogen or stunted root development caused by phosphorus deficiency. Action: A moderate amount of fertilizer is required to increase the nutrient levels that will enhance better plant health and yield. This calls for balanced fertilization so as not to waste nutrients or cause environmental damage.

Medium:

Definition: Soils with medium fertility contain an adequate amount of nutrients to support normal growth for most crops under average conditions.

Implication: This level is generally adequate but may still benefit from additional fertilization depending on crop-specific needs and soil conditions.

Action: Fertilization should be adjusted to meet the specific needs of the crop and identified deficiencies. This level needs frequent monitoring to maintain optimal fertility.

Moderately High:

Definition: Moderately high fertility levels indicate that the soil has more than enough nutrients.

Implication: Such conditions are likely to favor crops, which will grow well and yield well. However, after some time, nutrient levels may require slight supplementation to maintain balance.

Action: Minimal fertilization is required. Farmers should apply fertilizers in moderation to maintain the current levels without causing excess.

High:

Definition: Soils with high nutrient levels are well-supplied with essential nutrients.

Implication: This is a condition most crops thrive in, and they will likely grow well and yield highly without further fertilization.

Action: Further fertilization is usually not required and may result in nutrient excess and associated environmental problems like runoff and pollution.

Very High:

Definition: Very high fertility levels mean the soil has an excess of nutrients.

Implication: Though it would seem that too much of any- thing good can’t hurt, actually it can hurt the plant. Excessive levels of any nutrient can lead to toxicities, interfere with uptake of other nutrients essential to plants, and damage the plants themselves.

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Nutrient	N(In kg/ha)	P(In kg/ha)	K(In kg/ha)
Low	< 240	< 11	< 110
Medium	250-480	11-22	110-280
High	> 480	> 22	> 280

Fig. 2.1: Nutrient Levels for N, P, and K

Action: Fertilization should be avoided to avoid excessive levels of nutrients. Sometimes a cover crop will need to be planted to reduce the level of nutrients available to the crops.

Soil Type	Fine	Medium	Coarse
Exact	80-100	88-100	90-100
Moderate	60-80	70-88	80-90
No water	below 60	below 70	below 80

Fig. 2.2: Moisture levels in Soil

The above tables give the description about nutrient levels in soil (Fig.2.1.) and moisture levels in soil based on its type (Fig.2.2). [4] [5] [6]

According to the table, low levels of nitrogen (N) are less than 240 kg/ha, medium levels are between 250 and 480 kg/ha, and high levels are greater than 480 kg/ha. Sufficient levels of nitrogen must be maintained for plants to develop healthily since it is essential for vegetative growth and the synthesis of chlorophyll. While high nitrogen levels might promote robust growth, they can also produce in excessive foliage and poor fruit or grain yield. Low nitrogen levels can cause poor growth and fading leaves.

If phosphorus (P) levels fall below 11 kg/ha, they are classified as low; if they fall between 11 and 22 kg/ha, they are classified as medium; and if they surpass 22 kg/ha, they are classified as high. Energy transfer, root growth, and general plant health all depend on phosphorus. Poor root development and stunted growth might result from a phosphorus deficiency. Strong root systems and better blooming are supported by adequate phosphorus levels, whereas excessive levels promote root growth and fruiting but may obstruct the uptake of other elements, such as zinc.

A potassium (K) level is categorized as low if it is less than 110 kg/ha, medium if it is between 110 and 280 kg/ha, and high if it is more than 280 kg/ha. Enzyme activation, disease resistance, and water management all depend on potassium. Weak stems, poor disease resistance, and decreased plant health can result from low potassium levels. High amounts increase plant strength and vitality, while adequate levels increase stress tolerance and water efficiency. However, too much potassium can obstruct the absorption of other crucial elements like calcium and magnesium.

The table of moisture levels explains the detection of moisture in the soil. Fine(clay) type of soil has special characteristics, it is crucial to comprehend its moisture content. It is distinguished by its poor permeability, high water retention capacity, and tiny particles. Because of these characteristics, clay can retain water more effectively than other soil types and drain more slowly. While detecting the moisture levels if the result varies from 80-100 then it tends to have a good amount of moisture and if the level is between 60-80 then the water content is less and less than 60 shows extreme scarcity of water.

One of the best soil types for gardening and farming is loamy soil, sometimes known as ”medium soil,” which has a balanced composition of sand, silt, and clay particles. With a normal composition of 40percent sand, 40percent silt, and 20percent clay, it has exceptional water-holding and drainage properties. These qualities enable loamy soil to remove excess water to avoid waterlogging while retaining enough moisture for plants. Similarly, for this type of soil, moisture level detection tends to show the value in the range of 88-100 and below 70 shows no water in the soil.

In contrast to finer soil types like clay or loam, coarse, sandy soil has special qualities due to its huge particle size and loose structure. Because sandy soil has a low capacity to retain water and a high permeability, it drains water rapidly. Although this encourages proper aeration and lowers the possibility of waterlogging, sandy soil dries up more quickly and needs to be watered more frequently to keep plant moisture levels sufficient. If the detection process shows the value in between 90-100, it explains about good water content in soil whereas below 80 explains about no water.

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III. WORKING PRINCIPLE

The system for measuring the amount of nutrients in soil using an Arduino Uno NPK sensor is very interactive in its components and processes. The first process involves jumper wires to aid in mounting an NPK sensor and the moisture sensor to the Arduino Uno. This is achieved through data transmission, which in turn calls for a highly robust Modbus module to allow proper communication of the sensors to the Arduino.

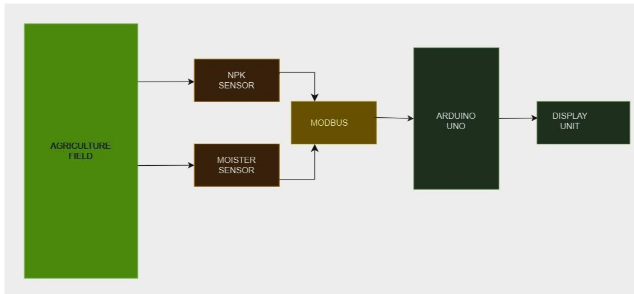

Fig. 1. Block Diagram

The NPK sensor quantifies the concentration of Nitrogen (N), Phosphorus (P), and Potassium (K) found in the soil. Nonetheless, the moisture sensor monitors the moisture level in the soil. The sensors transform the information they read into electric signals, which are in turn translated into digital values in the Modbus module. The Modbus module sends the data in forms read by the Arduino Uno in its proper processing. The Arduino Uno will extract digital data from the Modbus module. The Arduino will interpret this data and analyze levels of NPK and moisture in the soil by having a preset code that converts raw data to meaningful information about the available nutrient content in the soil and the amount of available moisture in the soil.

The output appears on an LCD display screen as readings of Nitrogen, Phosphorus, Potassium, and moisture. The farmers make intelligent decisions at the right times about fertilizer application and irrigation for optimal crop yields by utilizing resources correctly.

This setup offers an extremely efficient and effective means of on-site monitoring of soil nutrient levels and moisture thus offering invaluable information for use in managing resource more effectively and enhancing agricultural productivity.[1] [4]

A. Measurement of NPK Content and Moisture Level in Soil Samples

Measurement of NPK Content

Sample Collection: Collect the soil samples from various sites in the field for the representative sample. Mix the samples very well to obtain a composite sample.

Sample Preparation: Dry the soil samples in the air and sieve it to remove debris and large particles. Homogenize the samples for uniformity.

Chemical Analysis:

Nitrogen (N): Estimation of nitrogen levels through digestion, distillation, and titration using Kjeldahl method.

Phosphorus estimation can be carried out by the Olsen technique, which incorporates the extraction of phosphorus using sodium bicarbonate solution and spectrophotometric estimation of its concentration in extracts. Potassium may also be done by flame photometry wherein potassium was quantified by taking the soil sample treated with neutral ammonium acetate and determining its concentration by measuring the intensity of light emitted. Determination of

Moisture Content Using Direct Methods.

Oven-Drying Method: Dry the wet soil sample in an oven at 105°C to constant weight. Weigh the dry sample. The following formula is used for calculating moisture content:

The moisture content (%) can be calculated using the following formula:

$$\text{Moisture Content} = \frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Dry Weight}} \times 100$$

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Volumetric Method Collect:
A soil sample by using a core sampler or tube auger whose volume is known. Dry the sample and calculate the moisture content based on the volume of water lost.

Indirect Methods:
Tensiometer: A tensiometer is used for measuring soil water suction, or negative pressure, expressed in terms of tension. It is put into the soil, and the reading of the vacuum gauge tells the tension value.
Gypsum Block: Gypsum blocks measure soil moisture by changing electrical resistance with moisture content.
Neutron Probe: A neutron probe can measure soil moisture by identifying hydrogen atoms. Hydrogen atoms are readily available in water.
Pressure Plate Apparatus: This will determine the amount of water held by soils at varied pressures.
This measurement method will be used to get accurate readings of NPK and moisture contents in samples obtained from soils. They supply farmers with a foundation on proper utilization of fertilizers, as well as irrigation.[9] [10]

IV. APPLICATIONS

A key component of modern precision agriculture is the identification of soil nutrients, including moisture content, phosphorus (P), potassium (K), and nitrogen (N). Real-time and precise evaluation of soil health is made possible by NPK and moisture sensors, which offer vital information for maximizing irrigation and fertilizer application plans. Effective applications are explained as follows:

- Precision Agriculture: Targeted fertilizer application is made possible by real-time soil nutrient monitoring with NPK sensors, which reduces waste and contamination in the environment. By combining sensor data with automated systems, fertilizer delivery is optimized, guar- anteeing that the soil receives just the right amount.
- Increased Crop Productivity: Crop productivity is in- creased and the risk of nutrient deficiencies is reduced by maintaining ideal soil moisture and nutrient levels.
- Water Conservation: By using moisture sensors to mea- sure soil moisture content, irrigation systems can only run when necessary, saving water
- Effective Water Dispersion: Smart irrigation systems that integrate moisture and NPK sensors improve water supply according to crops' current needs, resulting in consistent soil moisture distribution.
- Environmental Preservation: Sensors assist in minimizing fertilizer use, lowering the possibility of nutrient runoff into water bodies and averting eutrophication and pollu- tion of the environment.
- Constant Soil Monitoring: Farmers may preserve soil health and enhance decision-making by keeping an eye on temperature, NPK nutrients, and soil moisture.
- Real-Time Data Access: By integrating IoT with moisture and NPK sensors, farmers may access data in real-time through online platforms or mobile apps, improving farm management.
- Soil Mapping: Sensor networks are able to provide com- prehensive maps of soil nutrient levels, which aid in com- prehending the diversity of soil in expansive agricultural areas.
- Crop Selection And Rotation Planning: To maintain soil productivity, selecting the appropriate crops and organiz- ing crop rotations are made easier with an understanding of the nutrient profiles of the soil.
- Cost Reduction: Farming becomes more economically viable when water and nutrients are applied strategically, which lowers input costs.[10]

V. CONCLUSION

The small research on employing moisture and NPK sensors to monitor soil nutrients has shown how important current technology is to improving farming methods. We can get accurate and up-to-date information on the soil's moisture content and vital nutrients (potassium, phosphorus, and nitrogen) by using these sensors. Understanding soil health and making wise decisions about irrigation and fertilization require knowledge of these information.
Precision agriculture is made possible by the use of NPK and moisture sensors, which enable farmers to apply the right amounts of water and fertilizer depending on the soil's real demands. This accuracy reduces waste and guarantees that

crops get the right amount of water and nutrients, which increases agricultural yields.

By avoiding overfertilization and overirrigation, accurate soil nutrient and moisture detection supports sustainable farming. This contributes to water resource conservation, pollution reduction, and soil health maintenance.

Farmers can save needless fertilizer and water applications by understanding the precise nutrition and moisture needs of their land. This economical method maximizes resource utilization, increasing agricultural profitability. Timely interventions are made possible by real-time monitoring of soil conditions, guaranteeing that crops receive the water and nutrients they require throughout crucial growth stages. Food security is eventually aided by this proactive management, which produces healthier plants and increased yield.

In conclusion, a revolutionary step toward advanced and sustainable agriculture is the incorporation of moisture and NPK sensors into soil nutrient detection. This study opens the door for further developments in soil health monitoring and management by showcasing the usefulness and advantages of sensor technology. We can enhance food security, encourage environmental sustainability, and support more resilient agri- cultural systems by utilizing these technologies.

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