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REAL TIME SOIL ANALYSIS THROUGH NPK MONITORING SYSTEM.

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Abstract:

NPK monitoring system real time soil analysis plays an important role in the modern agriculture for improving soil fertility management and increasing crop productivity. The increasing world population requires more food production and therefore the efficient use of fertilizers. Nitrogen (N), phosphorus (P) and potassium (K) are the major nutrients required for healthy growth of plants. Accurate monitoring of these nutrients helps the farmers in applying fertilizers in right quantity and at the right time. Traditional soil testing methods are time consuming, expensive and labor intensive, and are not conducive to continuous field monitoring. To overcome the limitations, this study proposes a real-time monitoring system of NPK integrated with IoT and sensor technologies.

The proposed system utilizes NPK sensor that is attached with Arduino Nano microcontroller for measuring soil nutrient levels. The sensed data is processed, calibrated and communicated through communication modules to a mobile application or cloud platform for real time monitoring and analysis. The system allows farmers to remotely monitor the status of soil nutrients and promote precision agriculture. Graphical data visualization, automated alerts and fertilizer recommendations further aid decision making.

The study further emphasizes the combination of Artificial Intelligence (AI), Machine Learning (ML) and IoT technologies to perform advanced soil analysis and crop management. The experimental testing showed reliable sensor performance with acceptable accuracy against laboratory results. In conclusion, the suggested system is an economical, compact, and effective method for sustainable farming practices that reduce fertilizer wastage, improve soil quality, and increase crop productivity through real-time nutrient monitoring.

Keywords:

- Soil analysis in real time NPK monitoring system.
- Soil nutrients detection
- Internet of things
- Smart farming
- Ardiuno Nano
- Precision Agriculture
- Soil fertility Management

1. Introduction :

Food production must rise in order to meet the growing demands of an expanding population. Fertilizers that mostly comprise nitrate (N), phosphate (P), and potassium (K) are necessary to boost crop output(1). Discrete temporal readings have been displayed by these sensors. However, these sensors are not suitable for field-based measurements since they usually require sufficient moisture content to create an electrochemical cell, which necessitates the creation of soil slurries by combining the tested soil with deionized water. The excellent sensitivity and selectivity that electrochemical sensors provide is one of their main advantages. The most significant obstacles, however, are the variability and very low signal-to-noise ratio with different soil types and textures.(2) They are typically limited by their high cost, lengthy processing times, and need for specialized equipment. Quick testing models have been employed to assess soil health in a variety of contexts in an effort to address these issues.(3) The type of crop and the state of plant growth determine the amount of NPK. The amount of NPK nutrients that are now present in the soil further determines how much fertilizer should be applied. Agricultural researchers are trying to figure out how to maximize plant yield while using less fertilizer. Many researchers have tried to create sensors to map these nutrient concentrations because these macro-nutrients change even on a tiny scale throughout a planted field. Systems for integrated crop management have been developed to investigate the temporal and spatial dynamics of NPK. These techniques use a lot of computing power to examine thousands of photos. Other techniques include optical sensors with high sensitivity, however they are severely hampered by large spectrometer gear, site-specific calibration, and inaccurate detection of nutrients that are not fully seen in the Vis-NIR region. (2,4)

Nitrogen, phosphorus, potassium, calcium, and magnesium are the main nutrients that plants absorb from soils. For healthy crop growth, we frequently need to add fertilizer, manure, or compost to the soil to augment its nutrients. Many other nutrients are taken up by plants from the soil, but these secondary nutrients are typically present in sufficient amounts in the soil, negating the need to add more.(5). Farming practices that deteriorate rather than preserve the soil are frequently the cause of soil deterioration. Reduced organic matter, decreased biodiversity, and compromised soil ecosystem services are the results of intensive monoculture and overuse of chemical inputs.
that agricultural soils offer a variety of services, such as climate regulation, water purification, and food provision.(6)

1.1 Role of Nitrogen potassium and Phosphorus in plant growth:

- identifying the potassium, phosphorus, and nitrogen contents.
- aids in assessing the soil's fertility.
- methodical evaluation of the state of the soil.
- sensor to analyze the properties of the soil and produce comprehensive maps of the farm area.
  Productivity is tracked using smartphones.

1.2 Limitation of traditional soil testing methods:

- Time consuming method
- High cost
- Limited accuracy for mobile Nutrients
- Distructive Metholodologies
- Limited deapth and temporary scope

1.3 Need of real time monitoring systems:

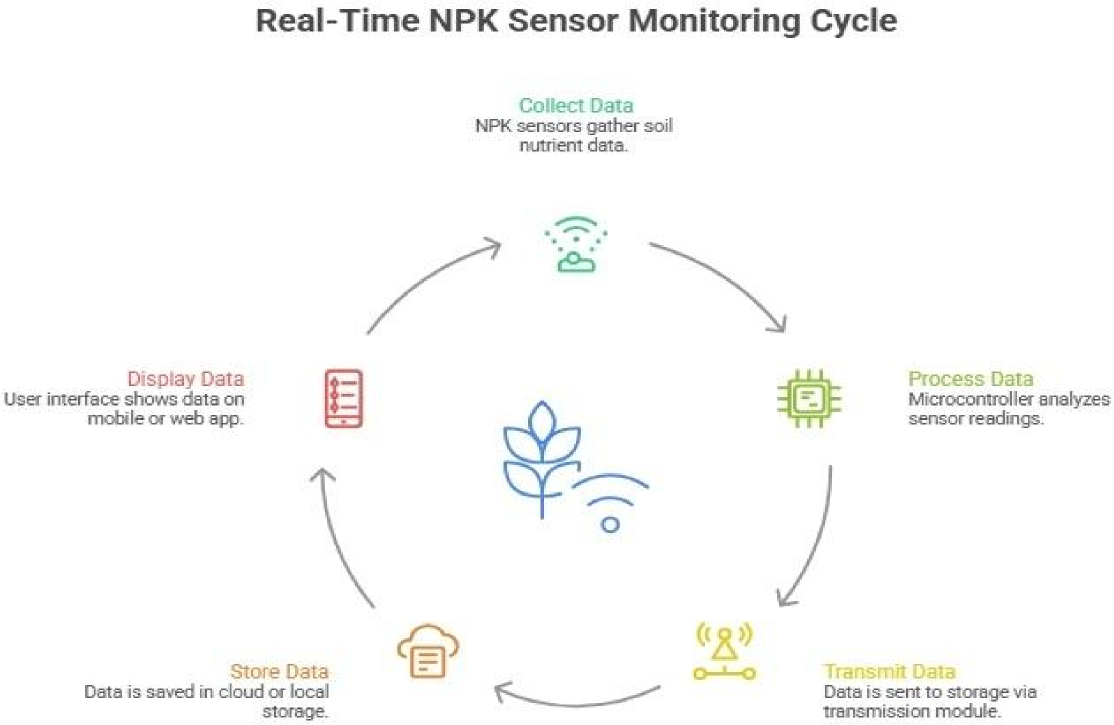


Fig.1 Real time NPK sensor monitoring cycle.

2. Objective :

- The application of machine learning (ML), deep learning (DL), and hybrid AI models on soil datasets from sensors, chemicals, and satellites is discussed.
- Examining the function of AI in crop recommendation systems, comparing the effectiveness and performance of different machine learning models, and identifying the main obstacles and constraints—such as data scarcity, cost-effectiveness, regional variability, and scalability—in implementing AI systems in actual agricultural situations are the secondary goals.
- This study's primary goal is to examine artificial intelligence (AI) tools and methods for classifying soil nutrients, including supervised, unsupervised, and deep learning techniques.(7)

Litearture :

Soil testing is an important process in agriculture as it helps farmers to understand the nutrient condition of soil and apply fertilizers in the right amount. For many years, conventional soil-testing methods have been used to measure nutrients such as nitrogen (N), phosphorus (P), and potassium (K). These methods usually involve collecting soil samples from different locations within a field and submitting them to laboratories for chemical analysis. The Kjeldahl method is commonly used for nitrogen analysis, flame photometry for potassium determination and colorimetric methods for phosphorus analysis. While these methods are accurate, they are expensive, time consuming and require skilled professionals and specialized equipment. These limitations do not permit the use of traditional methods for continuous or real-time monitoring of soil nutrients. To address these problems, researchers have proposed modern soil monitoring systems based on sensors and Internet of Things (IoT) technologies. NPK sensors are common for direct detection of soil nutrient levels in the field. Sensors are also used to measure the nitrogen, phosphorus and potassium content (in real time, without laboratory testing). Modern sensors are more rapid, portable and easier to use than traditional methods. Researchers have created electrochemical and optical sensors that are highly sensitive and accurate for the detection of nutrients. However, the accuracy of some sensors may be reduced by soil texture, moisture content and environmental conditions. The popularity of IoT-based systems of agriculture has grown a lot in recent years, because they allow farmers to monitor the soil conditions remotely, using a smartphone or a computer. In these systems, sensors are connected to microcontrollers like Arduino, ESP32 or Raspberry Pi. The collected data is sent to the cloud platforms or mobile applications through wireless communication technologies such as Wi-Fi, GSM, Bluetooth or LoRa. Farmers can monitor nutrient levels, soil moisture, temperature and humidity in real time. These systems assist farmers to take quick decisions regarding fertilizer application and irrigation management, thereby enhancing crop productivity and minimizing resource waste. Several studies have shown that combining Artificial Intelligence (AI) and Machine Learning (ML) with IoT systems can further boost agricultural performance. AI and ML algorithms can process large volumes of soil data, detect nutrient deficiencies and make recommendations on fertilizers. Some sophisticated systems even forecast future soil and crop requirements. Researchers have used satellite imagery and deep learning to study soil fertility and crop health over large agricultural areas. These technologies allow precision agriculture to improve decision making and increase farming efficiency. The modern approaches are more useful than the traditional methods in terms of saving time, reduction of labour costs and continuous monitoring. Smart farming technologies prevent over fertilization which protects the soil health and reduces environmental pollution. Farmers can access soil information anytime and anywhere through mobile applications and cloud storage systems. However, challenges such as sensor calibration, high installation costs, internet availability and data accuracy in some rural areas are still present.

2.3 Comparision between traditional and modern approach:

Traditional Approach:

Taking samples from various areas of a field is typically the first stage in the soil testing process.
Chemical analysis is then carried out in a lab. Common methods include colorimetric assays for phosphorus, titration for acidity or calcium and magnesium content, gravimetric methods for calculating moisture and organic matter, and spectrophotometry for figuring out absorbance levels after chemical reactions. Although Walkley-Black oxidation is frequently

The Kjeldahl method is frequently used for nitrogen and organic carbon Flame photometry is also used to determine potassium and sodium levels. Farmers frequently use real-world field methods for fast assessments in addition to laboratory procedures, such as the feel method for soil texture and the use of portable test kits (e.g., for pH and NPK) These methods are labor-intensive, time-consuming, and frequently expensive, even though they are accurate for small-scale, point-based testing. Additionally, their scalability is restricted, and accurate result interpretation requires technical skill.(7)

Modern approach: Farmers have been advised to use a number of techniques to preserve their soils. These include zero tillage, minimum tillage, and the cultivation of vetiver grass to lessen erosion. Farmers have chosen conservation techniques that are inexpensive, easy to install and maintain, labor-intensive, highly cost-effective, and consistent with the current farming system in an effort to keep their farmlands viable (8)

Additionally, because a variety of sensors are readily available on the market, farmers may easily and remotely monitor the soil with IoT. These technologies have a big impact on agricultural output since they cut down on the time, money, resources, and equipment needed for farming. Farmers are able to keep an eye on the soil and apply the proper amount of fertilizer and water. By using a wireless network to retrieve data from their mobile devices, farmers can examine the soil's nutrient level and other factors.
Sensor technology has been created with the goal of creating a system that can analyze pH, humidity, soil temperature, nutrients, and light intensity while sending emergency signals to a predefined database.(9)

2. System Architcture

Components of system :

1. **NPK sensor :** Multimode plastic optical fibers are used in the construction of the NPK sensor. The seven fibers that make up a sensor probe are organized in a concentric pattern, with the central fiber serving as a receiving fiber and the surrounding six fibers serving as transmission fibers.(1)

Microcontroller: Every Arduino board has a microcontroller of its own.
Think of it as the board's brain. The Arduino's primary integrated circuit (IC) varies slightly between boards.
It has 32 kb of flash memory and an ATMEGA328 microcontroller (CPU) that operates at 16 MHz.(5)

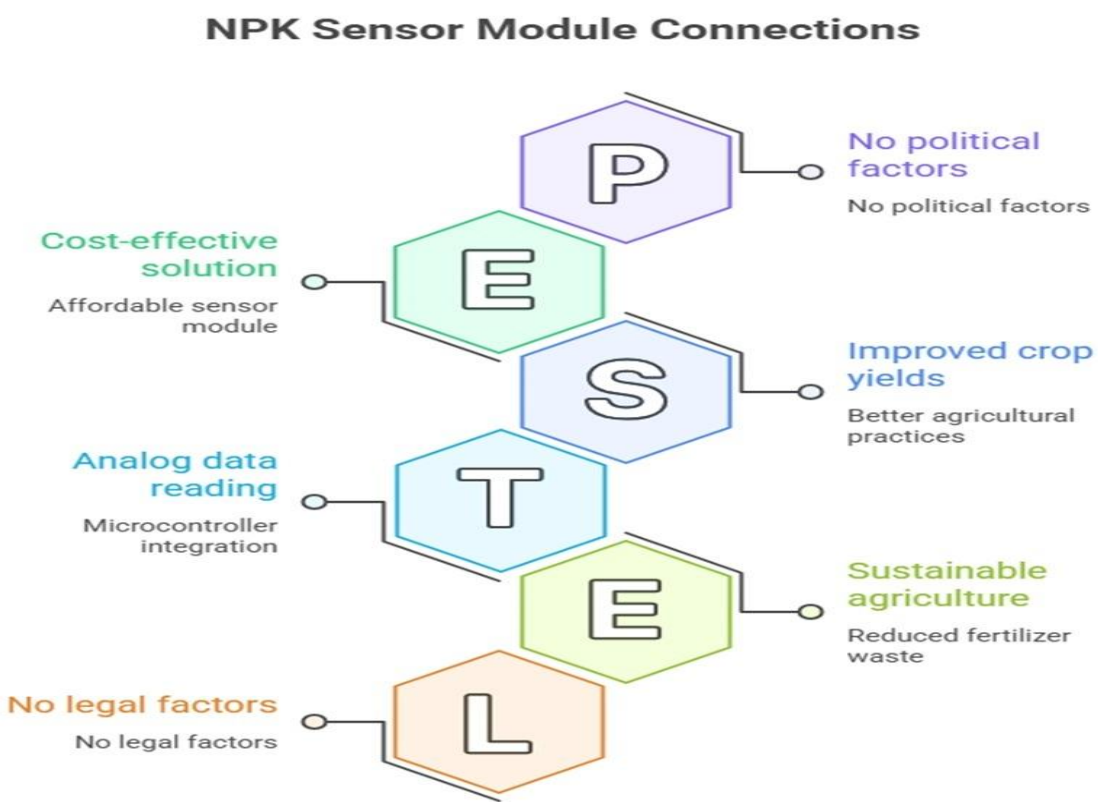


Fig. 2 NPK sensor Model connection.

5.0 **Methology**: Standard soil sampling procedures were used to gather representative soil samples from the study region, guaranteeing random sampling throughout the whole site. A systematic approach was used to extract the supernatant from the soil samples. After that, a chemical substance that was known to have an affinity for nitrogen (N) and phosphorus (P) compounds was added to the supernatant. In order to ensure that there were few air bubbles or contaminants, the resultant mixture was carefully put into a clear, clean glass cuvette. The solution-containing cuvette was put into a high-resolution spectrum analyzer. To determine whether the solution absorbed or transmitted light, the spectral analyzer was calibrated and set to the proper wavelength range. At the specified wavelengths, the spectrum analyzer recorded the solution's optical characteristics. To guarantee precise and dependable data collection, a number of measures were made. Regression analysis was performed on the obtained spectral data using an appropriate mathematical model.

The model was created using a calibration dataset with known N and P concentrations, which made it possible to ascertain the amounts of each element in the soil samples. The available nitrogen and phosphorus concentrations in the soil samples were computed and reported in parts per million (ppm) based on the regression analysis. Using the proper conversion factors, the calculated concentrations of accessible nitrogen and phosphorus in parts per million (ppm) were then converted to kilograms per hectare (Kg/h). (10)

6.0 Working principle:

Primarily based on ion selective sensor, electrochemical, and unique analysis techniques. Fertilizer management, soil health evaluation, and personation farming management are just a few of the many agricultural applications for this sensor, which is actually a soil NPK analyzer. We can optimize the planting system by using the information about soil nutrients that this NPK sensing study provides.

Working:

An Ardiuno nano microcontroller is linked to the display moule.

↓

A 9V battery powers this Ardiuno Nano.

↓

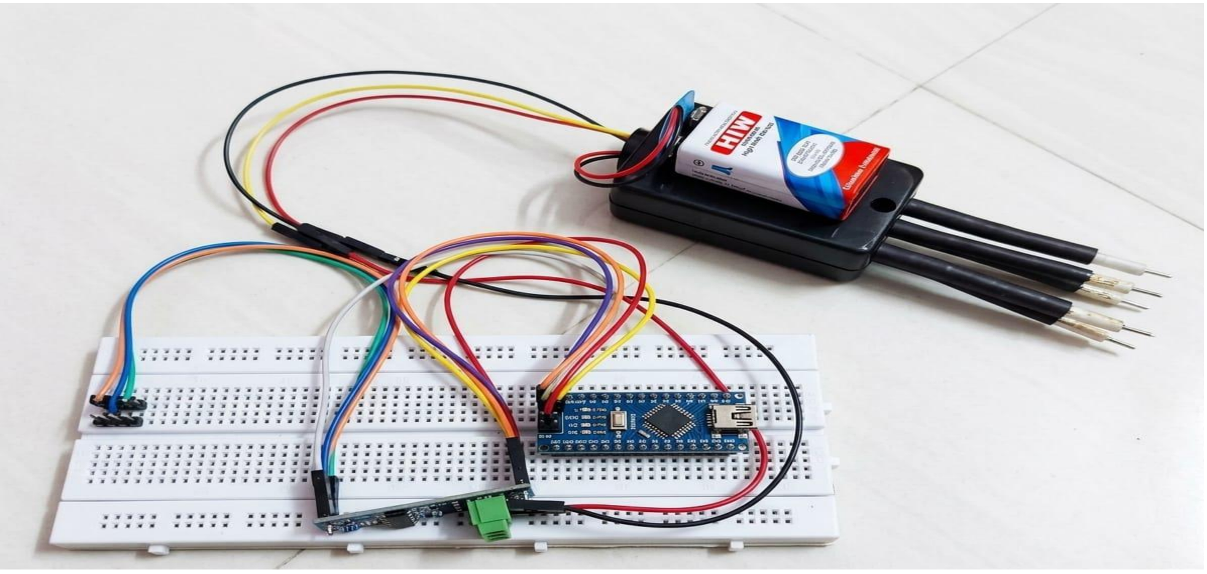
The signal converter, which is linked to the Arduino nano microcontroller, is another device we utilized.

↓

We require a single application that places the NPK sensor data with the React interface in order to condense the display.

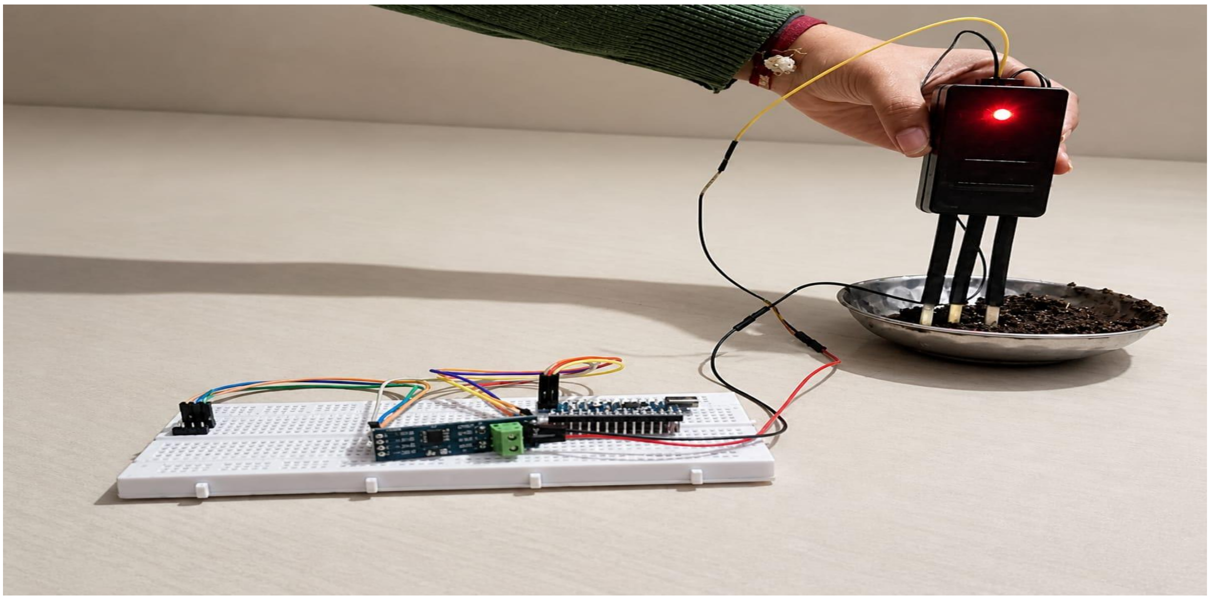
↓

The NPK analyzer detects vital soil nutrients including potassium (K), phosphorus (S), and nitrogen (N) using a standard measurement system.



Mechanism: Soil sensing is the first step in the real-time data analysis process of an NPK [nitrogen, phosphorus, and potassium] monitoring system. To continuously measure the content of vital nutrients nitrogen, phosphorus, and potassium, specialized NPK sensors are placed into the soil. Usually, this sensor works on the basis of ion-selective or electrochemical principles, in which variations in nutrient content result in corresponding electrical impulses. The output produced at the stage often takes the form of analog signals that accurately indicate the amount of nutrients in the soil at that particular time. Following acquisition, the signals go through signal conditioning and conversion. due to the fact that sensor signals are frequently poor and may contain noise. First, signals made up of circuits are used to amplify and filter them. An analogy-to-digital converter (ADC) then transforms the analogy signals into digital data so that electronic systems may process them. This stage guarantees that the data is reliable, accurate, and appropriate for computer analysis in the future. A micro controller or embedded system, such the Arduino ESP323, then handles the digital data. At this point, the system calibrates using predetermined reference values to guarantee measurement accuracy. Additionally, it transforms the unprocessed digital value into useful quantities like milligrams per kilogramme (Mg/Kg) or parts per million (PPM). The system memory may be used to temporarily store and prepare the process data for transmission. This step comes from the monitoring system's central processing unit. IoT-based communication methods like wi-fi, GSM, or lora are used to transfer the data. The system transmits real-time nutritional data via mobile applications like Blynk IoT or cloud performance platforms. As a result, customers were able to remotely monitor the condition of the soil from any location.

The system is very effective for real-time applications because the use of IoT guarantees that there is no delay in accessing updated information. Real-time data analysis occurs in the cloud or server environment, where software algorithms are continuously used to store and analyze incoming data. The system determines if the nutrient levels are optimal, deficient, or excessive by comparing the measure value with the standard level. Additionally, sophisticated systems can estimate future soil conditions and fertilizer requirements through trend analysis or predictive modeling. The user is shown the analyzed data via visual interfaces like web dashboards or mobile apps. This interface shows graphical trends of real-time values and adjusts for anomalous conditions. Based on this data, the system can make recommendations for soil management and fertilizer application. This creates a continuous feedback loop in which soil data is continuously monitored, analyzed, and used to support informed agricultural decisions, increasing crop productivity and resource efficiency.



6.3 Data interpretation:

In order to evaluate soil fertility and inform agricultural decisions, data interpretation in soil detection using an NPK sensor entails analyzing the measured concentrations of nitrogen (N), phosphorus (P), and potassium (K). This sensor usually provides values in mg/kg or ppm, which are compared against standard ranges (low, medium, and high) to determine nutrient status.

Nitrogen levels show the possibility for vegetative development when analyzing the data. While excessive nitrogen can result in overgrowth and worse crop quality, low nitrogen indicates poor leaf development and may require treatment. Low levels of phosphorus can lead to a weak root system and delayed maturity. Phosphorus is necessary for root development and energy transfer. Potential supports water control, disease resistance, and

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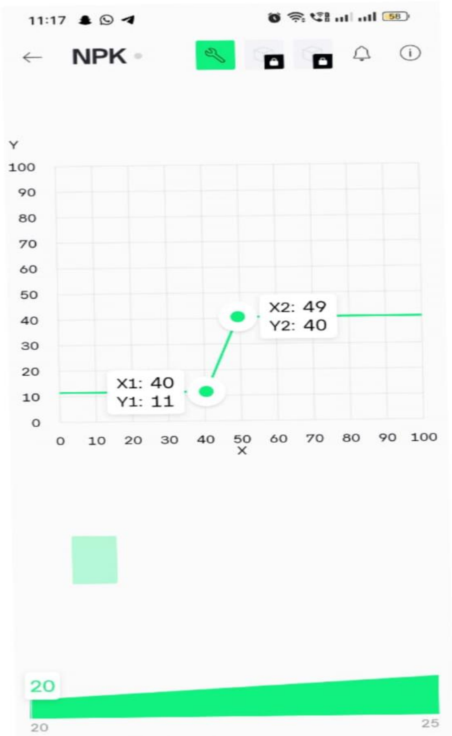
general plant health; hence, deficits may result in low yield and poor stress tolerance. To guarantee accuracy, the sensor data is frequently calibrated against lab findings. Multiple readings are advised for reliability because variations may arise from soil moisture, temperature, or sensor positioning. To make decision-making easier, data can be represented using graphs or divided into zones (low, medium, and high). NPK sensor data is connected with IoT platforms in real-time monitoring systems, enabling automated alerts and ongoing tracking. This lessens waste and the impact on the environment by assisting farmers in applying fertilizers precisely (precision agriculture). In general, effective nitrogen management, increased crop output, and sustained soil health maintenance are made possible by accurate interpretation of NPK sensor data.

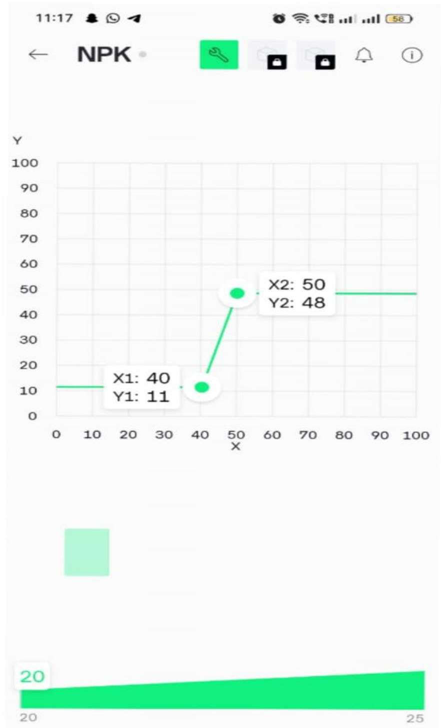
6.4Output display and mobile app:

A useful and effective method of tracking soil health in real time is to use a mobile application for soil analysis that uses an NPK sensor (nitrogen, phosphorus, and potassium). Such a system's output display is essential for converting unprocessed sensor data into information that farmers, agronomists, and even gardeners can comprehend. Usually, the NPK sensor uses optical or electrochemical sensing methods to measure the concentration of vital nutrients in the soil. The micro controller receives this raw data id =s, processes the signals, and transforms them into readable values. This processed data is delivered to the mobile application via Bluetooth, wi-fi, or IoT platforms, where it is presented in an easy-to-use style. The mobile app's output display is often created with clarity and simplicity in mind. It frequently has a dashboard that displays the current levels of potassium, phosphorus, and nitrogen, usually expressed in parts per million (ppm) or mg/kg. In addition to numerical values, the app may offer graphical representations like bars and charts that allow users to observe changes in soil nutrients over time. These values are frequently color-coated, with red denoting optimal levels, blue denoting moderate deficiency or excess, and green highlighting critical imbalance. This visual representation helps users quickly assess soil condition without requiring deep technical knowledge.

Another important feature is the ability to store historical data, which allows users to monitor soil health during many crop cycles or seasons. Mobile apps that measure soil nutrients using an NPK sensor frequently incorporate sophisticated reaccommodating in addition to just presenting values. The app can recommend suitable fertilizers or soil amendments based on the observed nutrient levels. For instance, if nitrogen levels are low, the app might suggest urea or organic compost along with recommended amounts. More sophisticated applications might use machine learning algorithms to improve reaccommodating over time, accounting for things like crop type, soil texture, condition, and previous treatments.

As a result, the app becomes a decision-support system rather than a sample monitoring tool. Localization and customisation are crucial components of the result presentation; given the widespread nature of agricultural operations, the app may enable users to choose their region, crop type, and soil category. This guarantees that interpretation and accommodations are pertinent to the local situation. Additionally, some apps offer many languages, making them accessible to a wider variety of consumers. When nutrients fall outside of the ideal range, alerts and notifications are frequently incorporated into the system to notify users of the need for quick action. This proactive strategy enhances production quality and helps avoid crop damage. Technically speaking, accurate NPK sensor calibration and effective data processing algorithms are critical to the output's accuracy and rehabilitation. To guarantee that the display results accurately reflect the state of the soil, noise filtering, error correction, and regular calibration procedures are crucial. The mobile app may additionally have a calibration interface that walks users through the process of preserving sensor accuracy. Another aspect that improves usefulness is data synchronization with cloud platforms, which enables users to evaluate soil data from numerous devices and share it with agricultural professionals.



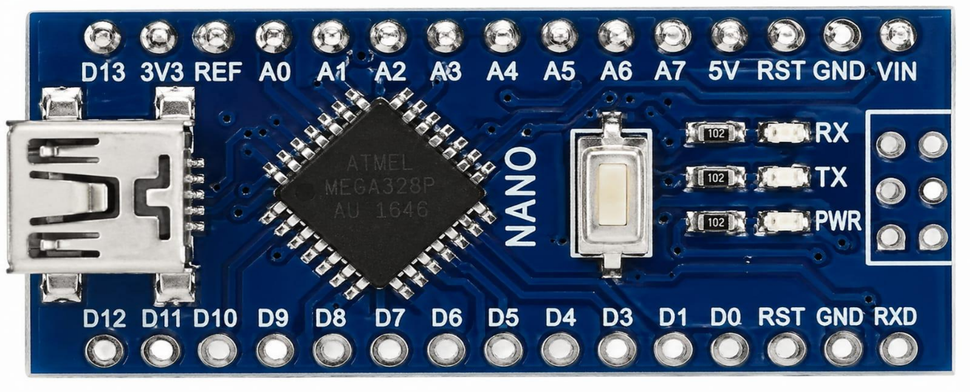


7.0 Implementation :

- **Hardware setup:**

Arduino Nano 33BL: The pins on both boards are equivalent and serve the same purpose. The Audino Nano has enough PWM-capable pins and operates at 5V. This makes it appropriate for tasks requiring the cooperation of several pins. One benefit is that programs written with Arduino code are compatible with other boards of a similar design. The Arduino Nano can be bought with or without pre-solider headers. If the headers aren't soldered, you can do it yourself if necessary. It is preferable to use a nano with a pre-solder header since the header extended the pins downward and made it easier to attach the board. Usually, a USB connection is used to link the Arduino nano to a computer**.**

Compact in size, the Arduino nano offers the same capabilities as a much bigger development board.It is perfect for real-time applications because it can fit into a compact space. To demonstrate the actual arrangement of the pins on the board, we utilized the Arduino nano33BLE version. The pin function is the same even though the pin layout may vary slightly. The design convenience of the spacing between the pins makes it easy to plug the board into a breadboard, which makes it ideal for solder-less prototyping and suitable for a variety of projects. Overall, the board is functionally identical, with the exception of the physical arrangement of the pins.



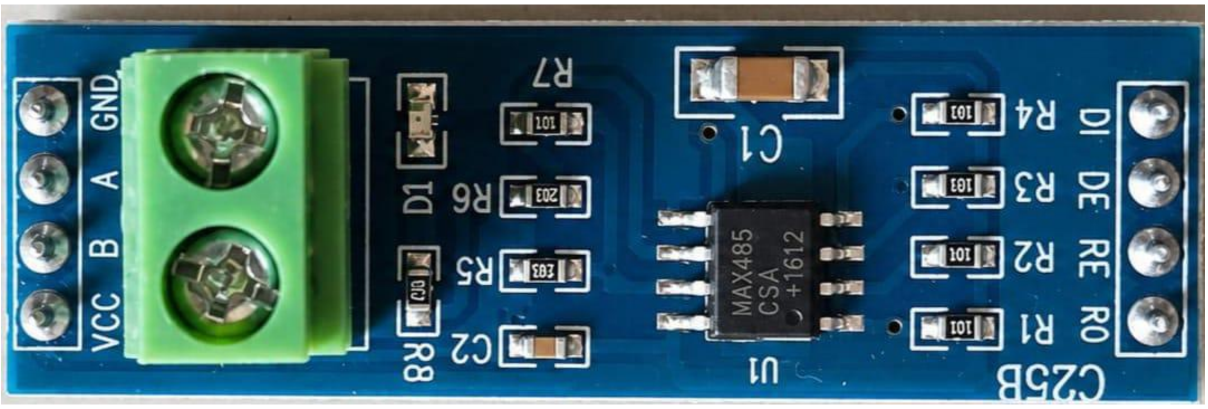
Microcontroller:

When using microcontrollers for long-distance communication, a better way to communicate is needed. One such protocol is RS-485, which lets you talk to someone from up to 1200 meters away. We look at the MAX485IC to learn more about how RS485 works with Ardiuno. For RS485 communication, the MX485 is a low-power transceiver design. It runs on a 5V power source and offers high noise humidity through differentiated signalling. It is therefore perfect for settings where there is a lot of electrical interference. Over a distance of up to 1200 meters, the MX485 can reach transmission speeds of up to 2.5 Mbps. It is unable to transmit data in a dependable and effective manner.

Half duplex communication, which allows data to be sent and received over a signal pair of wires but not simultaneously, is supported by the Ic support. It has pins for the driver and receiver that can be used to switch between the transmission and reception models. Up to 32 devices can be linked on an RS 485 signal thanks to this device's half duplex driver design and unit load rating.

Simplex communication:

Refers to a data transmission where two devices communicate exclusively in one direction. One device in this system only serves as the sender, and the other device only serves as a receiver. The direction of communication and data flow in addiction alone cannot be received. In systems where one-way information flow is adequate, this kind of communication is employed.



7.2 Software tools used : The definition of software resource needs and prerequisites that must be installed on the computer system in order for a program to operate at its best is known as software requirements.

Specification of Requirements:

The web browser that works with HTML5 and above:

1. PHP, HTML, CSS, and JS are the languages utilized.
2. Thing Speak is the cloud.
3. IDE for Arduino 1.8(11)

7.3 Coding

7.4 System testing:

The main goals of soil detection system testing with an NPK sensor are to confirm the system's accuracy, realiability, response time, and real-time performance. It guarantees that the sensor nutrients—nitrogen (N), phosphorus (P), and potassium (K)—provide reliable findings for farming.

The NPK sensor, a microcontroller (such as an Ardiuno or ESP-based board), a power supply, and an IoT module or display are the first components of the testing setup. Different soil samples with known nutrient levels (low, medium, and high) are introduced with the sensor. For comparison, these reference samples are often pre-tested in a lab. The system periodically gathers sensor readings during testing. The output values are noted and contrasted with typical laboratory findings. This comparison aids in assessing the sensor's accuracy. The system is deemed dependable if there is little variance between sensor data (usually within +-5–10%). The same soil sample is then measured several times in order to perform repeatability testing. Consistent readings show that the system is stable. The speed at which the sensor provides a reading after being inserted into the soil is another way to measure response time. An additional phase is environmental testing. The system is tested in real-world field circumstances with varying soil kinds, temperatures, and moisture conditions.

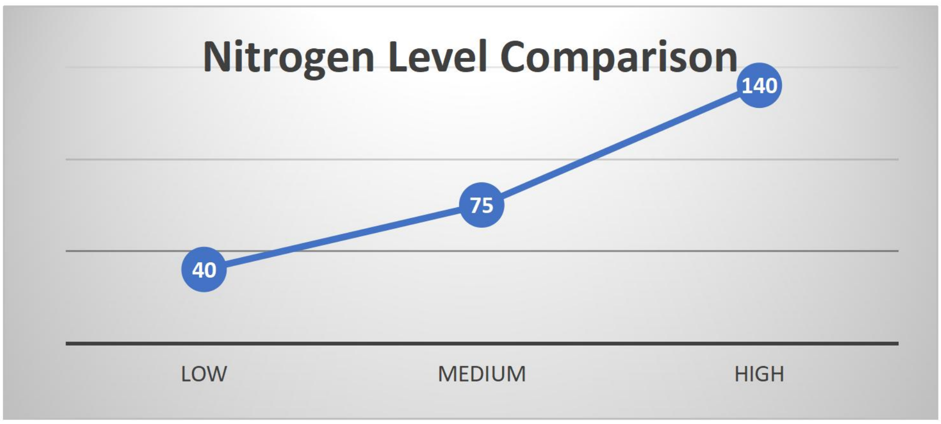
Calibration is yet another crucial stage. To guarantee constant performance in actual field circumstances, the system is tested under various soil types, temperatures, and moisture levels. Lastly, data transmission to a mobile app or cloud platform is used to assess IoT functionality. This guarantees accurate data display and real-time monitoring.

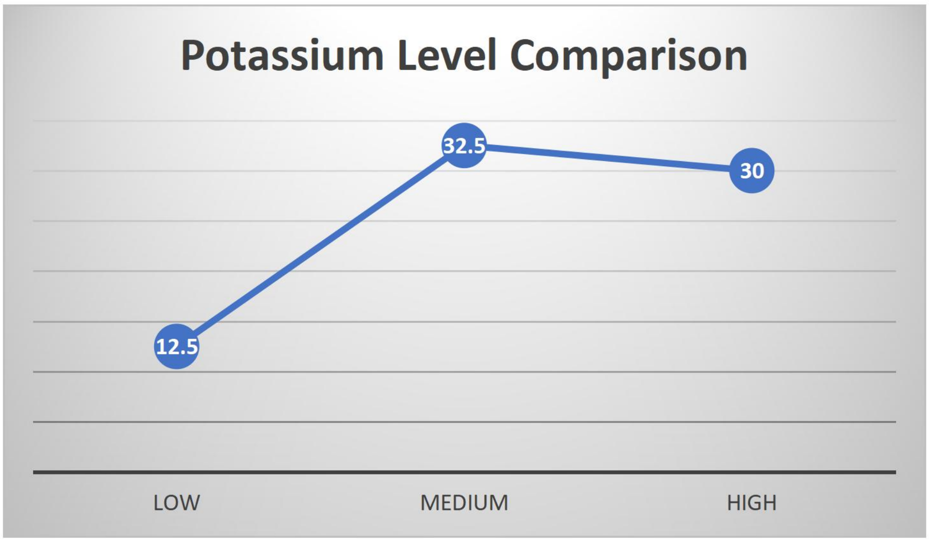
Result and analysis:

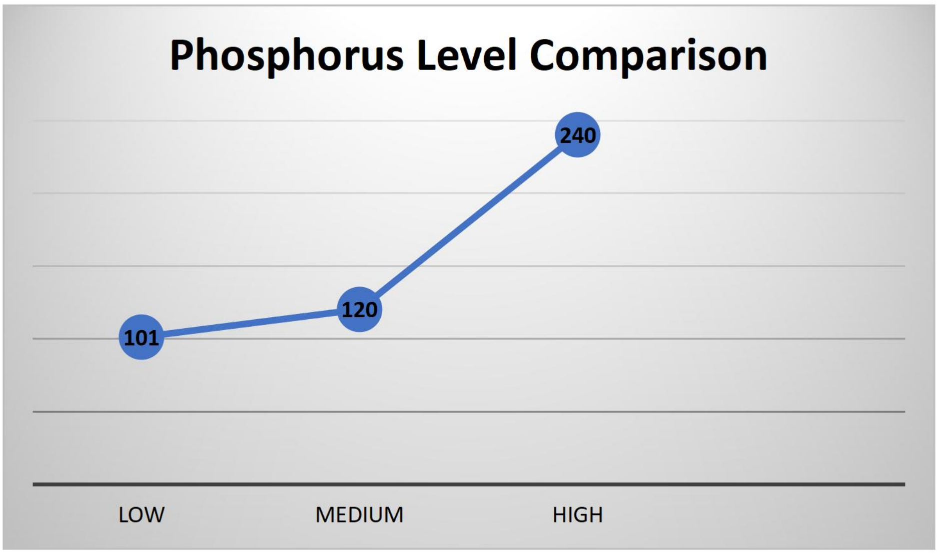
- **Observed NPK value**

LEVEL	NITROGEN	POTASSIUM	SODHIUM
LOW	40-50	10-15	100-110
HIGH	120-140	20-40	200-250
MEDIUM	50-100	15-50	90-150

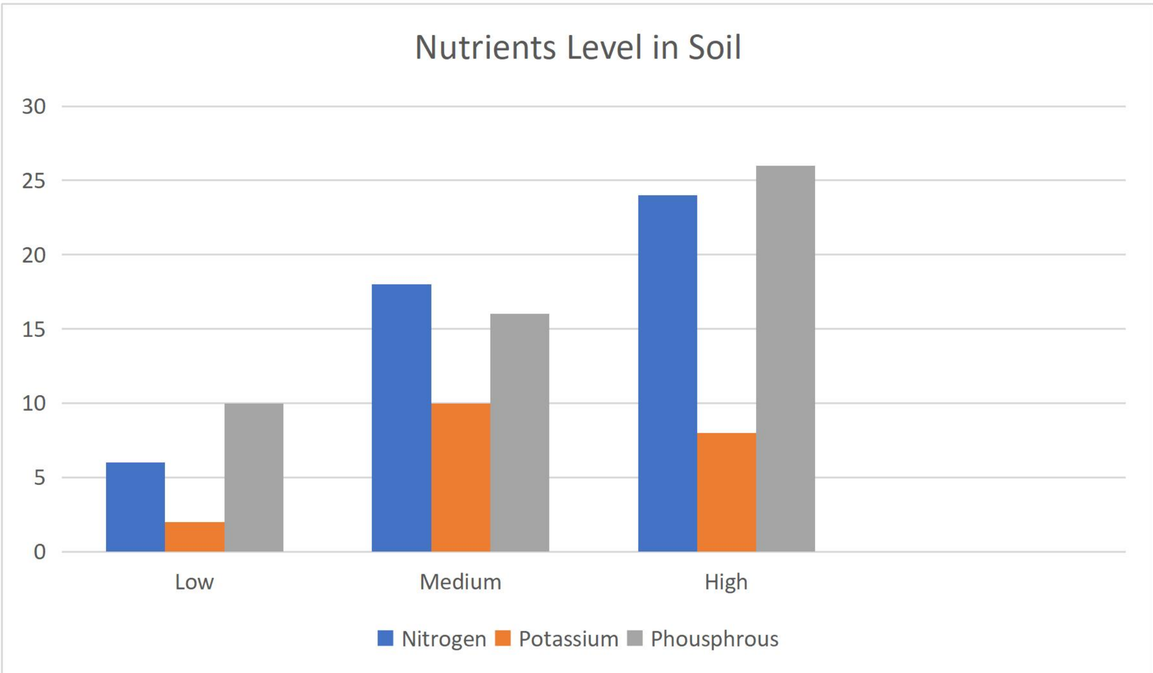
- **Accuracy Comparison with lab result:**





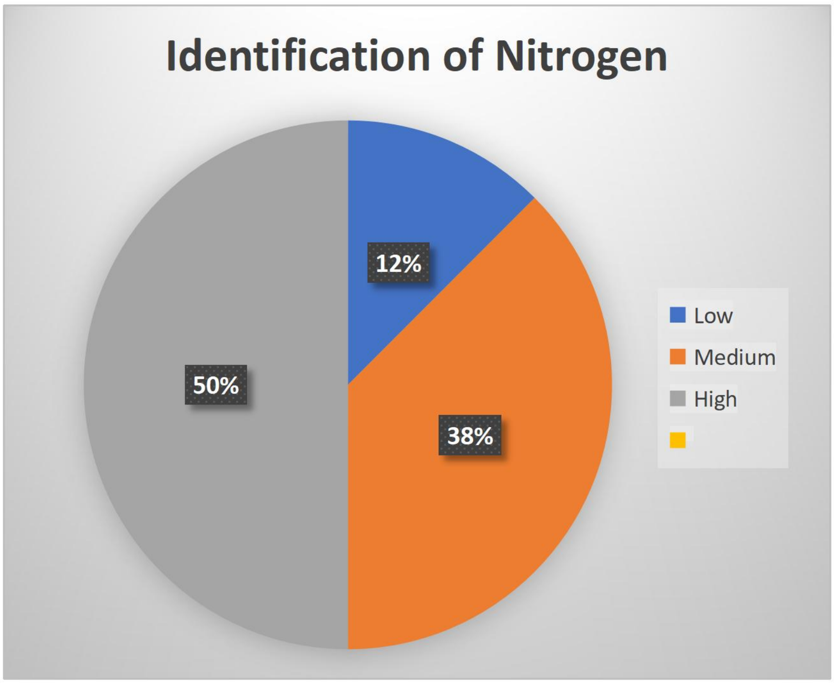


- **Graph for data representation**

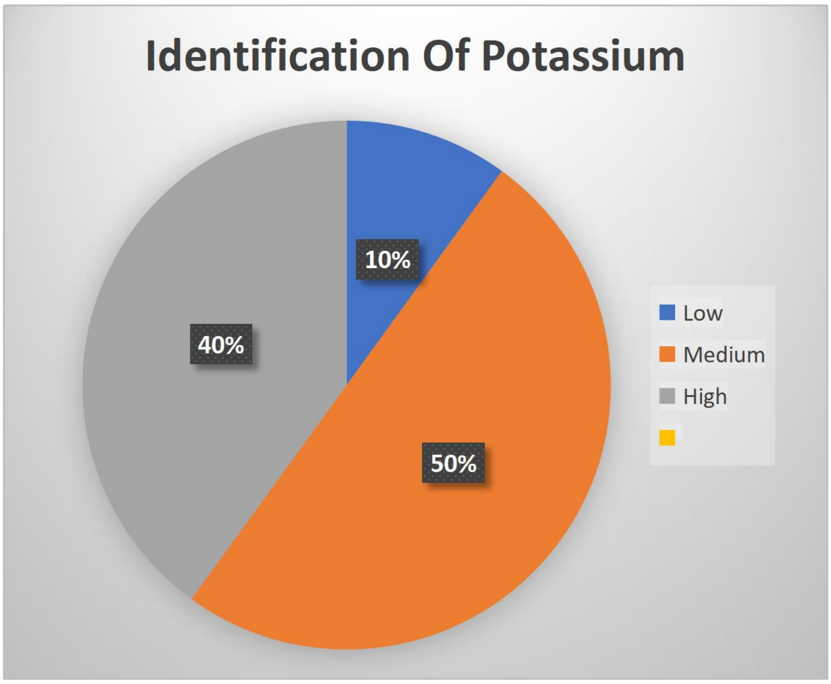


- **Performance evaluation:**

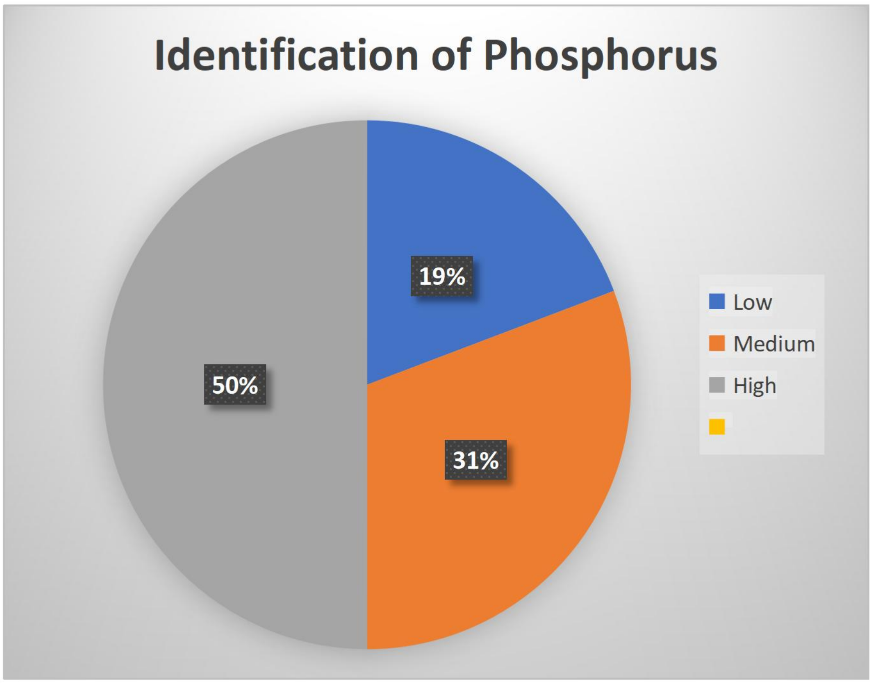
Nitrogen :



Potassium:



Sodium:



Future scope:

- Integration with AI/ ML for predication
- Mobile app with recommendations
- Automated irrigation/ fertilization system
- Cloud data storage and analytics

Conclusion:

The NPK monitoring system provides real-time soil analysis and is a modern and effective solution for improving agricultural productivity and soil health management. The system aids in continuous monitoring of vital soil nutrients such as nitrogen (N), phosphorus (P) and potassium (K), which are crucial for the proper growth of plants and crop yield. Conventional soil testing methods are slow, costly, and challenging to implement on a regular basis over large areas on the farm. The proposed system aims to overcome these limitations through the use of IoT technology, sensors and microcontrollers for real-time monitoring and analysis. The system developed uses an NPK sensor connected to an Arduino Nano microcontroller for accurate collection of soil nutrient data. Farmers can remotely monitor soil conditions using mobile applications or cloud platforms which process and display the collected information. The integration of wireless communication technologies like Wi-Fi, GSM, IoT platforms makes the system more efficient and user-friendly. Farmers can quickly detect nutrient deficiencies and initiate prompt remedial measures, thereby minimizing the use of excess fertilizers and enhancing crop quality.

The experimental results indicated that the system operates with reliable and acceptable accuracy when compared with laboratory testing methods. The data analysis, prediction and fertilizer recommendation system is further improved by using AI and Machine Learning technique. The graphical representation of data and automatic alerts also help the farmers to take better decisions on agriculture. The system helps in precision agriculture by cutting down on fertilizer waste, reducing pollution to the environment and keeping the soil fertile for future generations. It is compact, low cost, portable and suitable for small and large scale farm applications. In the future, the system can be made better by incorporating advanced AI-based prediction models, automated irrigation systems and cloud-based analytics for smarter farming solutions. In conclusion, the real-time NPK monitoring system offers a new perspective towards sustainable agriculture and efficient soil management, helping farmers achieve higher productivity with better resource utilization.

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