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Plant and soil nutrient monitoring in precision agriculture: A review of IoT and machine learning

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Abstract- The paper provides a comprehensive review of modern technologies in Agriculture —particularly the Internet of Things (IoT), Artificial Intelligence (AI), and Machine Learning (ML) and how they are transforming the agricultural sector. It also focuses on the issues faced in the current traditional farming methods and technologies like climate variations, reduced soil fertility, water scarcity, and the lack of real-time data for decision-making. The review explains the use of technology like IoT devices such as Sensors for soil, drones, remote-sensing satellites, and weather stations, which are used for continuous monitoring and data collection for soil nutrients, pH, moisture, temperature, and crop health. When the data is processed through ML algorithms like Random Forest, SVM, XGBoost, and ANN, it enables accurate crop prediction, fertilizer recommendation, yield forecasting, disease detection, and soil quality assessment, etc. The paper also intends to provide brief about the important parameters of soil like NPK, Texture, PH level, Moisture level, CEC, organic carbon and micronutrients. It also explains previous research which mentioned use of IoT based sensing, spectroscopy, image processing, etc. how they are useful to monitor these indicators. By a detailed literature review, this paper shows intends to explain how multisensory data fusion and ML-driven decision systems can result in providing faster cheaper and accurate analysis for precision agriculture in comparison to conventional laboratory methods.

Keywords: Agriculture, Internet of things, Machine learning, CEC, NPK, Soil Texture.

I. INTRODUCTION

Agriculture

AGRICULTURE means cultivation of land. It comprises activities like growing pulses, food grains, sugarcane, cotton, jute, oilseeds, etc. It also includes horticulture, animal husbandry, forestry, dairy and poultry farming. In India agriculture has been considered as one of the primary sectors because 70% of area in India are of villages and only 30% are of cities. And in villages almost all people adopt farming or agriculture as its full-time profession [1]. Due to this reason agriculture is considered as backbone of the country. It plays vital role in development of the rural area. It also provides large number of jobs for agricultural as well as non-agricultural people. It provides opportunities for agricultural people in form of jobs of farm workers, farm managers, agricultural officers, horticulturists, organic farming specialists, dairy farmers etc. And it also comes with the job for non-agricultural people such as food technologists, food scientists, food and fertilizer manufacturers, agricultural engineers, agricultural loan officers etc. Agriculture fulfils food as well as non-food need. It gives food like rice along with this it also encourages non-food business like cotton, sugarcane, dairy products etc. [2]. Hence Agriculture is considered as largest employment providing sector in India. Agriculture has become helpful in other industries as raw materials required for that industry become available from agriculture itself.

Internet Of Things (IoT)

IoT stands for the Internet of Things. It refers to a network of interconnected devices that communicate and exchange data with each other over the internet. These devices can range from everyday objects like household appliances, thermostats, and wearable fitness trackers to industrial machinery and sensors used in smart cities. The concept behind IoT is to enable these devices to collect and share data, allowing for automation, remote monitoring, and control of various systems and processes.

Machine Learning (ML)

ML stands for machine learning. It is one of the types of Artificial Intelligence (AI). It teaches computers to learn from data. It is also useful in decision making, future prediction with the help of past data.

IoT for Agriculture

Though agriculture plays an important role in India and it is also important for Indian economy, there is not much earning from agriculture due to decrease in the cultivation land, lower yield from farming lands, poor infrastructure for storage and market etc. [1]. Along with this the technologies which are used in agriculture are old and obvious in comparison with other developed countries. Hence this calls for advancements for technologies available for farming and agriculture which will help to increase yields for cultivable lands. Information technology (IT) is essential for the advancement of farming technologies. It helps to collect real-time data such as temperature data, fertility data, track the record and to take decisions based on data [3][4]. IOT plays a vital role in the evolution of agriculture. Figure 1 provided the information about how IoT helps in revamping agriculture.

Figure 1: Different possibilities for smart farming technology. [5]

Different devices available in IoT such as Drones, remote sensors, and satellites gather 24/7 data on weather patterns in and around the fields, providing farmers with vital information on temperature, rainfall, soil, humidity, etc. [4][5] helps in revamping the agriculture. Figure 2 shows numerous technical solutions using IoT devices --- such as yuktix green sense device, Agrela PheNode Device, Fasal to device etc. All these devices can integrate IoT with other technologies like AI, ML, Cloud etc.

Figure 2: Technical solutions using IoT devices for smart agriculture. [6]

Agrela PheNode Device: This device is used for crop monitoring, precision farming, and research applications. It is designed to collect real-time data from the field, helping farmers and researchers make informed decisions about crop health, environmental conditions, and growth patterns.

Yuktix green sense device: It is used for real-time monitoring of soil, weather, and environmental conditions. The device also collects weather data such as humidity, wind speed, and rainfall. With AI-powered pest and disease prediction, it minimizes crop losses and reduces unnecessary pesticide use. Farmers can remotely access real-time data through mobile apps, making precision farming more efficient, sustainable, and data driven.

Fasal Device: This device provides real-time monitoring of soil, weather, and crop conditions to help farmers make data-driven decisions. It tracks soil moisture, temperature, humidity, and disease risks, enabling smart irrigation management and reducing water wastage.

II. MACHINE LEARNING FOR AGRICULTURE

Agriculture is considered as important pillar of country as it fulfills all need of human beings. It also plays an important role for employment of country as well [7]. Still farming sector faces many challenges and problems due to uncertain climate conditions and uncertain market trends [8]. Farmers may have insufficient knowledge and information regarding latest technologies, soil type, weed type, suitable weather for any seed, improper use of pesticides, improper supply of water etc., which can also lead to losses in the production. These losses lead to the need for technology. Integration of machine learning with IoT devices helps farmers to make proper decision based on the data. ML helps farmers in crop management like weed detection, dieses detection, yield prediction, breeding selection, water management like irrigation, detecting leaks, soil management and livestock management [7]. By integrating ML with IoT and Application various data like ph level, NPK level, weather condition, water level etc. are collected from different sensors and by using that data particular decision has been taken. Based on that decision various actions have been taken or that decision might sent into application. Few examples of technologies used in smart farming which are using ML are depicted in figure 3.

Figure 3: Technologies of smart farming using ML [9]

Irrigation Drone: This device consists of motors, electronic speed controllers (ESC), Flight controller, radio receiver, battery, GPS, accelerometers, barometer, camera etc. This helps agriculture in soil and field analysis, planting, crop spraying, crop monitoring [10]. Additionally, it also helps in checking growing of the crop, calculation of vegetable index and in many more similar functionalities [10]. Drones equipped with sensors and cameras detect current data of water requirement in the crop and spray liquid or water to the plant as required [10].

Autonomous Tractor: This device is generally used to reduce risk on the labour and provide more safety to the labour which is addressed to preserve human operator health. This helps with different tasks like planting, harvesting high precision and tilling [11]. With this 24/7 operation become possible and reduced labour and material cost [11]. This is wireless vehicle which includes GPS, Sensors etc.

III. LITERATURE REVIEW

This section evaluates scholarly materials, such as publications, journal articles, and research papers, to give an overview of previous efforts on the subject.
According to article [12], author focuses on modernization in agriculture by using IoT, AI, ML, robotics etc. To make this work it requires data which are collected by STSDM (Spacio-Temporal Semantic Data Management) system. In this paper author discusses the need of technology in agriculture. Need for data collection and requirement for atomization in agriculture leads to the need of technology. This whole thing is explained with the help of stages of evaluation of agriculture by denoting agriculture 1.0, agriculture 2.0, agriculture 3.0, agriculture 4.0 and agriculture 5.0. In Agriculture 1.0 only handmade machines are used for farming. Agriculture 2.0 is considered as beginning of agricultural mechanization - machines, such as the animal-drawn plow and the first combine harvesters. In agriculture 3.0 massive application of technology - use of synthetic fertilizers, pesticides, advanced agricultural machinery, and intensive farming techniques are used. In Agriculture 4.0 application of information and communication technologies (ICT) in agriculture - use of sensors, drones, geographic information systems (GIS), the Internet of Things (IoT), and data analytics.

Along with various technologies, different nutrients such as NPK (Nitrogen, Phosphorus, Potassium), Soil pH, Soil moisture, zinc (zn), Boron(B), Iron(Fe), Manganese(Mn), Soil Texture, CEC(Cation Exchange Capacity), soil carbon which are useful and important for precision farming. Detailed review based on the nutrients is explained below.

Literature Review on pH Level and NPK Level

pH level refers to the measure of how acidic or alkaline the soil is, on a scale from 0 to 14. A pH value of 7 is considered neutral, values below 7 indicate acidity, and values above 7 indicate alkalinity. The pH level of soil affects nutrient availability and overall plant health, as different crops require specific pH ranges to thrive.

NPK level denotes the concentration of three essential macronutrients in the soil: Nitrogen (N), Phosphorus (P), and Potassium (K). These nutrients are critical for plant growth—nitrogen promotes leafy growth, phosphorus supports root and flower development, and potassium enhances overall plant vigor and disease resistance. Monitoring and adjusting NPK levels help ensure optimal crop yield and soil fertility.

Research in article [13] examines the selection of appropriate land for crop cultivation, as planting in unsuitable regions results in diminished output. In order to determine which crop is appropriate for a certain region and environment, the author uses information on soil nutrients, such as pH and NPK levels, as well as climate variables, such as temperature, rainfall, and humidity. To anticipate ideal crops for maximum productivity, the author employs a few prediction algorithms, including support vector machines (SVM), random forests (RF), eXtreme gradient boosting (XGBoost), K-Nearest Neighbors (KNN), and decision trees (DT), based on data gathered from the Kaggle repository. The XGBoost method yields the most accurate results out of all of these machine learning techniques.

[14] In order to improve soil quality and crop yield, soil micro- and macronutrients are analyzed. Various nutrients, including magnesium, boron, zinc, copper, Sulphur, nitrogen, potassium, and pH level, were extracted from the soil to assess its quality. Crop recommendations in this study are based on the values of a few variables, including temperature, humidity, rainfall, and the soil's pH and NPK levels. Then, nutrients are recommended to enhance soil quality with the aid of an extreme learning machine (ELM) of machine learning requirements.

[15] The suggested system uses a variety of sensors to continuously measure the soil's pH, NPK, temperature, moisture, and other parameters. The data is then saved on the cloud. To determine which fertilizer type is best for a certain crop at a given temperature, a machine learning algorithm is now applied to the data. Several machine learning methods, including Logistic Regression, SVM Classification, Random Forest Classifier, and XGB Classifier, are used to select the best fertilizer. Based on crop type, soil conditions, and moisture content, these algorithms forecast how much fertilizer will be needed.

Based on the values of N, P, K, temperature, humidity, light various functionalities and decision has to be taken [16]. Temperature sensors, Humidity sensors, Light sensors, Water Hardness Sensors are used to collect data related to this. And based on this data decision has to be taken about turning off or on the water pump. Along Propose to develop architecture where machine learning algorithm will autonomously select crops, irrigate, and recommend fertilizers. Post selection and decision making, system will improve irrigation through selective methods and crop rotation intelligence to increase the crop yield using the limited sources and farm lands.

Soil Testing is done on regular intervals to derive Nitrogen (N) Potassium (P) and Phosphorous(K) values. The system considering these values, expected rainfall and humidity / moisture level and with help of the AI-ML algorithm to decide that which crop will be beneficial for farmer. After selection of the crop and initial seeding completion, the IoTs and AI ML operates watering or irrigation system and suggests the fertilizer selection and application cycles, pesticides application cycles using subsequent soil testing data, moisture levels, growth of plants and weather conditions.

This paper presents a model that includes android-based fertilizer recommendation decision support system that assist NPK fertilizer and pH level which help farmer to apply right fertilizer at right time [17]. All data such as NPK level, pH level, soil type, crop details irrigation system are collected and using fuzzy logic particular decision has to be taken by model.

Literature Review on pH Level and NPK Level

Soil texture refers to the relative proportion of different-sized mineral particles in soil, specifically sand, silt, and clay. The combination of these particles determines the soil's physical characteristics, such as its ability to retain water, support plant growth, and promote nutrient availability. Soil texture influences how easily root can penetrate the soil, how well nutrients are held, and how water moves through the ground.

[18] In this paper author focus on estimation of soil nutrients such as Nitrogen, Phosphorus, Magnesium, Ammonium, Clay, Silt and soil texture using open- source remote sensing imagery and machine learning. Images of the soil has been collected through open-source imagery and with the help of DOS1 atmospheric correction atmospheric noise has been removed. These corrected data and raw data have been compared and based on the machine learning algorithm such as Gradient Boosting (GB), Extreme Gradient Boosting (XGB), Random Forest Regression (RFR) efficiency of nutrients and texture has been examined. The objective of this paper is to develop cost-effective device rather use of expensive UAV or lab-based soil testing.

[19] As crop yield prediction and maintenance through the heterogeneous data from sensors, satellite and textual report is challenging, author in this paper focus on developing device using multisensory data fusion, machine learning and text classification for easy decision-making regarding crop. Various data has been collected such as texture, moisture, NPK, pH, temperature, rainfall, humidity, multispectral satellite imagery. Along with these data textual agriculture reports are also pre-processed through NLP techniques. With the help of these data and few machine learning algorithm such as Random Forest (RF), Support Vector Machines (SVM), Gradient Boosting (GBM), and Neural Networks (ANN) decision regarding prediction of crop yield and soil health has been taken.

The main aim of this paper is to develop low-cost model for texture classification, soil monitoring which helps in precision agriculture [22]. Rather using laboratory testing, author collected RGB images of soil using standard camera. These images are processed through image processing and then based on that data machine learning algorithm has been applied for checking and monitoring soil texture.

Literature Review on CEC

[26] In this paper author focus prediction and estimation of CEC in arid region. As lab testing of CEC is slow and expensive, author develop fast, low-cost and non-destructive method for CEC prediction. Various methods and technologies like Visible–Near Infrared (Vis–NIR) spectroscopy, spectral transformations, chemometric techniques, and Partial Least Squares Regression (PLSR) combined with Ordinary Kriging (OK) are used for developing model.

104 samples were collected and tested using different prediction model but author found spatial map using ordinary kriging, the best method for prediction. For sample collection author target hot and dry regions and measure soil texture, pH, EC and CEC. Based on these all data estimation and prediction of CEC for that particular land has been done.

[27] The main purpose of this research is to predict CEC and pH for sugarcane soils. In this paper author uses Visible–Near Infrared (Vis–NIR) spectroscopy combined with machine learning models for accurate prediction of soil chemical properties instantly. Researchers build spectral libraries for soil data and send that data to ML models like cubits, Random Forest, PLSR and SVM to predict soil properties. In this paper author test two approaches- Depth specific models and Multi-depth model.

[28] In this paper for CEC prediction authors focus on pH%, percentage of clay and Organic carbon (OC). According to author Organic Carbon is

the strongest and most reliable predictor of CEC. They believes that if we combined pH, clay and OC all three together for prediction, it gives highest accuracy in result.

Contribution

Table -1: Objectives and technology used for achieving that objective

Ref No	Objective	Technology used
[12]	Focus on modernization of agriculture	AI, IoT, Robotics
[15]	To develop model which helps to decide fertilizer type based on temperature.	ML
[16]	To develop model which helps farmers to select suitable crop based on data.	AI-ML, IoT
[17]	To develop cost-effective fertilizer recommendation model	Fuzzy-logic
[18]	To develop cost-effective way of estimating soil-nutrients and textures.	ML, Remote sensing
[19]	To develop device for crop yield prediction and health monitoring	ML, IoT, Big data, Blockchain
[20]	To develop a model which helps in soil analysis and classification.	CJOA(Combined Joint Operation Area) for Optimization, ML for classification, Image Processing
[21]	Focus on how technologies help in food security, soil monitoring, crop health tracking.	IoT, AI, drones, big data, block chain
[22]	To develop low-cost, non-invasive, image-based method for texture classification	Image Processing, Classification model of ML
[25]	To focus on how AI+IoT improves crop yield.	AI+IoT, ML

Table -2: Types of data collected for measurement, prediction and decision making

Ref No	PH Level	NPK Level	Soil Nutrients	Soil Texture	Soil Moisture	nperature	ainfall	umidity
[13]	Y	Y				Y	Y	Y
[14]	Y	Y	Y			Y	Y	Y
[15]	Y	Y			Y	Y		
[16]		Y						
[17]	Y	Y						
[18]			Y	Y				
[22]				Y				
[23]	Y	Y	Y					
[24]					Y	Y		Y
[25]	Y	Y			Y	Y		

Table -3: Models with accuracy percentage

Ref No	Model Name	Accuracy %
[19]	Gradient Boosting,ANN	20-25 % accuracy in prediction
[25]	DNN + CJOA	>95% accuracy in soil classification

IV. CONCLUSION

The research through the paper concludes that use of IoT and Lachine Learning (ML) is essential to revolutionize agriculture to address the current challenges like low productivity, sustainability and lack of analysis for decision making in selection of right crops. that IoT and ML-based smart farming systems are essential to address the growing challenges in agriculture and to improve productivity, sustainability, and decision-making. Use of IOTs for real-time monitoring of soil health, weather conditions, crop growth, etc. helps to reduce fertilizer misuse, optimize irrigation, and enhance crop yields. The review explains the importance of studying soil nutrients and properties like PH level, NPK level, organic carbon, moisture level, micronutrients, etc., which is essential to determine the crop selection, sensors to be used and also offers cost effective alternatives to traditional solutions and testing.

Consistent use of technologies and Machine learning models reduces uncertainty inherited in manual decision making and also provides accurate and reliable predictions and recommendations in number of scenarios of agricultural stages. By shifting to IoT, AI, cloud computing, remote sensing, etc., future of the agricultural sector can be reshaped, leading to automated, data driven and sustainable farming systems which can bring another stage of green revolution using the current sources only. Overall, the paper emphasize on use of integrating digital technologies into agriculture, as the same is not just beneficial but also necessary to achieve precision farming and meet the future demands of produces to achieve overall food security.

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