

RESEARCH ARTICLE

## IOT-BASED SMART FARMING SYSTEM FOR NON-DESTRUCTIVE REAL-TIME SOIL MONITORING OF SORGHUM CROP

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ABSTRACT

As a solution to challenges associated with global agricultural productivity, Sustainable Development Goals (SDGs) focus on smart agricultural practices in order to support the global population of 9.7 billion people projected to exist in 2050. This study presents an IoT-based smart system to monitor soil nutrients and prescribe fertilizers on real time basis, which measures eight major soil parameters namely moisture, salinity, temperature, electrical conductivity (EC), pH, nitrogen, phosphorus, and potassium. The real-time monitoring capability of the system was confirmed by field experiments conducted on the vegetative stage of the sorghum crops at Rahim Yar Khan, in Pakistan. 10 samples of the soil were taken using the proposed IoT device at the depth of 0-6 inches in different locations within the sorghum field. The system was proved to be quicker than the manual soil testing technique in measurements, therefore providing a more precise, real-time observation of soil fertility, decreasing human error, and providing a timely and data-driven decision-making to optimize crop management.

KEYWORDS

soil surveillance, nutrient management, Internet of Things, smart agriculture, precision farming, sustainability, crop management, sorghum.

### 1. INTRODUCTION

Understanding soil is indeed crucial for achieving success in sustainable agriculture, as it directly influences crop productivity, soil health, and resource management (Lemaire et al., 2021). The integration of soil science with modern technologies, such as machine learning and IoT, enhances the ability to manage soil effectively, thereby promoting sustainable practices (ostolache et al., 2023). In developing nations like Pakistan, agriculture is one of the main occupations that are necessary for human survival.

The economy of Pakistan heavily relies on agriculture, making it a vital sector for national prosperity. The success of agriculture, in turn, depends on the health of the soil and the knowledge farmers possess about crops and soil management. A healthy soil ensures sustainable crop production, while smart farmers can make take better decisions of planting, irrigation, and fertilization. Soil acts as a reservoir for nutrients and moisture, essential for crop growth and microbial activity, which are vital for maintaining soil health. Together, these factors are crucial for maintaining agricultural productivity and, by extension, the economic stability of the country (Rogers et al., 2025; Verma et 2025; Biswas et al., 2025; Clayton, E. S., 1941).

Conventional agricultural practices are largely dependent on manual observation and making of decisions based on experiences which in most cases are inefficient and may result in over-irrigation, poor application of fertilizers and low yield of crops (Penuelas et al., 2023). The sorghum is a significant cereal crop that has been planted in most areas because it is able to withstand droughts and extreme weather conditions (Beillouin et

al., 2020). It is popular in food, livestock food, and biofuel production (Alaswad et al., 2015). Although it is resilient, the yield of sorghum has a very high dependence on soil health, nutrient availability and the environment (Panda et al., 2024). Regular observation of soil parameters has the potential to enhance the productivity of crops and resource management to a large extent (Yang, 2006). The Internet of Things (IoT) has become an influential technology of smart agriculture (Ray, 2017). IoT facilitates the incorporation of sensors, communication systems and cloud computing technologies to track agricultural fields on-site (Siam et al., 2021).

IoT technologies also allow farmers to monitor the soil remotely, automate irrigation systems, and base their decisions on data about crop management (Ramani et al., 2025). This study suggests a smart of agriculture system with IoT to monitor the soil parameter in sorghum fields and give automatic recommendations on how to manage irrigation and fertilizers (Elliott et al., 2017). Recently, there have been many sensor-based crop management monitoring systems brought on by the advancements in precision agriculture (Sharma, 2023). WSNs have extensively been used in environmental surveillance like moisture, temperature, and humidity of the soil (Rogers et al., 2025). Various researchers have created IoT-based systems that can be used to collect data and monitor farming fields in real-time (Verma et al., 2025).

Farmers can save and process volumes of sensor data on cloud computing platforms, which enhance decision-making (Biswas et al., 2025). Machine learning methods are being used to predict crops, detect diseases and irrigate crops using techniques in agriculture data (Clayton, 1941). Nevertheless, most of the available systems currently only measure few

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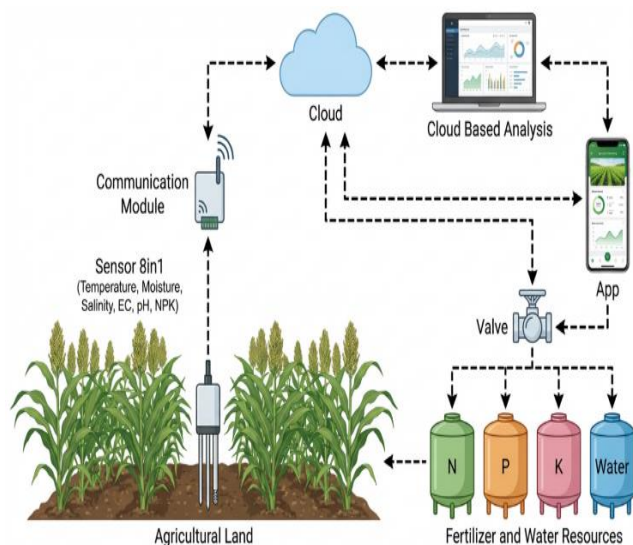
soil parameters and an effective monitoring on soil nutrients has been a very important issue in precision agriculture (Penuelas et al., 2023). The proposed research work addresses these gaps through two methods, that is, incorporation of a multi-parameter soil sensor with IoT cloud-based platform, which would facilitate real-time monitoring of the essential parameters of the sorghum crop soil such as soil temperature, soil moisture, salinity, EC, pH, nitrogen, phosphorus, and potassium.

**2. MATERIALS AND METHODOLOGY**

The proposed IoT-based system methodology and materials are outlined in this section. The system is developed to improve the management of the sorghum crop with the objective of maximizing on the use of fertilizers and irrigation habits.

**2.1 Smart IoT-based system**

The proposed system is a smart agriculture management system as shown in Figure 1, which integrates advanced sensors, IoT communication, and cloud technology to monitor and manage crops effectively. A JXCT Electronic Technology (China) soil sensor of 8 in 1 was placed in the field. It is an instrument that is constantly recording the soil temperature, moisture, salinity, electrical conductivity (EC), pH, and the NPK nutrients (nitrogen, phosphorus, potassium). The 8in1 sensor system transmits data with the use of a communication module to a cloud platform, where it is stored, processed and analyzed. The farmers are then provided with real-time insights and advice through a mobile application. The data can be analyzed by the system to manage irrigation and fertilizer valves which regulate the supply of water and nutrients (N,P,K) supplied by the special tanks. This will guarantee effective utilization of resources and increase the productivity of sorghum.



**Figure 1:** Proposed framework.

It is an IoT-based smart farming system which uses ESP8266 Wi-Fi chip and 8-in-1 soil nutrient sensor. It provides real-time monitoring (Jiosu IoT Cloud) and presents the data in a graphic format and allows to export into

a CSV file. The unit is configured to operate in precision agriculture, and its power is 5-24 V DC with a current consumption of 15mA at 12 V. It can be connected through RS485 and communicated at 9600Bps. Measurements that the sensor is capable of taking include: temperature (-40 -85 o C), soil moisture (0 -100% RH), EC/salinity (0 -10 000 ug/cm), NPK levels (0 -200 mg/kg), and pH (0 -14). The sensor has high resistance to stainless steel probes and epoxy seal.

**2.2 Setup of experiment and testing**

The field research was done at various fields of sorghum growing in Rahim Yar Khan, Pakistan, to measure the soil health and define the possible limitations to the growth of sorghum under the proposed system of IoT-based monitoring. The research examined involved gathering soil samples at various sites on the sorghum fields in the aim of comparing differences in the soils and the availability of the nutrients. Figure 2 shows the working flowchart of proposed system and Figure 3 shows the laboratory and field experimental works which includes sampling of the soil, installation of sensors and installation of the monitoring equipment to collect real time data.



**Figure 2:** Working Flowchart of proposed system



**Figure 3:** Field testing in sorghum crop.

Data on soil temperature, pH, soil moisture, salinity ( $\mu\text{S}/\text{cm}$ ), electrical conductivity (EC,  $\mu\text{S}/\text{cm}$ ), and nutrient levels including nitrogen (N), phosphorus (P), and potassium (K) were collected for each sorghum field sample using the proposed IoT-based monitoring system, as shown in Table 1.

Table 1: Sorghum field sample readings								
Soil Sample	Soil Temperature (°C)	Soil EC ( $\mu\text{S}/\text{cm}$ )	Soil Moisture (%)	Soil Salinity ( $\mu\text{S}/\text{cm}$ )	Soil pH	Nitrogen (mg/kg)	Phosphorus (mg/kg)	Potassium (mg/kg)
Location 1	32.0	1860	58.4	1680	7.80	70	17	102
Location 2	33.5	1825	62.0	1672	7.20	82	16	118
Location 3	31.2	1840	60.5	1690	8.05	100	15	115
Location 4	31.5	1650	64.0	1205	7.25	92	16	110
Location 5	32.3	1250	78.5	1230	8.07	77	15	116
Location 6	32.8	1175	88.0	1200	7.75	97	18	140
Location 7	33.0	1185	91.2	1220	8.00	100	17	125
Location 8	34.2	1235	78.0	1360	7.15	76	18	123
Location 9	33.0	1240	85.0	1280	8.20	80	16	138
Location 10	32.5	1200	79.5	1345	8.10	83	15	120

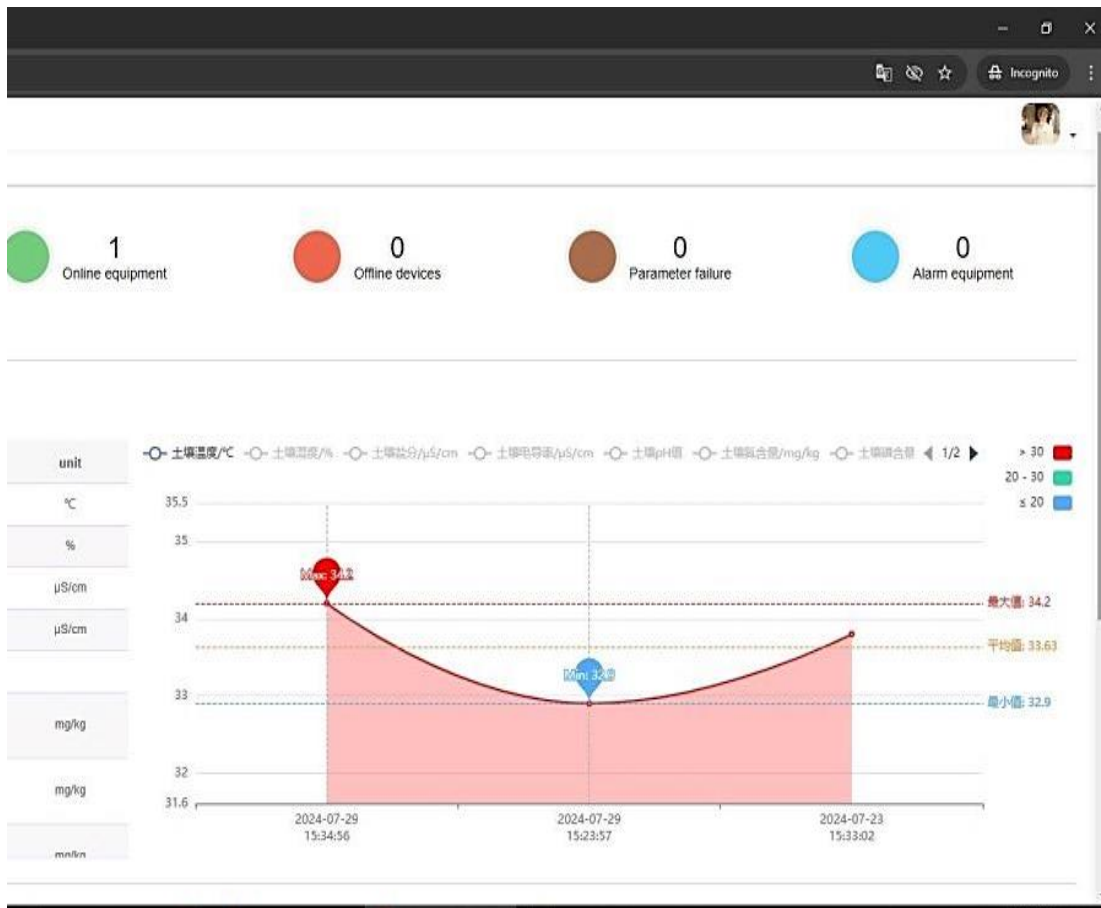


Figure 4: Screenshot of real-time monitoring cloud platform

The outcome of the proposed system is evaluated through web-based cloud platform where the information on sorghum fields is stored as indicated in Figure 4.

2.3 Mobile App

Plantix is an expert mobile App in crops, and it uses AI to diagnose issues

with the health of plants and recommend fertilizers and pest controls. In this research, the app was used to input soil NPK information of the proposed system to develop the specific requirements of fertilizer on the sorghum crops.

The app presented straightforward personalized advice of fertilizer activity based on the soil analysis as presented in Figure 5.

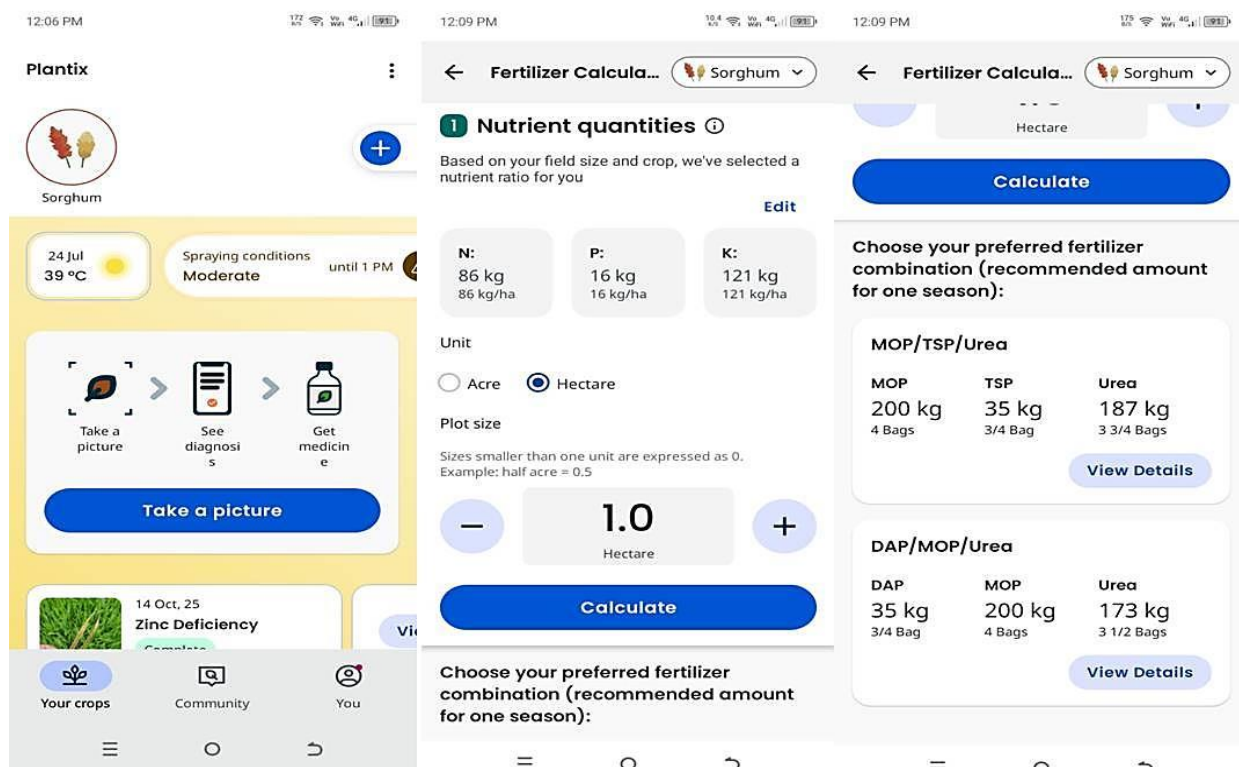


Figure 5: Plantix mobile app.

### 3. DISCUSSION FOR ESSENTIAL REQUIREMENTS

The practical study of sorghum soils in Rahim Yar Khan, Pakistan, was very insightful on the necessary soil parameters to have best crop growth. The activators of the sampling sites were reported to be between 31.2 -33.5 o C which is conducive to sorghum indicating that it is tolerant to a moderate temperature level.

The content of moisture in the soil was also 58.4% to 91.2 highlighting the adaptability of the crop to semi-arid conditions. The more moist samples (Sample 6 and Sample 7) represent regions where more irrigation applied successfully, whereas the low moisture content of Sample 1 implies that there are drier areas and which need to be considered in terms of water management.

The values of electrical conductivity (EC) were between 1175 and 1860 mS/cm, and salinity was between 1200 and 1690 mS/cm, which are non-saline to slightly saline soils, conducive to sorghum. The pH of the soil was

found to be between 7.15 and 8.20 a neutral and a moderately alkaline profile with a good nutrient uptake. Analysis of the nutrients showed that the levels of nitrogen, phosphorus, and potassium are 70-100 mg/kg, 15-18 mg/kg and 115-140 mg/kg respectively.

It is worth noting that Sample 3 and Sample 7 had greater nitrogen content, which could help to stimulate better growth in vegetation, whereas the phosphorus levels were comparatively consistent over samples, and sufficient root and grain growth took place. Sample 6 and Sample 9 contained the highest level of potassium, which indicated that the areas had high nutrient availability favoring the development of better stress tolerance and grain quality.

Generally, the soil in Rahim Yar Khan, Pakistan is favorable to the growth of sorghum though irrigation and nutrient supplementation should be managed properly to maximize production and performance of crops in the field. The summary of comparison with existing iot based smart agriculture management systems is given below in table 3.

**Table 2: Comparison with existing IoT based Smart Agriculture Management Systems**

Study / System	Parameters Monitored	Technology Used	Limitations	Remarks
Smart Farming System	Moisture, Temperature	Raspberry Pi, basic sensors	Limited parameters, no nutrients	(Kumar et al., 2025).
Smart Fertilizer	NPK only	Arduino-based NPK sensor	No environmental parameters	(Kabilan et al., 2024).
Fertilizer Intimation System	NPK	IoT + fuzzy logic	No real-time multi-parameter sensing	(Pallavi and Usha, 2022)
Smart Irrigation System	Moisture, Temperature, Humidity	IoT + Cloud	No NPK monitoring	(Ndunagu et al., 2022).
Proposed 8-in-1 IoT System	Temperature, Moisture, Salinity, EC, pH, NPK	ESP8266 + Cloud + Mobile App	—	Comprehensive real-time monitoring with automation

### 4. CONCLUSION

The proposed smart farming system IoT technology was used to monitor the important soil parameters of sorghum crop, including temperature, moisture, salinity, EC, pH, and NPK in the vegetative growth phase of sorghum in Rahim Yar Khan, Pakistan. Field outcomes indicated that although the general soil conditions were favorable, there were specific places where moisture and nutrient control had to be done carefully in order to optimize the yield.

The system facilitated timely interventions and efficient utilization of resources using real-time information provided by the cloud computing and an AI-based mobile application. This research proves that the use of the IoT-enabled monitoring can promote the high-yield and sustainable production of sorghum and promote the growth of the precision agriculture.

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