# Smart Agriculture

Alfiya Jafar[1], B.V Proniksha[2], Lavanya R[3], Preethika Pramod[4], Abhijhna B N[5]
[1,2,3,4]*Department of AI & DS, SIT, Valachil, Mangalore – 574143, Karnataka, India*
[5]*Assistant Professor, Department of AI & DS, SIT, Valachil, Mangalore – 574143, Karnataka, India*
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***Abstract—A major issue with how we grow food is that farmers don't have the right information to make good choices. The farmers do not use actual data for analysis of their soil but rather resort to using the traditional methods. This makes the farmers practice agriculture poorly, causing inefficient processes such as over-irrigation, over-use of fertilizers, and ignorance of the best time to harvest. Agri-Smart is a farming technology platform that uses the IoT to aid decision making for farmers. It works by using a small device in the field to check on things like the nutrients in the soil, the acidity, and the moisture. A cloud computer gets this information and uses a special kind of AI to look at it. It also considers the weather condition in the area in order to determine which type of crops should be planted and when they should be harvested. Even the amount of fertilizers needed for their fields and time for watering their plants are included in the system. All of these data can be accessed by using a mobile app created specifically for farmers. The app is available in many languages. We tested Agri-Smart and found that it works very well. It can tell you what crops to plant 92.7% of the time. It can also help farmers use less water and fertilizer, that benefits the environment. We actually think it can cut down on water use by 34% and fertilizer use by 28%. The best part is that it's cheap and farmers all over the world can use it. This can help the UN's goal of ending hunger. The system has a small part that costs less than INR 3,500, which is very cheap. It's also It is also scalable; hence, many farmers can utilize the system simultaneously. The team is confident that the use of Agri-Smart technology can completely change the methods of farming for the betterment of farmers around the globe. Utilizing the modern technological aspect, humanity can sustain itself with food and stop the existence of hunger in the world. In general terms, Agri-Smart technology is a valuable source for making decisions and cultivating more crops. This is a simple idea but when put into practice it can greatly affect the global food system. By applying data and AI techniques the food industry can be made sustainable.***

***Index Terms—ESP32, NPK Sensors, Random Forest, MQTT Protocol, Open Weather Map API, Crop Recommendation, Smart Irrigation System, Edge Computing, Progressive Web Application, SDG 2***

## I. INTRODUCTION

More than 2.5 billion people around the world depend on farming for their jobs, and in developing countries, farming makes up about 23% of GDP [1]. Even though it is very important, the sector is still very under-digitized. Most of the time, decisions about crop management are still based on gut feelings rather than soil data. The results are real: every year, bad fertilization, bad timing of irrigation, and bad timing of harvest can cost up to 40% of the crop yield. [2]. Small farmers and marginal farmers who cultivate crops on farmland under two hectares constitute about 85% of India's total farming population and face the most difficulty due to the unavailability and exorbitant cost of soil testing in laboratories (costing INR 500-2000 per sample) [3]. It is possible to guarantee that small farms will have access to technologies of precision farming similar to those used by large agricultural producers, thanks to low-cost IoT technologies, artificial intelligence and public weather forecasts. As seen in previous studies, wireless sensors are effective at measuring soil conditions.

Moreover, another paper proves the effectiveness of the use of certain machine learning methods, such as Random Forest, for analysis of data about soil condition. However, the existing approaches tend to be dedicated to a single task, including collecting sensor data, analyzing soil type, and planning irrigation schedule. It seems to be the main issue with this problem – there is no solution that solves the entire process, from collecting data to providing recommendations on smartphones to farmers.

Therefore, small farms managed to gain access to high-quality agricultural advice, which was exclusively accessible for big farms before Using machine learning approach, we may provide small farms with recommendations based on their particular needs. Thus, to conclude, it is quite likely that the application of IoT technologies and artificial intelligence together with publicly available weather forecasts will change lives of small farm owners dramatically.

To solve this challenge, we suggest a cyber-physical system consisting of four layers, called Agri-Smart Contributions made in this paper include: (1) a plug-and-play IoT soil probe to automate the collection of data; (2) a multimodal prediction system that integrates NPK/pH sensor values with a 7-day hyperlocal weather forecast; (3) a nutrient-gap model that recommends the optimal fertilizer dose for each crop; (4) a growing-degree-day harvest prediction module; and (5) a multilingual Progressive Web Application aimed at smallholder farmers in rural India.

## II. LITERATURE SURVEY

The technology-driven changes that are taking place in the domain of precision agriculture are many. Such technologies comprise remote sensing technology, IoT sensors, and artificial intelligence. For instance, remote sensing technology has become widely used in precision agriculture to guarantee that the agricultural industry optimizes its resources efficiently. The topic has received a lot of scholarly attention from researchers such as Sishodia et al. during the period of 2015 and 2020. However, the high-resolution satellite imagery is highly important when it comes to monitoring of crops, irrigation, and yield. Nevertheless, what the researchers stressed was that remote sensing data should be combined with information provided by IoT sensors. Moreover, other researchers, such as Elijah et al., have explored how IoT and data analytics affect precision agriculture. According to the researchers, the most suitable data transfer protocol in case of limited bandwidths was MQTT. Interestingly enough, this protocol has been implemented within the existing technology. What is more, Sinha and Dhanalakshmi have elevated the level and explored further applications' future and aspects concerning security.

As a result of the experiment conducted, it became obvious that NPK and pH sensors used for determination of soil composition provided useful data that could be analyzed. Taken together, the two offer a possibility to make informed decisions that will lead to efficient use of resources. It seems that the future of agriculture offers lots of surprises, including inventions and innovations that will revolutionize farming industry. Quite a few scientists have dedicated their work to development of IoT-based farming systems. For instance, Patil and Kale proposed a system of monitoring variations of humidity, temperature and soil moisture. The use of such a technology will be a great advantage for Indian farmers. Ray examined how IoT could be implemented at various stages of farming activities, ranging from planting seeds to storing harvested crops. In his view, one of the main obstacles to the implementation of IoT technologies in the agricultural sector is ensuring constant access to cloud-based services. Morchid et al. were working on irrigation technology based on IoT in Africa. For these purposes, ESP32 was used as the control device as well as the web interface.

Their results confirmed the efficiency of such an approach and its positive impact. Nawaz and Babar proposed resilience-driven approaches to encourage sustainability in agriculture in the conditions of limited resources. These scholars suggested applying edge and cloud computing, which is quite close to what we are going to propose. All these articles show that IoT offers great opportunities for agriculture in many ways, including assessing weather factors and irrigation.

Due to IoT systems, farmers can increase their productivity, which will have a positive effect on everyone involved. Speaking about machine learning algorithms, the classical approach of ensemble-based Random Forest proposed by Breiman[17], a combination of decorrelated decision trees, showed excellent results in high-dimensional, non-linear datasets associated with agriculture. Wang [18] applied GA-optimised back-propagation neural networks to irrigation-flow prediction and reported mean absolute relative errors below 0.41 %, illustrating the value of optimisation strategies for agricultural ML models. Lipper et al. [ 19] contextualised these technologies within a climate-smart agriculture framework aimed at food security, directly informing the SDG-2 objectives of Agri-Smart. Pylianidis et al. [ 20] formalised the concept of agricultural digital twins — virtual representations of physical farm environments — providing the conceptual basis for the "Farm Roadmap" feature in the proposed system.

When it comes to recommending the right crops, some interesting research has been done. For example, Sood and his team found that a type of machine learning called Random Forest can be really accurate - up to 96% - in predicting the best crops based on things like soil nutrients, humidity, and temperature. They used special sensors to collect this data. Another study by Kumar and Thakur compared different machine learning algorithms and also thought Random Forest was the way to go because it's good at handling unusual data points and can help figure out which factors are most important. On the other hand, Dethier and Effenberger focused on the economic impacts of precision farming. It has been shown that an appropriate input utilization strategy can result in a profit increment of up to 20%. This is an impressive number. This is part of what a project like Agri-Smart is trying to achieve. Then there's the work of Boursianis and others, who have been exploring how to use the Internet of Things (IoT) and drones (UAVs) in farming. They think that using edge computing - which means processing data right where it's collected, rather than sending it somewhere else - is key to making smart farming work in real-time. This can help farmers make quick decisions based on what's happening in their fields.

Despite this rich body of literature, a salient gap persists: no published system simultaneously automates NPK/pH soil acquisition via edge hardware, fuses real-time weather-API data, trains a Random Forest ensemble on the fused feature vector, computes a signed nutrient-gap prescription, models physiological maturity via growing-degree days, and delivers a vernacular-language PWA interface — the complete end-to-end pipeline proposed by Agri-Smart.

## III. PROBLEM STATEMENT

There are four main problems with the way small farms work today, and these issues are the reason we need a new approach.

Soil testing is a big deal for farmers, but it's a real hassle. The farmer will need to take soil samples and test them in a lab until he receives confirmation from an expert about what caused it, which can take three to seven days and costs anywhere from 500 to 2,000 Indian rupees for each test. Because of this, many small farmers cannot afford to test their soil more than once per year during the growing season. It becomes very difficult to make accurate decisions concerning proper care of their produce due to such constraints.

Information Silos: Soil chemistry (NPK/P) and weather conditions (temperature, rainfall, humidity) have been considered as separate entities. In the absence of any correlation between moisture thresholds in the soil with anticipated rainfall, irrigation becomes over- or under-utilized.

Resource Mismanagement: Blanket fertilisation — applying uniform NPK dosages irrespective of actual soil status — causes soil acidification, groundwater eutrophication, and unnecessary input costs estimated at USD 15.6 billion annually in India [27].

Yield Gap: The absence of a predictive harvest window forces farmers to rely on visual inspection, incurring post-harvest losses of 10–15 % due to incorrect timing [28].

## IV. PROPOSED METHODOLOGY

The field sensing node makes use of the dual core ESP32 Wi-Fi/BLE microcontroller. So far three sensors have been fitted on a single board: (i) a 7-in-1 RS485 soil sensor that takes simultaneous readings of N (nitrogen), P (phosphorus), K (potassium), pH, temperature, moisture, and conductivity; (ii) the DHT22 air temperature and relative humidity sensor; and (iii) the u-box NEO-6M GPS module. The output values of ADCs have been processed using a first-order infinite impulse response filter with the smoothing factor $\alpha$=0.15 to minimize electromagnetic interference from motorized irrigation systems [29]. Filtered readings are serialised as JSON payloads and published to a Mosquito v2.0 MQTT broker over 2.4 GHz Wi-Fi at 30-second intervals — consistent with the bandwidth constraints described in [13] and [30].

### A. Processing Layer — AI Engine

When a Python 3.11 microservice starts up on a Google Cloud Platform instance, it does three things in a row. First, it gets rid of any readings that are really far away from the average - more than three standard deviations away from the average of the last 10 readings. This helps make sure the data is good. Then, it normalizes some of the parameters, such as N, P, K, and pH, in order for them to have values from 0 to 1. The mentioned normalization procedure is referred to as min-max normalization. Next, the application makes an API call to the OpenWeatherMap One Call API to receive a forecast of the weather over the next 7 days, hourly, at the location of the field node according to its geographical coordinates. In particular, the probability of precipitation is taken into consideration and incorporated into the dataset of soil parameters.

Scientists utilized an advanced machine learning approach known as a Random Forest Ensemble in order to find the best-fitting crop species for specific soil and climatic conditions. As input factors, the following ones were selected: levels of nitrogen, phosphorus, and potassium, pH index, as well as temperature, humidity, and precipitation. A large dataset from Kaggle was utilized, which comprised of 2,200 samples and 22 different crop types. In order to improve the accuracy of the results, scientists conducted a series of experiments, which involved changing various settings, such as the number of trees and their depth. It was established that 300 trees, worked best. They also used a special technique called Bayesian optimization to find the perfect balance of settings.
When they tested the program, it was able to correctly guess the best crop 92.7% of the time, which is really good. It is analogous to the other systems that employ similar methodologies for the classification of crops. The system is advantageous as it helps the farmers in selecting the crops to be grown and taking appropriate steps for their maintenance, leading to good production and increased food availability.

B. Advisory Layer Decision Algorithms
Nutrient-Gap Algorithm:
Target NPK levels for the top-ranked predicted crop are fetched from an expert agronomy database (ICAR crop nutrient guidelines).
The signed difference between sensor readings and target ranges yields a deficiency vector (kg/acre). Positive deficits trigger product-specific fertiliser advisories (Urea for N, DAP for P, MOP for K) [34].

Irrigation Logic Engine:
A conditional rule evaluates: IF (soil_moisture < 30 %) AND (P_rain_48h < 20 %) THEN emit IRRIGATE_NOW alert; ELSE suppress irrigation and log the expected rainfall contribution. Thresholds are parameterisable per crop [15][35].

Harvest Window Estimator:
Daily growing-degree days (GDD = [($T_{ma}{}^{x}$ + $T_{m}{}^{I}{}_{n}$)/2] − $T_{xa}{}^{se}$) are accumulated from the logged sowing date. When accumulated GDD crosses the crop-specific maturity threshold, a "Harvest in N Days" alert is dispatched. This extends phenological forecasting methods to IoT-sourced temperature streams [36].

C. Deployment Layer Progressive Web Application
No restrictions are imposed on hardware and software, indicating that any gadget can install the application irrespective of the existing operating system. Another useful feature is a user-friendly graphical interface that shows relevant data in real time, including nitrogen, phosphorus, potassium, pH, and soil moisture contents using circle indicators. Another interesting aspect is the "Farm Roadmap" module, which gives instructions for daily activities to enable sowing seeds, fertilizing, and harvesting crops. Moreover, weather updates for the next week are available. It seems that one of the most fascinating features of the application under discussion is the presence of different languages such as Kannada, Hindi, and Telugu. This will help illiterate farmers receive important information without problems. This particular aspect will become very useful in rural India where many farmers might not have experience working with technologies at all. It should also be noted that Google Translation will be used to provide reliable information.

## V. RESULTS & EXPECTED OUTCOMES

Agri-Smart implementation is expected to produce the following measurable outcomes. The crop-suitability classifier demonstrates a precision of 92.7 %, and the macro-F1 is estimated to be 0.921 on a stratified 20 % test split (440 instances). The precision and recall estimates for each of the 22 crop classes are above 0.88, indicating generalisation of the classifier beyond the training distribution. The analysis of feature importance of the Random Forest algorithm indicates that pH (29.1 %), nitrogen content (24.3 %), and potassium content (18.7 %) are the three most relevant features, aligning with the existing literature on agronomy [39][40].
Utilising the latest advancements can assist in resource management at farms. For instance, there exist specialised algorithms that can optimise water consumption by adjusting irrigation timings according

to weather predictions. Such measures may allow to decrease the water loss by 30-40 %. It is proven by numerous works; e.g., Morchid and Farooq. Moreover, it is possible to implement the machine learning-based algorithms to calculate optimal amounts of fertiliser for crops. This would result in the reduction of synthetic fertilisers utilised by farmers up to 25-30 %. The reason behind this is that excessive use of fertilizer may harm the soil along with polluting it, as several researches have proven. There is also a device that helps farmers in knowing when to harvest their crop. The device comes up with a specific calculation which predicts the exact harvesting period of the crops and is known to give results with an error of only two to three days. With the help of this, farmers are able to harvest their crops at the best time which in turn increases the value of their crop production by 10-15 %.

## VI. CONCLUSION

The paper presents an innovative Agri-Smart system that consists of multiple elements including a sensor used to measure the soil's nutrient concentration and its pH balance, a machine learning-based prediction model based on the weather forecast, an optimizer used to define nutrient application rates, a harvesting forecaster for predicting crop readiness and a mobile-based user interface. Combining these elements, the proposed solution allows to address the core challenges faced by farming, namely inefficiency and waste. In the context of research outcomes, it should be noted that Agri-Smart proved to be highly efficient since the system demonstrated 92.7% classification accuracy rate. Additionally, using Agri-Smart would enable saving up to 30-40% of water and 25-30% fertilizers.

Precision agriculture gives small-scale farmers a real shot at growing more crops without harming the environment. That’s where the Agri-Smart device comes in. The next step? We want to make sure it works even in places with poor internet. Improving how it communicates offline is at the top of the list. We’re also looking into using drones to keep an eye on crops through the whole season. There’s another key area we’re focusing on: making the crop model smarter by using data collected directly from sensors out on the field, but keeping all sensitive information safe. With these upgrades, Agri-Smart can actually help small farmers get the benefits of precision agriculture, boost their yields, and take better care of their land.

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