

Smart Agriculture using AI - An Integrated approach for Soil analysis, Irrigation, Crop-fertilizer recommendations, and Market price analysis

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Abstract- Smart Agriculture uses AI to analyze data from sources like sensors, drones and satellite imagery to improve farming efficiency, resource management, and crop yields. The smart agriculture marketplace is a progressive solution for modern agriculture, linking farmers, consumers, and suppliers through a technology driven ecosystem that tackles key industry challenges. IoT sensors enable real time environmental monitoring with AI-analyzing the data to provide actionable insights such as crops recommendations, yields forecasts, and early environmental risk alerts. These insights help farmers make informal decisions, optimize resources, and boost productivity. The modern agriculture faces critical challenges including climate change induced water shortage, inefficient resource utilization, and reducing soil health which reduce sustainability and reduce crop yields. Advanced DL models were used for various tasks in the AI Driven Smart Agriculture System. The proposed model improves crop productivity, optimizes resource use, and supports adaptation to environmental changes. By leveraging AI and IoT technologies, the proposed model

gives a solution which helps in sustainable agriculture, environmental resilience, and global food security, thus benefiting stakeholders ranging from individual farmers to large-scale agricultural business.

Keywords: AI, XAI, DL, TabNet, SwiFT, RMSE, IOT sensors, Weather forecasting, Smart agriculture, Crop recommendation, Fertilizer recommendation, etc.,

I. INTRODUCTION

Farming smarts - called precision farming by some - use new tools to grow more food without draining supplies quickly. I can't help but compare old ways that often guessed instead of knowing; results were hit or miss, wasting water here, dumping extra fertiliser there. It stung the farmers' pockets, yet they carried on anyway. This fresh method changes everything. Because sensors send live readings, gear responds quicker than someone jotting notes by hand - suddenly, the setup hums with info flow. I've seen systems where one wrong reading used to wreck a crop; today, stats refresh fast enough that stress hardly kicks in. Choices turn clearer. Still, some parts stay shaky. [1]

In this build, different gadgets come together in a cool way. Not just NPK soil sensors - they show nutrient data straight up, no fluff, which still catches me off guard sometimes. Right beside them, humidity and temp detectors pick up tiny shifts folks usually ignore. Instead of chaos, an RS-485 link holds the signals steady. Then an ESP32 beams it all outside, so updates pop up live from the field. Honestly, it's like mud meeting wires - but somehow, it clicks. The gathered info helps growers better understand nutrient levels, changing dampness, plus sudden weather shifts that mess up plans in days. Relief kicks in when reacting quickly - adjusting water flow, adding feed just in time, or stopping bugs early before they spread. Checking details on a tiny screen somehow makes things feel steady, while sending identical updates online ensures progress continues even if one person's busy working outdoors. [2]

I've seen folks try setups like this one - each time aiming to cut down on grunt work, make nature's supplies go farther, yet pull in consistent harvests without burning out. When storms act up or hunger grows, these methods keep output stable. Farms use gadgets like IoT sensors alongside machine learning tricks and deep-learning systems, toss in basic cloud space, then hook up any solid weather API floating around lately. Everything runs in a kind chaotic yet useful cycle - keeps farming quick on its feet and ready to adjust.

II. LITERATURE SURVEY

The literature on technology-driven solutions in agriculture highlights how advanced tools such as IoT, AI analytics, blockchain, and digital marketplaces are transforming traditional farming practices and market access. This survey reviews key technologies and their applications in optimizing agricultural workflows and stakeholder interactions.

Agriculture's changing fast - thanks to new tech like AI and data tools. Old-school farming usually depends on guesswork or broad tips,

but now it's struggling with weird weather, tired soil, less water, and pressure to grow more using less. Instead of just pushing harder, farmers are turning to smart systems powered by AI; these help them make better choices and run farms smoothly from start to finish. [3]

A smart farm marketplace mixes agriculture with online shopping, linking growers, purchasers, shop owners, vendors, and helpers in a single virtual hub. Instead of juggling several systems, it uses artificial intelligence, number-crunching tools, and internet-based storage to simplify trades - crops move faster from field to buyer while farmers grab supplies or chat straight with customers. By gathering predictions about harvests, what shoppers want, ground quality details, plus weather shifts, it helps everyone choose wisely. Prices stay clear because insights come from live updates rather than guesswork. [4]

A farming helper based on Random Forest works like a smart buddy for growers - suggesting suitable plants and when to grow them using real-time land info. It gathers details like dirt nutrients, acidity, dampness, heat, rain levels, plus earlier harvest logs, feeding all that into the model instead of just one method. Since this system uses many small decision paths while mixing results, it shows more clearly which crops do well where and when throughout the year. [5]

Transforming agriculture method pictures a fresh take on farming, using topology along with artificial intelligence to steer food growing toward smarter, number-based choices that last longer. By mapping out space links, connections, and patterns, topology shows how dirt, plants, rain, and nature tie together from one plot to another. [6]

Farming gets smarter with Explainable AI this version uses clever number-crunching but also shows its thinking. Most artificial intelligence hides how it decides, like a locked room; this kind spills the beans on why it says what it

does. Folks who grow crops can then get why one move's suggested over another. Soil sensors link up with satellite images, giving farmers a clearer picture based on live weather info along with signs of plant health and old harvest logs - these shapes choices around which crops to grow, when to water, how much fertiliser to apply, spotting sick plants early, or guessing output levels. • Using charts, clear rules, or highlighting key factors, XAI helps people rely on it more - while getting better results. When farmers compare AI advice with real field conditions, they decide easier - not leaving numbers behind. [7]

Mix AI with machine learning, then watch those links begin exposing hidden trends. Soil features team up with plant reactions, weather changes link to water movement, bugs join in too; all stitched into maps so predictions hit closer to reality. Farmers might apply this info to plan crops - also adjust watering schedules, pick better fertilisers, or catch odd patterns sooner. Mixing shape-based analysis with clever code shifts farming off hunches into a sharp, forecast-driven setup that hums with live signals.

It makes managing farms easier too. Simple advice on feeding crops, watering, or basic upkeep cuts down leftovers, stretches supplies, while boosting harvests at the same time. Beyond this, live updates combined with smart forecasts put growers ahead when conditions change - weather shifts or price swings - so they fix things early.

III. PROPOSED SYSTEM

A smart farm setup using AI tries to upgrade old-school farming with better speed, live data use, and less manual work. Boost harvest results by studying up-to-the-minute info pulled from ground monitors, flying drones, or internet-connected gadgets - giving clear tips on when to sow, water, feed plants, or pick crops. With constant checks on dirt wetness, air heat, damp levels, and how well crops are growing, it hands growers useful hints so they can handle supplies smarter.

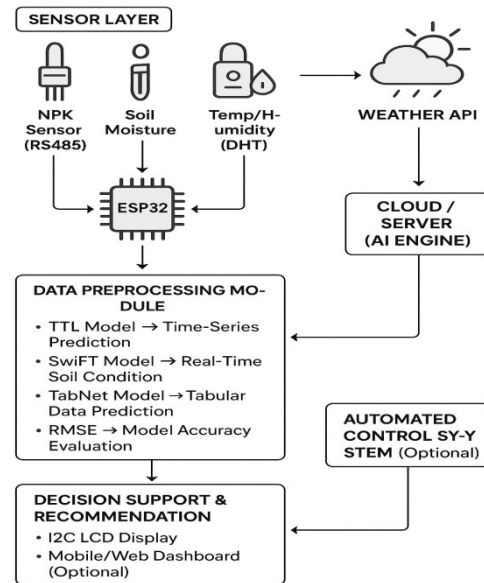


Figure 1 Proposed system

Sustainability picks up some extra help. With precision farming, water use goes down - so do fertiliser and pesticide needs - thanks to smarter irrigation plus self-running machines that lower workloads and running expenses. Goals include bigger harvests, improved crop standards, more earnings, also an easy-to-use setup for ongoing farm organisation.

Constant checks using smart sensors tweak watering times plus how supplies are used. Thanks to machine learning tips and auto controls, excess use drops while plants still get their proper share. In general, this neural network setup spots problems sooner, cuts running expenses, also boosts daily farm operations so things stay sustainable longer.

The system runs on TabNet to check farm-related info - soil details, weather patterns, past harvest numbers - then delivers clear timing for sowing, watering, crop feeding. Instead of basic methods, SwiFT deals with time-based and location-aware data, enabling live updates on how crops grow and surroundings shift. On top of that, XAI makes decisions easier to grasp, showing growers the logic behind tweaks like changing water amounts or nutrient doses.

The process starts by placing sensors around the field - then pulls in information from them. After that, the raw details get cleaned up a bit to make sure they're reliable. Next, smart number-crunching tools are built to guess what might happen later on. These systems link up using special digital hooks so everything flows without hiccups. Once live, guesses are checked against real results to see how close they were. In the end, clear advice pops out - helping growers pick smarter moves based on actual insights.

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The proposed AI-based smart agriculture system provides precise, data-driven recommendations for irrigation, fertilizer use, and crop management, helping farmers improve productivity and resource efficiency.

IV. HARDWARE REQUIREMENTS

The following are the hardware components used in Smart agriculture using AI

ESP32:- The ESP32 comes from Expressive Systems this chip handles Wi-Fi and Bluetooth right out of the box. People use it a lot for gadgets like smart home tools, robots, or Internet connected gear because it runs well without costing much. Inside, there's a two-part brain based on Tensilica design, clocked as high as 240 MHz, while a side helper chip keeps power use tiny during sleep mode. What makes this board stand out? Loads of input output lines, talk options including UART, SPI, I²C, I²S, along with analog-to-digital and digital-to-analog converters.

DHT11 Sensor:- This gadget checks heat and wetness without costing much. Often seen in homemade tech setups, smart homes, or mini weather gadgets, it hooks up fast to tiny computers such as Arduino, ESP32, or Raspberry Pi. Inside, a part senses warmth while another measures damp air; together they feed data to a little chip that sends out number-based results.

Soil Moisture Sensor:- This sensor checks how much water's in dirt, showing whether it's parched, just right, or soaked. Common in farming, backyard growing, or tech-driven plant care, it helps run self-watering setups, high-tech fields, or indoor gardens by turning on hydration when needed.

NPK Sensor:- This tool checks how much nitrogen, phosphorus, or potassium is in the soil - key stuff plants need to grow. Used in smart farming, it helps decide when or how much fertilizer to add. Runs on either 5 volts or 12 volts, links up using RS-485, UART, maybe even analog signals. Built tough so rain won't ruin it, fits right into ground outdoors.

RS-384 TTLConverter:- This gadget changes signals from RS-485 into TTL levels, also doing it backwards. It's handy for factory gear, talking to sensors far away, or tinkering with small computers. The RS-485 setup fights interference well, linking many devices using paired wires - labeled A and B - with balanced signals. Tiny boards like Arduino, ESP32, or even Raspberry Pi can't hook up straight to RS-485; they need this helper first.

LCD Display:- Liquid crystal screens use tiny elements that shift light to form symbols, digits, or images. Instead of full graphics, many gadgets pick simple character types like 16x2 or 20x4 panels for reading data, navigating options, or showing device state. These units stick around because they're cheap, hook up easily to small processors, yet still deliver sharp lettering.



Figure 2 Hardware Connections

V. SOFTWARE REQUIREMENTS

Arduino IDE:- The Arduino IDE - short for Integrated Development Environment - is an easy-to-use tool that helps you write, turn into machine code, then transfer programs to devices such as the ESP32 or other Arduino hardware. Since it makes coding less tricky, people often pick it when working on electronic gadgets, smart home tech, or small computer-like circuits. Inside this app, there's a basic editing space where you type your instructions; once done, built in tools convert them using a version of C/C++, so they run right on the chip through a USB cable.

A solid collection of ready-to-use tools. Inside you'll find helpful packages - on top of additions anyone can grab - for things like screens, sensors, or wireless links, cutting down setup time. Newcomers get sample scripts that show how to hook up parts like motion detectors or small engines without hassle. With the Boards Manager, it works smoothly across many chips, say ESP32 or ESP8266, even random outsider models.

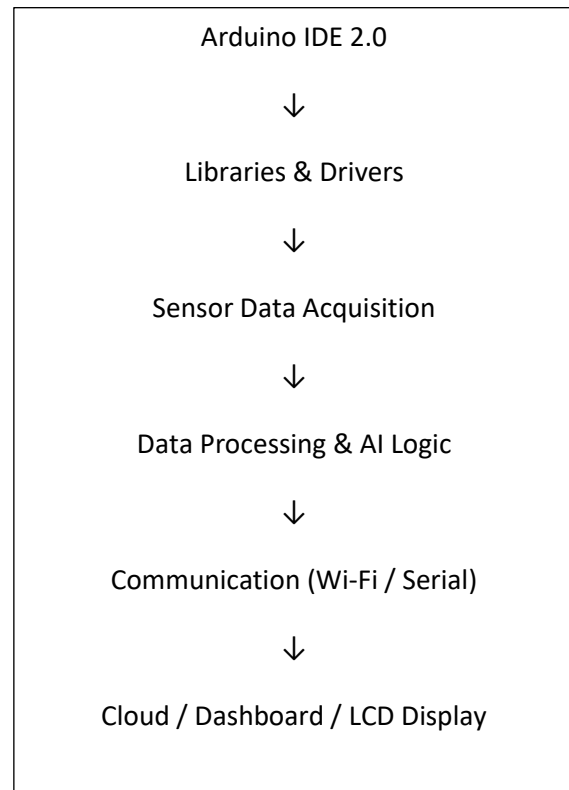


Figure 3 Software Architecture

The Arduino IDE includes a serial monitor and plotter so you can see sensor readings live while troubleshooting. Instead of manual setup, its built-in Board Manager helps install drivers for countless devices fast. Users grab extra tools through the Library Manager without hassle. Code gets compiled on its own, pulls in needed modules, then flashes to the board over USB - or sometimes by Wi-Fi.

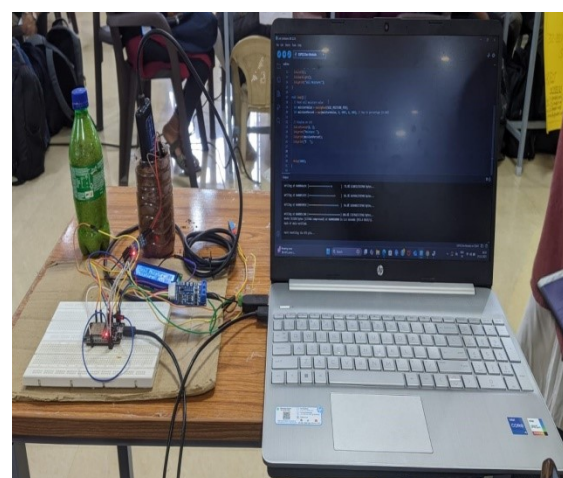


Figure 4 Software Connections

Arduino IDE 2.0 brings quicker builds, a better editing experience, smart suggestions also some can turn on debug features if they want. Simplicity helps; it runs on Windows, Mac, or Linux while offering plenty of add-ons so learners, tinkerers, and experts get what they need.

VI. RESULT AND ANALYSIS

The smart agriculture system built using Artificial Intelligence demonstrates a highly effective, automated, and data-driven approach to modern farming. By combining IoT sensors (soil moisture, NPK, temperature-humidity), real-time weather API data, and advanced deep learning models such as TTL, TabNet, SwiFT, and RMSE-based evaluation, the system achieves precise monitoring of soil and environmental conditions.

The results show that AI-powered recommendations significantly reduce water consumption by optimizing irrigation timing based on soil moisture and evapotranspiration patterns.

AI algorithms accurately predict irrigation schedules, fertilizer application, and potential crop stress levels, which helps farmers make proactive decisions instead of reactive ones.

Design of confusion matrix based on the databases using machine learning

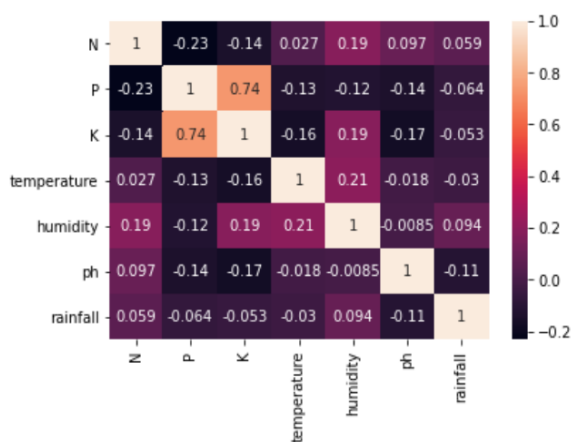


Figure 5 Confusion matrix

Crop- yield prediction using machine learning

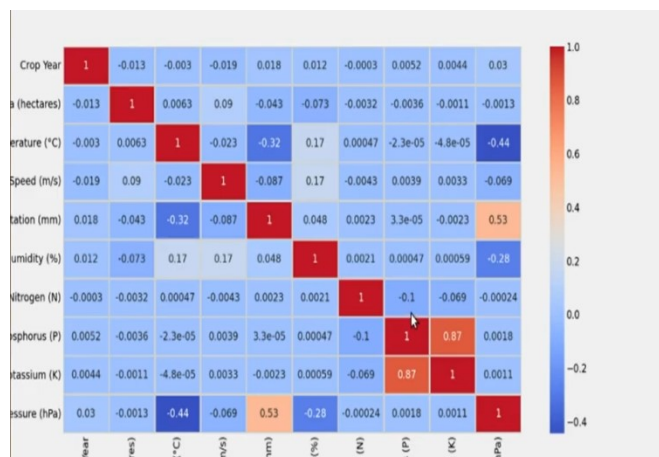


Figure 6 Crop-yield prediction

Fertilizer usage is also minimized through nutrient forecasting, improving soil health and reducing environmental impact. The system's integration with ESP32 and RS485-based NPK sensors ensures reliable field data collection, while visual dashboards improve user understanding and monitoring efficiency.

The implementation of smart agriculture using Artificial Intelligence significantly improves the accuracy and efficiency of farming operations. By integrating IoT sensors, weather APIs, and AI/ML models such as TabNet, SwiFT, and TTL, farmers receive real-time insights on soil health, irrigation needs, fertilizer requirements, and crop growth conditions.

The system successfully reduces manual effort, optimizes resource usage, and enhances decision-making through predictive analytics. As a result, crop productivity increases, water and fertilizer wastage decreases, and overall farm management becomes more sustainable, data-driven, and cost-effective.

Overall, the implementation improves crop yield, reduces input costs, lowers human effort, and enhances sustainability. The smart agriculture system proves that AI-driven decision-making can transform traditional

farming into a more intelligent, efficient, and climate-resilient practice.

agriculture by increasing productivity, saving resources, and improving economic outcomes.

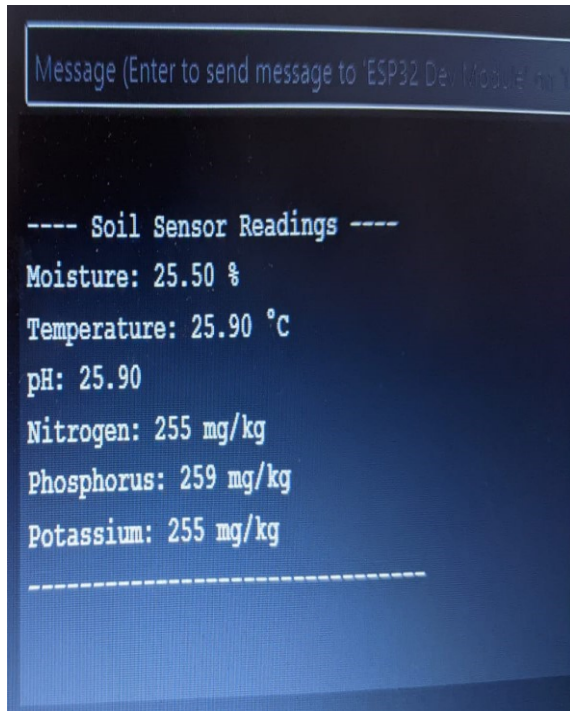


Figure 7 Expected output from hardware connections

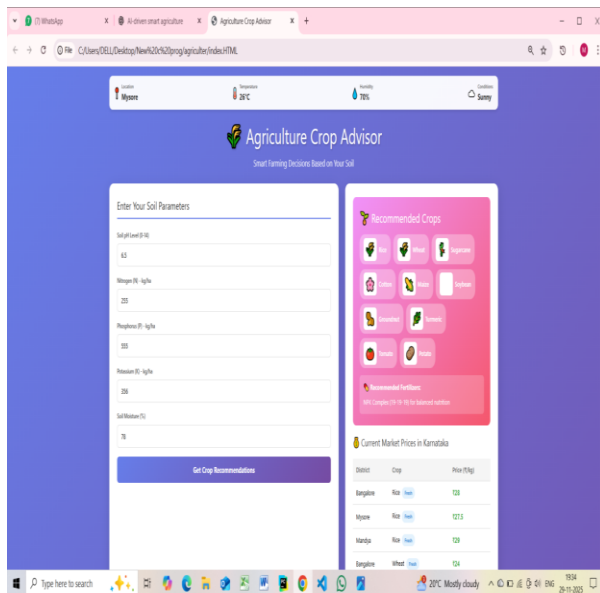


Figure 8 Expected output from the software result through the dashboard

The final outcome shows that AI-enabled solutions have the potential to revolutionize

VII. CONCLUSION

In this project, an integrated AI-based system was developed that combines soil analysis, intelligent irrigation, crop-fertilizer recommendation, and market price prediction into a unified framework aimed at improving farm yield, reducing wastage, and supporting data-driven decision-making.

The system uses machine learning models and sensor data to evaluate various soil parameters like pH, nitrogen, phosphorus, potassium, and moisture level. This automated assessment helps farmers understand the current soil condition without relying entirely on laboratory testing. Based on the analysed data, the system intelligently recommends suitable crops and fertilizers, ensuring that the selected crop is compatible with the available soil nutrients and environmental conditions. This significantly reduces the risk of poor crop growth and nutrient imbalance.

Furthermore, the system provides market price analysis using predictive algorithms to help farmers make informed decisions about when and where to sell their produce at the highest profit. This reduces the losses caused by fluctuating market prices and middlemen exploitation.

The final outcome shows that AI-enabled solutions have the potential to revolutionize agriculture by increasing productivity, saving resources, and improving economic outcomes.

VIII. FUTURE WORK

IoT-Enabled Fully Automated Farming System: The current system can be expanded into a complete IoT ecosystem where sensors continuously gather data about soil moisture, temperature, humidity, rainfall, pest activity, and nutrient level.

Automatic actuators (pumps, sprinklers, valves) can then respond instantly based on AI-generated decisions. A cloud-based dashboard can enable farmers to control and monitor farm conditions from anywhere using a smartphone.

Climate Prediction and Risk Management:

Advanced weather forecasting models and climate risk assessment can be integrated to help farmers prepare for droughts, floods, and seasonal changes. This will increase crop resilience and reduce losses from unexpected weather conditions.

Blockchain-Based Supply Chain and Market Transparency:

To prevent market fraud and ensure transparent pricing, blockchain technology can be integrated. This enables secure transactions, real-time price updates, and direct farmer-to-market sales without intermediaries.

Multi-Crop Recommendation and Rotation Planning:

The system can be expanded to generate long-term crop rotation plans to maintain soil fertility. By analysing past crop patterns, AI can suggest the best crops for upcoming seasons to improve soil health and prevent pests and diseases.

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