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AgriPulse: Smart Grain Storage System

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ABSTRACT- Storing grain, the right way makes all the difference, but let's be honest—traditional methods just don't cut it. Crops get hit by too much moisture, wild temperature swings, pests, and, honestly, most folks don't check on them as often as they should. That's where a Smart Grain Storage System works, it keeps an eye on temperature, humidity, even gas levels—using simple sensors and IoT tech. The best part is if something goes off, the system sends a warning straight to the farmer's phone or computer. No guessing, no waiting. This way, farmers catch problems early and save more of their harvest. It's all about making storage safer and cutting down on losses.

KEYWORDS- Smart Grain Storage, IoT-Based Monitoring, Crop Yield Prediction, Crop Rotation System, Direct Market Access, Environmental Sensors, Real-Time Alerts, Sustainable Farming

I. INTRODUCTION

Smart grain Storage systems are changing the way farmers store and manage their yield by using IoT detectors, AI, machine literacy and robotization. These technologies help corruption, improve grain quality, and increase gains through an intelligent storage terrain. They also give direct access through the website, allowing farmers to connect with buyers directly, get fair prices, and avoid mediators. With AI- grounded crop yield prediction, farmers can plan their storage needs and deals strategies more effectively by assaying rainfall, soil conditions, and former data.

In addition to perfecting storage, smart systems support better husbandry opinions through data- driven crop gyration, which helps maintain soil health and reduce pest issues. These combined features, including real- time monitoring, prophetic analytics, and digital request access, help farmers reduces post-harvest losses and achieve more stable and transparent deals.

II. RELATED WORK

Kumar and Sharma [1] present an affordable IoT- grounded system that uses temperature and moisture detectors to descry corruption pitfalls in real time and shoot SMS cautions to farmers. Designed for pastoral and offline conditions, the system effectively helps small- scale farmers cover grain quality. The authors report 25 reduction in-post-harvest losses, demonstrating its practical benefits. With a total cost of under$ 50, the study highlights a scalable and sustainable IoT result for perfecting grain storage practices.

Li et al.[2], developed an AI- powered camera system that scans stored grains for early signs of pests and earth using image recognition. The system achieves 95 discovery delicacy, enabling timely cautions before major damage occurs and helping help up to 30 grain losses. Being solar-powered, it's suitable for remote agrarian areas and offers easy installation with minimum conservation. This study contributes precious perceptivity into how AI- enabled systems can strengthen post-harvest operation and enhance food security.

B Patel and Verma [3] present a cost-effective wireless detector network for covering humidity, temperature, and CO_2 situations in grain storage. The system sends SMS cautions to farmers through introductory mobile phones, icing availability in pastoral, low- tech surroundings. It has been stationed among over 5,000 small farmers across India, who reported significant reductions in corruption and improve post-harvest grain corruption and preservation. This study highlights the value of affordable detector-grounded results in addressing major storage challenges faced by small farmers.

Singh et al.[4] developed a smart aeration result that optimizes tailwind in grain storage installations. Using real-time humidity detectors, the system activates ventilation suckers only when demanded, saving up to 60 energies compared to nonstop addict operation. It's compatible with being storage lockers and can extend grain newness up to three times longer than traditional styles. The study also notes that farmers generally recover the system's cost within a single crop season, making it economically feasible and supporting energy-effective, automated post-harvest grain operation.

Chen and Liu [5] shows how combining soil moisture sensors with AI- based models improves the accuracy of yield forecasting using real-time ground data. The system works with being farm detector setups, making relinquishment readily without major upgrades. It also helps farmers optimize water and use of toxin, supporting both effectiveness and environmental sustainability. This study highlights the strong eventuality of detector – AI integration in perfection husbandry.

Thompson et al.[6] developed an AI- grounded model designed for husbandry in draught-prone regions. The model predicts how climate affects crop product and provides adaptive strategies to reduce risks. By examining regional climate patterns and crop behavior, it helps farmers making better decisions under difficult environmental conditions.

Das et al.[7] developed an SMS alert system was used to deliver daily grain prices to farmers. This action supported over 100,000 Indian farmers, enabling them to make informed selling opinions using basic phones without internet access. The system improves their capability to time grain deals effectively and enhanced their participation in local markets.

Fernandez et al.[8], analyzed market trends used by AI, weather data, and historical records in order to forecast grain demand. This model helped farmers decide the stylish time to vend stored crops, leading to 15% increase in profits, demonstrating AI's value in perfecting agricultural marketing. The study also emphasizes how accurate predictions can support better long- term planning for stored grains.

Brown & Green [9] introduced an AI tool that recommended optimal crop rotation cycles based on soil type, weather, and market demand. Farmers using this system reported a 15% improvement in soil health over two seasons, highlighting AI's role in sustainable agriculture. The tool ensures healthier crop cycles by selecting rotations that reduce soil stress and improve productivity.

Rodriguez et al. [10] proposed using soil nutrient sensors that track nitrogen, phosphorus, and moisture levels to suggest crop rotations. The system works with mobile applications, helping farmers maintain soil fertility while being easy to install and use. By providing real-time soil data, the system supports smarter crop decisions without needing complex equipment.

Adebayo & Musa [11] developed a dynamic crop rotation framework for regions vulnerable to climate variability. The system is responsive to climate changes, helping farmers choose suitable crops based on shifting rainfall patterns. Farmers using this approach reported an average yield increase of 10%, showing its effectiveness in improving climate adaptability. By analyzing changing rainfall conditions, it supports better crop opinions for farmers facing uncertain climate conditions.

Mueller & Singh[12] implemented a free SMS alert system to advise farmers about adverse rainfall conditions that could spoil stored grain. The system helped reduce grain losses by 14% during stormy seasons, after being used by 2,000 Indian farmers. It works through basic mobile phones, making it accessible in low-technology rural areas, and shows the significance of timely weather-based alerts for protecting stored grain.

Patel & Xu [13] developed a WhatsApp-based chatbot that offers personalized crop rotation advice based on soil test photos sent by farmers. Indian users who followed its recommendations reported a 15% improvement in yields in a single season, showcasing the chatbot's effectiveness in digital agricultural extension.

Garcia et al. [14] combined insect forecast data with storage advice delivered through radio broadcasts. This system was beneficial to Nicaraguan maize farmers, who experienced a 25% reduction in pest-related storage damage due to timely alerts about locust threats and improved storage techniques.

Halima et al. [15] developed an SMS system that uses rainfall forecasts to predict potential harvest outcomes. Kenyan farmers receiving these alerts were able to adjust storage plans, preventing 15% of possible losses caused by climate variability, emphasizing the importance of proactive agricultural planning.

Nguyen [16] introduced a low-cost, battery powered device that alerts farmers when humidity in grain bins becomes too high. This simple technology, lasting two years on one battery, enabled Vietnamese farmers to act quickly, reducing grain spoilage by 22%.

Chen & Li [17] combined real-time soil sensor data with weather forecasts using a machine learning model. This system delivered 90% accurate yield predictions for rice crops in China up to two months in advance. The model's accuracy improved with each season, offering a scalable tool for yield forecasting.

Rodriguez [18] tested an AI system within a WhatsApp group where farmers upload crop photos. The AI assesses quality and suggests fair prices, bypassing middlemen. Among 800 Nigerian farmers, this method reduced price negotiation by 70% and increased profits by 20%, fostering market transparency.

Singh [19] developed an SMS-based reminder tool that notifies farmers when to rotate crops. The system learns each farm's conditions and schedules, sending personalized messages such as "Next week: plant beans after maize.

Kumar & Zhang [20] developed a machine learning model that identifies pest infestations from mobile phone images captured by farmers. The AI system analyzes visual indicators on crop leaves to detect early pest activity. Tested in pilot regions of India and China, it helped reduce pesticide usage by 30% and improved overall crop health monitoring.

As a result, post-harvest losses continue to increase, leading to reduced profitability for farmers. There is a critical need for an affordable, farmer-friendly smart storage system that integrates IoT detectors, data-based analysis, and real- time cautions to continuously monitor grain conditions, predict corruption, support crop rotation planning, and connect farmers to direct market buyers. Such a solution would help reduce waste, improve grain quality, and help small farmers make informed decisions, eventually leading to better income, reduced food loss, and stronger food security.

III. PROBLEM STATEMENT

Small farmers lose up to 30% of their crops due to poor storage conditions, lack of real- time market information, and unpredictable crop yields. These losses do substantially because traditional storage methods fail to control humidity, temperature, and pest infestation, resulting in rapid grain spoilage. Farmers also struggle with limited access to timely market prices, forces them to sell their product at lower rates and leads to financial instability. When farmers can't count on reliable crop yield predictions, planning gets tricky. Storage problems hit farmers hard. They lose crops because they can't monitor conditions properly, don't know the best time to sell, and lack the data to make smart choices. Most farmers in rural areas simply don't have access to monitoring systems, decent storage buildings, or tech tools they can actually afford. The result? Spoiled harvests and shrinking incomes. What these farmers actually need is straightforward: a storage system that works for them. Picture sensors that track grain conditions, software that flags spoilage risks early, instant alerts when something goes wrong, and tools that help plan the next season. Throw in direct connections to buyers, and you've got something useful.

The benefits stack up quickly. Less waste means better-quality grain reaching the market. Farmers finally get real information to base their decisions on instead of just guessing. Their income improves, food waste drops, and communities get more reliable food supplies. It's practical technology solving real problems.

IV. OBJECTIVE OF THE PROPOSED SYSTEM

- Reduce Post-Harvest Losses – Minimize spoilage from 30% to below 10% by using real- time monitoring of storage conditions like temperature, moisture, and gas situations.
- Enhance Farmer gains – Provide data-driven insights that help farmers make better storage and selling decisions, improving overall income.
- Improve Market Access – Deliver real- time price updates and enable direct connections with buyers to ensure fair pricing and reduce mediators.
- Promote Sustainable husbandry – Use AI/ ML- based crop yield prediction and crop rotation suggestions to maintain soil health and support long- term productivity.
- Increase Storage Safety & trustability – Detect harmful gases such as carbon dioxide and ammonia at an early stage to help prevent grain impurity and health risks.
- Improve Farmer Connectivity – Enable farmers to pierce all storage, crop predictions, and request updates through a single eco-friendly platform.

V. METHODOLOGY

A. Research & Data Collection

A detailed field study is conducted to understand the storage challenges faced by small farmers, including humidity issues, pest risks, and market access limitations. Existing datasets related to crop losses, regional climate patterns, and local request prices are collected and analyzed. Appropriate IoT components such as the DHT22 temperature/ moisture detector, soil humidity detector(for grain humidity), and alert mechanisms are named based on the conditions.

B. IoT System Development

The hardware setup includes ESP32 microcontrollers installed inside grain storage units, connected to detectors and introductory selectors. A real- time data channel is established where detector readings are transmitted to the microcontroller and which forwards the data to a cloud platform for processing, alert generation, and storage.

C. Crop Yield prediction Website(AIML- Grounded)

Data is collected from public sources similar as FAO databases and regional agricultural departments, along with homemade farmers inputs like soil pH, crop type, and irrigation details. All datasets are preprocessed by handling missing values, normalizing parameters, and organizing them into structured formats.

D. Digital Market Access Platform

Farmers can list their yield with details such as quantity, price, and location, as well as purchase agricultural inputs like seeds, fertilizers, and tools. Labor hiring features allow farmers to post job conditions(harvesting, furrowing, etc.). Buyers can browse listings, filter results based on specific criteria, and negotiate prices through an integrated bidding system.

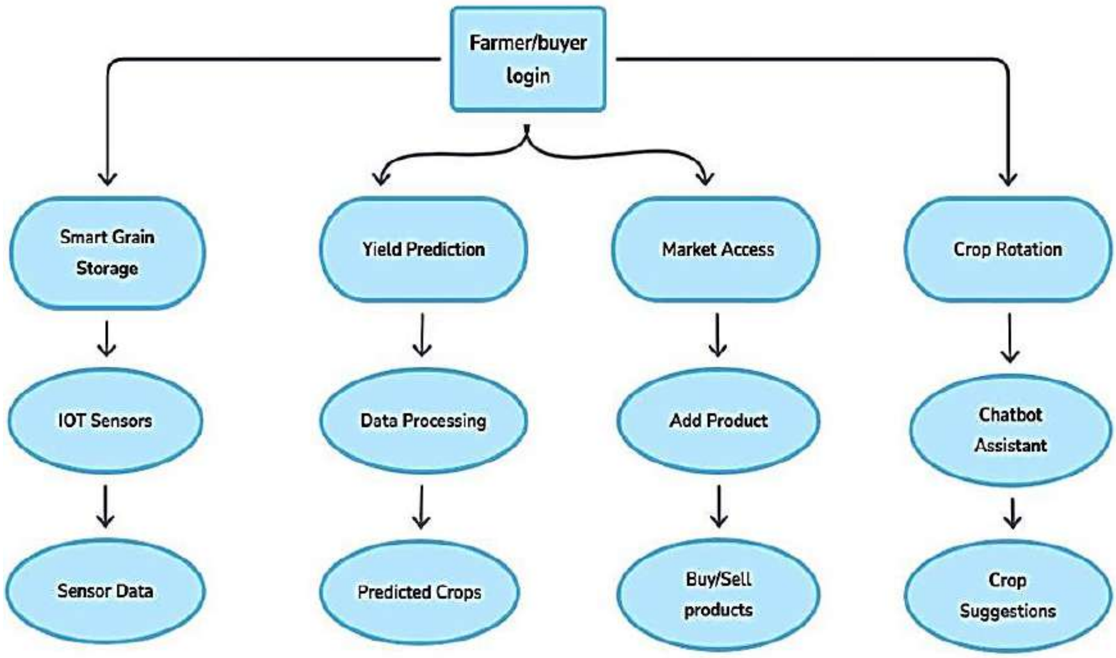

Figure 1: System Architecture

Smart Grain Storage allows farmers to cover stored grains using technology- driven tools. It helps track environmental conditions that affect grain quality, such as temperature, moisture, and humidity. The system reduces storehouse losses by transferring cautions whenever conditions become unsafe. It supports farmers in maintaining grain freshness for longer ages. Overall, it ensures safer storage and preserves grain quality until the product reaches the market.

IoT detectors collect real- time environmental data from inside the storage unit. Devices like DHT22 measure temperature and moisture, while humidity detectors track the grain's internal humidity situations. These readings help farmers understand grain conditions without physically checking. The detectors enable preventive measures before spoilage thresholds. They also support long- term analysis for improving storage practices.

The sensor data consists of real- time values captured from temperature, humidity, and moisture detectors. This data is reused and displayed for farmers in an easy- to- read format. It helps identify abnormal conditions such as excessive heat or humidity buildup. Farmers can use this data to take immediate action, reducing chances of spoilage. The collected records also help understand patterns and improve storage planning.

The yield prediction module uses machine learning to forecast expected crop production. It analyzes various parameters such as soil quality, rainfall, temperature, nitrogen, potassium and soil ph level.

E. Pilot Deployment & Scaling:

The system is tested on 10–20 farms to validate sensor performance, website usability, and market platform effectiveness. Data on post-harvest loss reduction and farmer profit gain is recorded. Grounded on feedback, UI is simplified, hardware stability is improved, and features like AI-based crop rotation recommendations are added.

The system helps farmers do better farming and taking market decisions. Predicting yields or crops early reduces risk and prepares farmers for market's adverse conditions. It ultimately improves farm management and profitability .

Data processing involves cleaning, filtering, and analyzing raw agricultural data. It converts inputs like soil data, weather data, and crop history into usable digital formats. Machine learning models rely on this processed data for accurate predictions. The system removes errors and inconsistencies before analysis. It ensures that yield prediction results are reliable and meaningful.

The crop prediction module analyzes farmer-provided inputs such as rainfall, moisture, soil nitrogen position, temperature, and pH value to understand the field conditions. Based on these inputs, the system applies machine literacy models to identify which crops are most compatible with the given soil and climate conditions. It also ranks the results and displays the top three best- suited crops for that specific land. This helps farmers select crops that gives advanced yield, better growth stability, and reduced risk. By choosing the recommended crops, farmers can make smarter opinions for both seasonal cultivation and long-term soil management.

Access to the market connects farmers directly to buyers without mediators. It gives farmers a platform to list and showcase their produce with prices and quantity. Buyers can browse available products and contact farmers easily. This reduces unfair pricing and increases farmer profits. The system encourages transparency and trust in agricultural trade.

The Add Product section allows farmers to upload details of the crops they want to sell. They can add images, price, offer price, product name and product description. This helps buyers evaluate the product before purchase. The feature improves product visibility and market reach.

The buy/sell section enables buyers to search, compare, and purchase listed farm products. It simplifies the trading process by providing real-time information and filters. Farmers receive notifications when buyers show interest. The system supports smooth transactions and fair pricing. It builds a structured marketplace for agricultural goods.

The crop rotation module guides farmers, what crop should they grow coming for better soil health. It considers soil nutrients, recent crops grown, and climatic conditions. Crop rotation also helps to reduce pests, conditions, and soil nutrient reduction. The point promotes sustainable husbandry practices. It ensures long- term soil fertility and improved crop productivity.

The chatbot assistant provides instant guidance to farmers on crop selection, soil conditions, and farming strategies. It answers queries related to diseases, fertilizers, and weather updates. The chatbot helps even unskilled farmers access expert-level advice. It operates in simple language to improve usability. This makes the farming process more informed and efficient.

Crop suggestions provide recommended crops based on soil type, weather, and previous cultivation patterns. These suggestions aim to increase yield and maintain soil balance. The system analyzes multiple factors before recommending an ideal crop. Farmers can choose the best crop for the next cycle using this guidance. This helps achieve sustainable and profitable farming.

VI. ALGORITHMS USED

A. Rule Based Filtering

The rule-based filtering method checks the farmer's soil parameters such as Nitrogen, Phosphorus, Potassium, pH, moisture, and temperature against the ideal requirements of each crop. It removes crops that do not satisfy the minimum conditions, ensuring only scientifically suitable options move to the next stage. This prevents unsuitable crops from being recommended even if they score well later. The system acts like an expert farmer by applying predefined agricultural rules. As a result, the filtering step ensures accuracy and eliminates mismatches early in the process.

B. Similarity Scoring(KNN like algorithm)

The similarity scoring technique compares the farmer's soil values with the ideal soil conditions of different crops. It calculates how close or distant each crop's requirements are from the farmer's actual soil readings. Crops that closely match the soil conditions receive higher similarity scores. This method ensures the system does not rely only on strict rules but also considers natural variations in soil. It makes recommendations more flexible and realistic for real-world farming conditions.

C. Top-k Selection

After scoring all crops, the ranking algorithm arranges them from highest to lowest based on suitability. Instead of overwhelming the farmer with many options, it selects only the top 3 to 5 crops that best match the given soil and climate conditions. This helps farmers make quick and confident decisions about what to grow. The method ensures the final suggestions are optimized, relevant, and practical. It also improves user experience by presenting only the most beneficial crop choices.

VII. SYSTEM IMPLEMENTATION

Snapshots- The following section presents a series of snapshots (Figure 1 to Figure 5) that illustrates the developed smart grain storage system prototype and its major functional modules. Figure 1 shows the hardware setup of the smart grain storage system, which is developed using IoT detectors to continuously cover critical parameters such as temperature, moisture, and grain humidity situations, icing safe storage conditions and reducing post-harvest losses. Figure 2 depicts the main dashboard interface, which acts as a centralized control panel by accessing to all major factors of the system, including storage monitoring, crop prediction, crop rotation, and market access features. Figure 3 represents the crop yield prediction module, which integrates AI/ ML ways to dissect environmental and literal data, enabling growers to make informed opinions regarding crop planning and anticipated yield issues. Figure 4 illustrates the crop rotation module integrated with a chatbot assistant that offers intelligent suggestions and guidance to farmers, helping improved soil health and promote sustainable husbandry practices. Figure 5 shows the direct request access to platform, designed as an E-commerce system that connects farmers directly with buyers, allowing transparent buying and selling of rural products at reasonable market prices while barring the part of mediators and icing better profitability for farmers. This website is an ecofriendly website which is set substantially for the small-scale farmers.

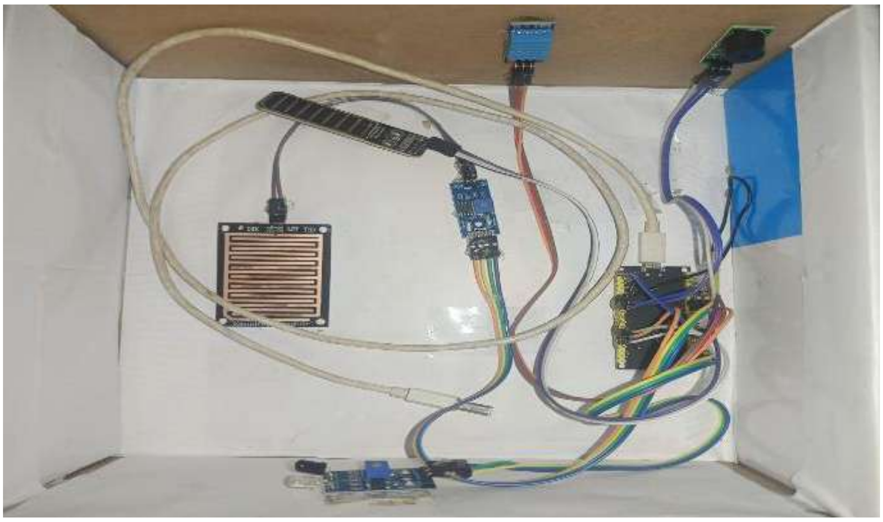

Figure 2: Hardware Setup

Figure 3: Crop Yield Prediction Module

Figure 4: Crop Yield Prediction Page

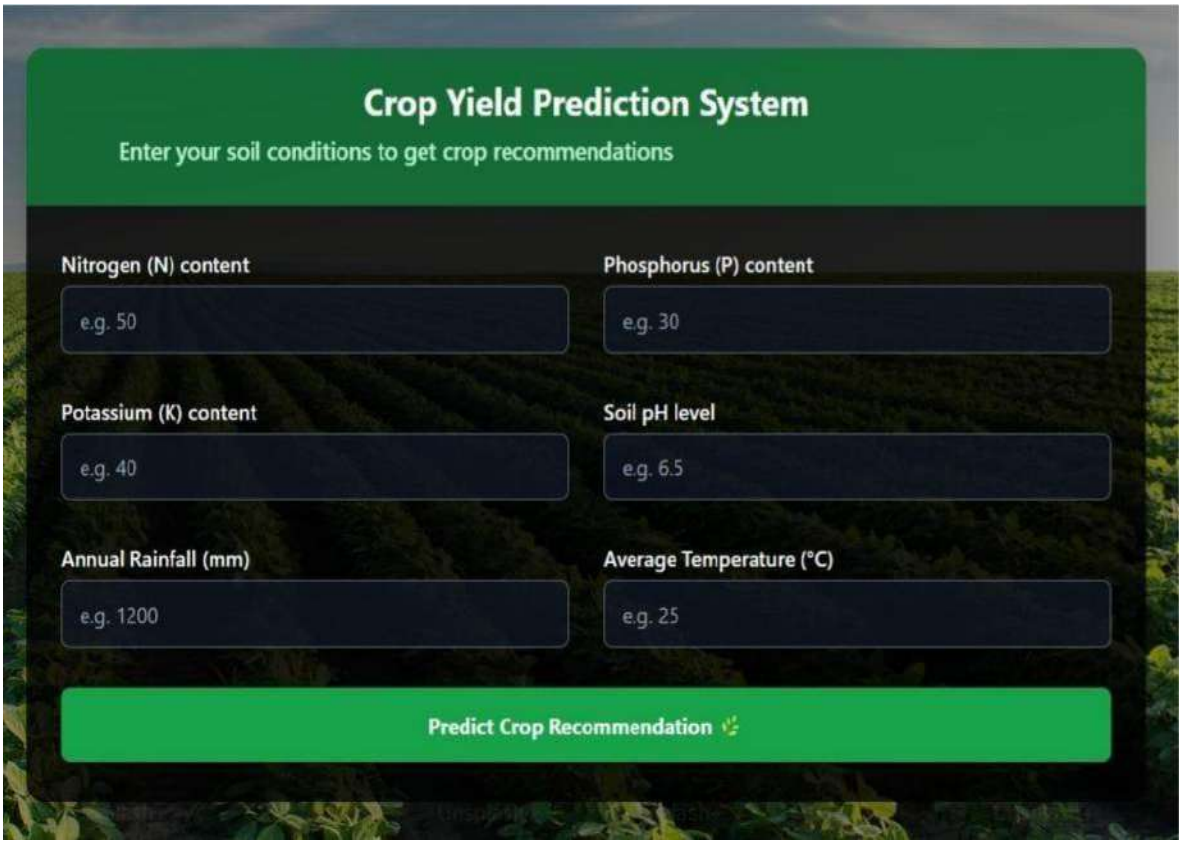

Figure 5 : Crop Rotation Page

Figure 6 : Direct Market Access Page

VIII. CONCLUSIONS

The development of a smart storage and crop operation system to reduce post-harvest losses among small- scale farmers have been a key focus of this design. The primary thing was to integrate IoT and AI technologies create an intelligent agricultural solution capable of monitoring environmental conditions, predicting crop yield, and improving market connectivity. The initial stage successfully established the core frame, demonstrating the system's potential to address challenges similar as poor storage, unpredictable yields, and limited market access.

While the current prototype provides real- time monitoring and yield prediction capabilities, fresh advancements are necessary to insure a completely scalable and comprehensive platform. Integration of advanced AI models, improved communication modules, and extended business features will strengthen the system's overall impact. This progress marks a significant step toward empowering growers with dependable, technology-enabled tools that enhance productivity, reduce losses, and promote sustainable agricultural practices.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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