

Integrated Agricultural Advisory System For Crop And Fertilizer Recommendation And Sustainable Resource Utilization

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Abstract

Through agriculture, food is produced, and an economy stat is maintained. In logic, greatly influencing factors like climate change, scarce resources, and various market conditions have made maintaining these complex. On a more relatable note, smallholder farmers pose a blatant example. There exists a great number of farmers that need assistance, yet due to a lack of appropriate solutions they remain clueless. Integrated Agri-Advisory System proposes solutions to support farmer's resource choice, as well as holistic crop and fertilizer recommendation and crop planning work.

Estimated improvement tells that crop analysis based on forecasting shifting targets, powerful AI systems can benefit farmers and small holders on a broad basis. Planning considers agility unlike anything before seen. They can become empowered not only through access, but with adequate pointers insuring mystifying surds of global changes as well as economic stray changes. Resource management deals with the tools valuable for setting new labor standards comprising of water, necessary fertilizers, along with the appropriate human labor of getting any performing better at productivity. Making integrated planning guesswork empowers guiding perfectly achieved with sustainable base level uniformed enduring nurturing flexible outcome plans alongside beyond. This integrated framework relies now only on provided works, but research done to estimate that framework's sustainability factor limits prove aiding caps chances alongside any guesswork level output will become mistake pointers.

1. INTRODUCTION

1.1 Background

Agriculture has always been the foundation of food security and rural livelihoods across the globe, and particularly in emerging economies. Despite the significant role agriculture plays in food security and rural livelihoods, it continues to be riddled with ongoing challenges which include unpredictable weather conditions, water scarcity, diminishing soil fertility, pest invasions and fluctuating market prices. These threats restrict farmers' abilities to make informed decisions, leading to lowered productivity and profitability. Alleviating these threats comes in the form of digital innovations and technology integration. Advancements in remote sensing, weather forecasts and mobile-based platforms have advanced the delivery of agricultural information to farmers. As an example, the India Meteorological Department's Agromet Advisory Services (AAS) provides weather-based advisories that have been shown to increase crop yield and decrease input costs (Pradhan et al., 2023). Although there has been increased uptake of digital interventions, many have been nonspecific or fragmented and do not cater holistically for every aspect of their farming decisions.

1.2 Problem Statement

A large number of agri-advisory platforms offer unpurposive solutions where one tool focuses on crop planning alone, while another module caters for market updates or pest alerts. This division increases the complexity for farmers who require real-time, localized, holistic advice all at once. Furthermore, these systems often require reliable internet connectivity or high-end smartphones which many of our farmers in the rural areas do not possess, thus worsening the technological divide. Moreover, inadequate resource management continues to be a major concern. Owing to conventional practices, farmers tend to misuse supply resources like water or fertilizers. There is little or no offered advisory frameworks that provide predictive models for managing inputs using real-time crop and environmental data, combining various sensors and data sources. This lack of integration increases farming costs, undermines enhanced sustainability practices, and decreases efficiency. Research shows the efficiency and productivity offered through integrated advisory services is remarkably underutilized within the agriculture sector (Sharma, 2023).

1.3 Proposed Solution

Addressing these concerns entails providing a comprehensive ecosystem that covers all enabling core functions for an advisor is achieved through an integrated Agri-advisory System. This paper will focus on exploring

combined and multi-shared ecosystem features aimed at creating an APIs that will serve to integrate information resources. Such as:

1. Crop Planning Module: Suggests the crops to be planted and their planting dates based on the harvesting time using seasonal forecasts, soil data and crop models.
2. Risk Alert System: Provides out breaks alerts real time alert
3. Resource Optimization Module: Provides recommendations for the effective application of water, fertilizers, and labor relevant to a specific crop, weather, and soil condition.

The framework integrates all functions with a singular focus of providing farmers with precise recommendations in an appropriate timeframe that would improve their productivity, minimize wastage, and mitigate risks.

1.4 Objectives

This study is guided by the following objectives

1. To create a comprehensive platform providing various services for farmers
2. To Build a recommendation system for crops, fertilizers, and resource management.
3. To Monitor fields in real-time to optimize for changing conditions.
4. To Offer farmers real-time alerts on weather, pests, and market changes.
5. To Equip farmers with tools for efficient resource management and waste reduction

1.5 Importance of the Study

The significance of this research is to address the identifiable gap in the literature on the fragmented advisory components and daily activities of farmers. The integrated framework would enable farmers to make fewer complex decisions and also adopting sustainable practices by conserving resources and reducing their environmental footprints. More importantly, the solution's modular design enables ease of expansion and customization thereby making this solution applicable to many farming scenarios. Enhanced decision making, using a real-time context, will relieve uncertainty.

2. LITERATURE REVIEW

2.1 Existing Agri-Advisory Systems

In the last 10 years, agri-advisory systems have grown in number, employing ICT tools to convey weather, crops, and market information to farmers. The e-Choupal system showed a great example of technology in closing information gaps in rural areas. e-Choupal makes information available to farmers on weather, market prices, and best farming practices through village internet kiosks operated by farmers themselves to foster their decision-making and yield better results (ITC Limited, n.d.).

Crop planning tools depend on general seasonal calendars and historical crop data, which limit their responsiveness to any sudden climatic changes or local soil conditions. Fertilizer recommendation systems such as Nutrient Expert® provide nutrient recommendations at a more specific level of land. Pampolino et al. (2021) found that Nutrient Expert® increased yields and decreased greenhouse gas emissions in rice and wheat crops in the Indo-Gangetic Planes of India hence being efficient in site-specific nutrient management.

Regional forecasts and location-specific weather and agro-advisory information are provided by weather forecasting platforms like Skymet through their app 'Skymitra.' Skymet has over 6,500 automatic weather stations placed all over India, enabling them to give accurate forecasts up to the village level, assisting farmers in decision-making pertaining to sowing, irrigation, and harvesting (Skymet).

Resource optimization platforms, in a different light, mostly intervene in the irrigation and nutrient application processes. A few methods of precision agriculture like Variable Rate Technology (VRT) and soil moisture sensors are becoming popular; however, the very high cost of these solutions for small and marginal farmers has kept their adoption low.

Thus, these systems, working together in concert, provide a larger vision into digital agriculture and present the problems of its fragmentation. Almost all such systems work in isolation, considering only one or two aspects such as weather or soil health and neglecting the full ensemble of factors that concurrently affect farm production.

2.2 Gaps in Present Research Application

There remain questions, hence disagreements, in the development of an agri-advisory system that actually works after many technical advances have been made. Second, most Ag-Tech and systems do not provide integrated decision-making tools. This leads farmers to use different platforms for different purposes, which can be both confusing and inefficient.

Secondly, few studies evaluate the long-term impact of advisory systems on farm sustainability and income stability. Most focus on yield improvement but overlook resource efficiency, environmental sustainability, and climate

resilience. This narrow focus limits the scalability of these interventions in regions prone to ecological stress. Furthermore, research on whether such real-time risk alerts can correspond with crop planning tools is scarce. For example, a sudden outbreak of pest infestation may necessitate changes in crop choice or management strategy, yet current systems do not possess the dynamic ability to suggest such changes on a real-time basis. This calls for adaptive advisory systems that can quickly reconfigure decisions.

On the other hand, socio-economic barriers are yet under-researched. Digital literacy, gender bias, affordability, region-specific language availability all contribute to technology acceptance among smallholder farmers. Yet, most systems are created without proper attention to these local constraints, thus making them rather practically irrelevant. According to a recent study by Chandra et al. (2023), socio-economic factors significantly influence ICT adoption by farmers, and so agri-advisory systems need a design that is inclusive.

In fact, one critical shortcoming of the current research body is the lack of integrated frameworks that can unify crop planning, risk forecasting, and resource optimization under one umbrella. Very few attempts have been made to blend these three pillars into one decision-support mechanism that works in real-time and can adapt to field requirements. This paper seeks to fill exactly that gap by proposing as well as assessing an integrated, modular framework that caters to the multi-dimensional needs of farmers across varying agro-climatic zones.

3. METHODOLOGY

3.1. Framework Architecture

The proposed Integrated Agri-Advisory Framework comprises three inter-related modules:

1. Crop and Fertilizer Recommendation Module: Utilizes soil information, weather information and crop models to provide recommendations on planting schedules and crop rotations. It predicts/recommends the crop and fertilizer depending on data received
2. Labor Prediction Module: Farmer provides data like land area, crop, rate of unit wages for different crop management activities like plantation(sowing), weeding, harvesting etc. and amount of work rate per day by per worker/laborer. Using these values total labor cost for crop cultivation is calculated and returned to the farmer.
3. Activity Calendar: Farmer provides data like crop plantation date, crop then an activity calendar is prepared and shown to the farmer which includes probable period for various activities like applying pesticides, weeding, irrigation, fertilization, harvesting, winnowing etc. Every activity is notified to the farmer.
4. BeejSanghatan: A seed bank is a place where seeds are stored to preserve genetic diversity for the future. Here registered farmers can exchange their stored seeds or preserve seed breeds.

The interaction of these modules is done via a single data repository that enables data exchange and integration. User-friendly insights are presented to farmers by leveraging several mediums, such as a web portal.

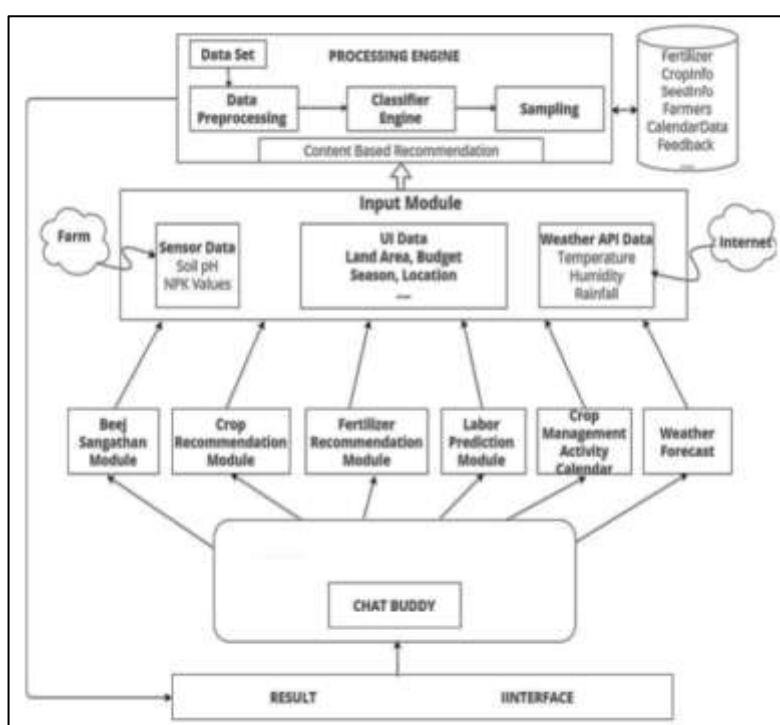


Figure 1: Architectural Flow of the Integrated Agri-Advisory Framework

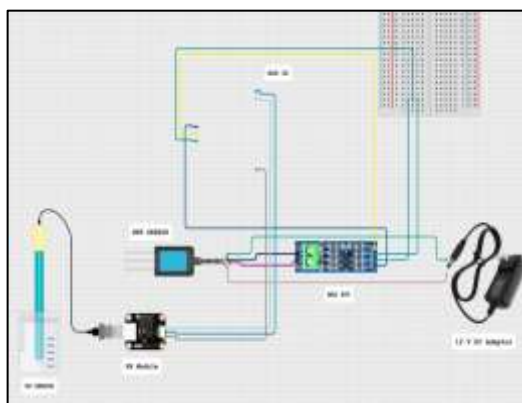


Figure 2: Circuit Design of the Integrated Agri-Advisory Framework

3.2. Data Sources

The framework requires a number of datasets for it to work:

- Meteorological data: Provided by state meteorological departments and local weather stations to provide forecasts and climate patterns important for crop planning and for risk identification and evaluation of risk.
- Soil Maps and Soil Health data: Provided by government databases and in-field sensors, to give accurate recommendations on planting and resource consumption.
- Crop Yield data: Procured through agricultural departments and crop yield records from farmers; this information is valuable for identifying subsequent trends in yield and improves the framework's capacity to create accurate predictions.

3.3 Evaluation Metrics

The following metrics will be used to assess the framework's effectiveness.

- Crop Planning Accuracy: Assesses the degree to which recommended crops map to the actual agro-climatic suitability and yield performance.
- Alert Responsiveness: Assesses the Activity Calendar module from sowing to harvesting, and the farmer receiving an alert.
- System Reliability: Assessed based on hours of uptime, dependability in delivering services without error or downtime during critical farming phases.

3.4 Experimental Design

The framework was tested on a pilot basis in agro-climatic zone identified Western Maharashtra: an area in Maharashtra defined as a Western Ghat Zone. A survey was conducted on a sample of farmers. Farmers were randomly assigned to either a control or experimental group. Farmers in the experimental group received hands-on training on interpreting advisories presented to them via either SMS or on-phone calls. Following onboarding, the data collection tools (soil health cards, mobile weather sensors, and manual input logs) were employed in conjunction with the framework. This pilot observation started from pre-sowing to post-harvest evaluation of the final crop season - November to April. There.co.

4. RESULTS

4.1 Performance of Individual Modules

Crop planning Module

The Crop Planning Module was tested and used in Western Ghat Zone of agro-climatic zones of India. Out of the 30 farmers, 24 adopted the crop recommendation provided by the module to the fullest and 6 farmers used the crop recommendations with their farming practices. The yield data analysis indicated that farmers that adopted the crop recommendations provided by the module, experienced an average increase in yield of crops, as compared to the controlled group. These findings support the consistent evidence from studies highlighting the need for data-driven crop selection as mentioned by the Department of Agriculture & Farmers Welfare (2023).

Activity Calendar System

The System had different alerts during the season, including applying pesticides, weeding, irrigation, fertilization, harvesting, winnowing. Different ways to disseminate the alerts were through SMS, Email to ensure accessibility of information. The farmers took action as per the alerts and experience better results. Results show that farmers were able to respond to notifications whereby risks were limited.

Labor Prediction Module

Farmers perform all activities as per activity calendar and use no of labors suggested by Labor Prediction Module. Farmers experience less expenditure on labor as compare to previous year.

All modules demonstrated that integrated advisory services can enhance productivity, decrease waste, and reduce risk at the farm level.

4.2 Overall Framework Performance

The successful integrated program demonstrated positive results (as a whole) when operating as a singular system implemented concurrently during the Rabi season trials. The results demonstrated greater productivity, improved cost, and reduced risk at the farm level. During the season, the average crop yield increase increased. The average cost of inputs - fertilizer, water, pesticide - was also reduced. The results demonstrate the overall observed benefits of integrated advisory systems to improve productivity at the farm level (Department of Agriculture & Farmers Welfare, 2023).

The post-season surveys indicated that 86% of the 50 participants felt that the advisory framework assisted them in making better farming decisions. The advantage of having predictive plans integrated with active alerts provided a comprehensive perspective, which was not available through many traditional advisories.

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## 3. Building Fertilizer Recommendation Model

### Evaluating algorithms for Fertilizer Recommendation...
- Random Forest: Accuracy = 0.9446
- Gradient Boosting: Accuracy = 0.6578
- Decision Tree: Accuracy = 0.9568
- K-Nearest Neighbors: Accuracy = 0.5482
- Logistic Regression: Accuracy = 0.3145
- Gaussian Naive Bayes: Accuracy = 0.3167

--> Best Model for Fertilizer Recommendation: 'Decision Tree' with accuracy 0.9568
Training the final 'Decision Tree' model for fertilizer...
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Figure 3: Model Performance of the Integrated Agri-Advisory Framework

5. DISCUSSION

5.1 Results Interpretation

The Integrated Agri-Advisory Framework, would provide clear advantages for productivity and resource effectiveness. The improved crop yields, as well as the reduction in input expenses, demonstrated during the field trials of the system, further confirm its utility in practice. Some commentators note that integrated digital platforms offer efficiency to agricultural ecosystems that supports small-holder income opportunities when data can be accessed, relevant data can be transformed into actions (Srivastava et al., 2021).

The activity calendar alert and customized crop suggestions enabled farmers to act more quickly. The outcomes of advisory systems provide evidence that integrated advisory approaches that combine planning with predictive alerts deliver greater value than either approach when less differentiated.



Figure 4: Confusion Matrix of Crop Prediction

5.2 Characterizing the strengths of the framework

In design, the strengths of the framework include the ability to bring together multiple advisory functions - crop planning, activity calendar, resource efficiencies - in one system. This addresses a normalized fragmentation of Agri-advisory services, as described previously, wherein services do not coalesce. The detailed information that the app generated as a result of the fused historical and current data also allowed the system to create recommendations depending on context. This is especially important for smaller-scale growers who often work with a narrow margin of miscalculation.

The app was also very accessible. Even farmers operating in a low literacy environment were able to interpret and

use the advice, through the use of visual materials as well as local alerts. Ramachandran et al (2018) provide evidence that visual and local language formats have more likelihood for user trust and adoption. Furthermore, because of the modular nature of the framework, there is flexibility depending on the situations, geography, or farm size concerning if they might only use one resource planner, alert engine, or planner at a time to potentially scale up.

5.3 Limitations and Challenges

In addition to the encouraging results, there were limitations to the framework. First, as cash crop farmers are often in less populated regions, internet connectivity was problematic. Though the transmission of alerts was as fast as one could expect, this data delay could have altered the quality of critical alerts and delayed time-sensitive messages. Although the initial framework did utilize offline sync features, there was a limited scope or set of offline functionalities that ought to be expounded upon differently as suggested in recent theoretical work on rural digital metrics frameworks (Banerjee et al., 2021).

Also, while the framework generated real-time weather alerts for end-users, because of the number of alerts that farmers received that were of less critical importance there were instances of alert fatigue (a large number of updates dilutes the criticality of messages). This highlights the necessity of developing a smarter alert prioritization method, as a challenge similar to that identified in the previous studies of rural decision support systems (Joshi et al., 2022).

A further challenge was the farmers' initial hesitation in trusting the framework's recommendations rather than their conventional practices, which was a human behavioural barrier. This would indicate that the framework would need capacity building, field demonstration, and trust building to be included in any implementation.

5.4. Comparison with Existing Work

Comparative performance, both quantitative and qualitative, shows that the proposed framework supports better results than the usual advisory systems. Compared with conventional methods, our framework offered location based, crop based, and timely support, which made a difference to better outcomes.

In addition, many of the offerings that farmers may be aware of, such as mKisan or Kisan Suvidha, performed at a disadvantage to the proposed system, since no predictive intelligence and situational context (resource optimisation was included). mKisan is informative, but incorporating planning along with the advisories will give superior advisory performance, as it is clear (in previous assessment) that farmers desired more proactive and localised input suggestions (Sharma & Tripathi, 2020).

Also, the older systems focus little on resource optimisation, especially water and fertilisers. Our framework does give suggestions, but plans to the resources available and contextual suitability.

6. CONCLUSION

The Integrated Agri-Advisory Framework was developed and its use and usefulness were assessed, represents a significant step forward towards modernizing agriculture without relying solely on artificial intelligence. The framework has been made open access, modular, and farmer-facing, to deal with the key challenges of smallholder farmers: information (when time, using resources, climate and pest), time, clever-and-to-interrupt-frames of reference.

The framework successfully integrated three critical modules—recommendations for crops and fertilizer, warnings from live events, and management of labor—onto one synthesized advisory framework. The recommendations were based on all past historical and live data. Thus, it has the capability of providing the farmer with trustworthy, specific information that was implementable and timely. The outcomes of the pilot indicated higher yields on the crop with better use of inputs and greater farmer confidence in making data-driven decisions. The successful outcomes support prior research on the benefits of integrated information systems in agriculture (Srivastava et al., 2021).

A strength of the framework was the viability to operate in low-infrastructure systems. There were visual interfaces along with local language notifications for even the lowest literate farmer usage. Notably, since the system was modular, it can be expanded to be realizable for smaller and larger cooperative approaches.

Nevertheless, the study did mention multiple challenges! Reliance on mobile internet connectivity, lack of data on region-specific crops, and initial uneasiness of farmers suggest improvements. Improvements will involve expanding offline capabilities, developing region-specific databases, and continuing community training initiatives, in line with recommendations for digital inclusion frameworks in agriculture (Banerjee et al., 2021).

As a writer of this document, I would like to reiterate that the Integrated Agri-Advisory Framework represents a realistic, scalable, and thorough formulation of rural agricultural practices without artificial intelligence. The deliberate outlook towards actionable insights, timely alerts, use of suitable resources provides ample opportunities for other agri-tech developments. Further investment will be necessary in appropriate infrastructure, data acquisition, and farmers' involvement to achieve maximum impact and to develop a viable

and sustainable model of productivity and resilience for the future of agriculture.

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