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# A Polymer-Based Recommender System for Precision Agriculture: Enhancing Crop Yield Analysis Using IoT Technology

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***Abstract***

*This study introduces an innovative recommender system that employs polymer-based sensors combined with advanced data analytics to deliver personalized recommendations for crop management optimization. The use of polymer-based materials in sensor design allows for the creation of durable, cost-effective, and efficient sensors, well-suited for the challenging conditions typical in agricultural environments. These sensors are designed to withstand variations in numerous factors like temperature of the surrounding, humidity level, and at the same time other external factors, making them highly reliable for continuous monitoring. The system can analyze and interpret real-time soil conditions, moisture levels, nutrient content, and other key indicators essential for crop health. The recommender system then processes this data to provide farmers with actionable insights tailored to specific crop needs, guiding decisions on irrigation, fertilization, and pest control. By following these targeted recommendations, farmers can optimize their resource use, reduce unnecessary input costs, minimize environmental impact, and ultimately enhance crop quality and yield. In conclusion, this research underscores the potential of polymer-based sensor-integrated recommender systems to advance precision agriculture. By offering farmers data-driven guidance that is both accessible and adaptive, this technology can significantly improve resource efficiency and crop yield outcomes. This approach demonstrates an important step forward in sustainable farming practices, as it not only supports higher productivity but also fosters a more environmentally conscious approach to agriculture.*

**Keywords:** Polymer-based sensors, polydimethylsiloxane, recommender system, artificial intelligence, IoT

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## INTRODUCTION

Farmers are an integral part of Indian society, since agriculture is a major economic driver in the country. Agriculture is a substantial contributor to the nation's economic growth. Lack of awareness and advantages of the farming programs and plans presented by the Government of India is a key reason of the ongoing suffering among Indian farmers [1][2]. The integrated Recommendation System for the Farming Industry that aims to address this issue. In order to aid farmers, our study system creates an outline of their fundamental needs via an online tool and suggests the best crop to grow under a wide range of environmental circumstances.

Many agricultural studies show that the world's population is expected to increase by 9.8 billion people by 2050, leading to a corresponding rise in the need for food. To address the aforementioned problem, experts have devised the "Precision Agriculture" technology to effectively address contemporary environmental concerns by enhancing agricultural processes. The main aim of this research is to create a novel agricultural decision-making system that can achieve high crop yields while requiring minimum involvement from farmers [3].

Precision Agriculture addresses these challenges via the use of object identification and continuous monitoring of soil moisture, humidity, and temperature, among other tasks, to improve crop output. Precision agriculture heavily relies on the Internet of Things (IoT) in several industrialized nations. Prior studies have focused on tackling two significant issues in the field of precision agriculture [4] [5].

The integration of Internet of Things (IoT) technology and advanced materials has led to significant advancements in various fields, including agriculture. Polymer-based sensors, in particular, have emerged as valuable tools for data collection and monitoring in precision agriculture.

Polymer-based sensors are designed to measure environmental parameters such as soil moisture, temperature, humidity, and light intensity. [6] These sensors offer several advantages over traditional sensors, including durability, low power consumption, and resistance to harsh agricultural conditions. Polymers like polydimethylsiloxane (PDMS), polyvinyl chloride (PVC), and polyurethanes are commonly used for sensor fabrication due to their flexibility, biocompatibility, and sensitivity to various environmental factors.[7] Recommender systems, powered by machine learning algorithms, can analyze vast datasets from these sensors to generate tailored recommendations for farmers. By considering factors such as crop type, soil conditions, weather patterns, and historical data, these systems can provide valuable insights for optimizing agricultural practices. Previous studies have demonstrated the effectiveness of polymer-based sensors and recommender systems in various agricultural applications.[8]

This research aims to contribute to the growing body of literature on polymer-based recommender systems for precision agriculture. By integrating IoT technology and advanced data analytics, we aim to develop a robust system that can provide farmers with actionable recommendations for enhancing crop yield and sustainability.

## METHODOLOGY

### Smart Agriculture

The IoT and Artificial Intelligence algorithms in agricultural system help to improve decision support systems. With the use of machine learning, the agricultural system may be improved and updated to meet the needs of farmers.

### IoT in Agriculture

There are several sectors where the IoT is being used to boost efficiency. The IoT is now widely used in agriculture for "smart farming." Internet of Things sensors may record data on weather patterns and soil conditions, which can be used by farmers to increase yields year after year [9]. There is a pressing need to apply novel ideas to agriculture today because of rising global population and food needs. The main purpose of IoT in agriculture is to increase yield while decreasing input costs. Numerous IoT uses for farming have been presented by researchers.

### Machine Learning in Agriculture

Predictive analytics is a subfield of data science and business intelligence that makes use of machine learning to do effective crop analysis in agriculture system. Machine learning algorithms are not a set of instructions to be followed to get a desired outcome. They are a collection of methods for "learning" patterns from past happenings and developing forecasting functions that may be trusted. Using a recommender system, AI-based algorithms for crop analysis may categorize data and provide a crucial answer [9].

 

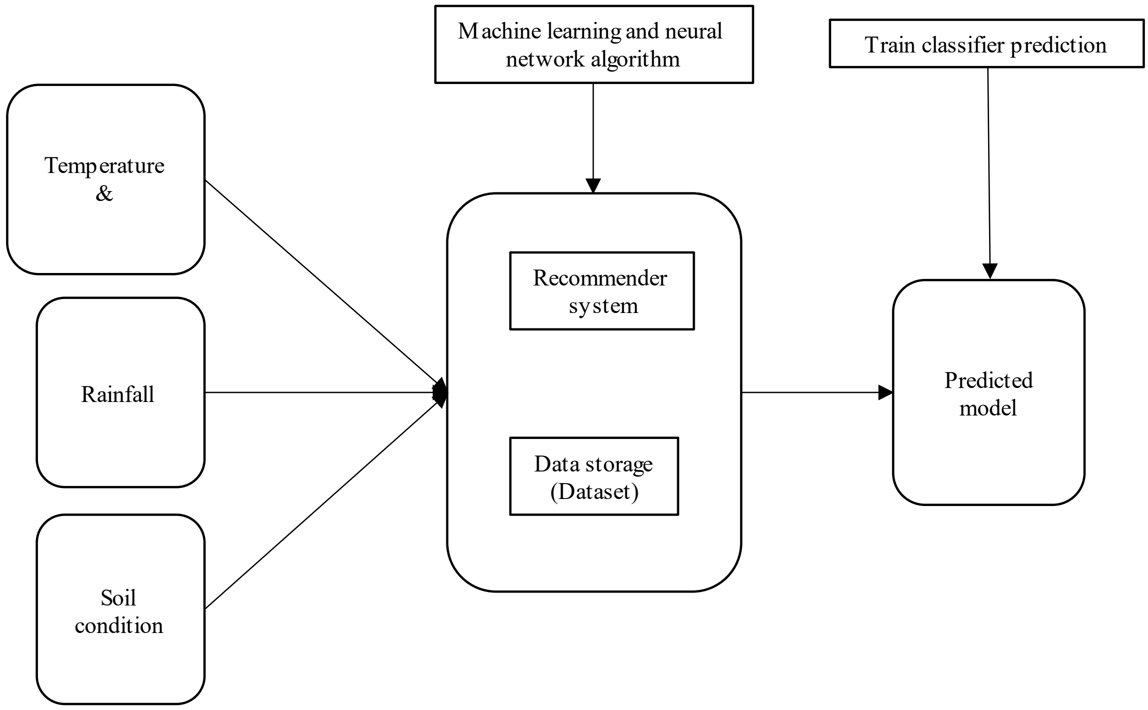


**Figure 1.** Recommender system for smart agriculture [10].

Supervised machine learning strategies need two distinct data sets: a training and a test dataset. With training set's knowledge of the document's classification variables, an automated classifier may evaluate its performance on a test set. Feature selection is crucial in a well-managed AI process, and classifier selection ultimately determines how well classification is carried out. Our recommender framework's primary goal is to provide recommendations that are based on farmer's true interests and preferences [10] [11].

The quality of the recommendation result should be significant, especially when a big number of datasets are used and audits are performed. A small subset of machine learning techniques, including recommender systems and sequential learning computations, will be the primary emphasis of this article.[12]

In figure1, showing the cycle of smart agriculture. In which, Climate related data and soil related data is collected by sensors and optimize by the recommender system using ML and deep learning algorithm, finally we will get our optimal crop prediction.

**Artificial Neural Network**

It is a very advanced kind of data modelling that can accurately capture and characterize intricate input-output relationships. Technology based on neural networks can do "intelligent" tasks in a way that is comparable to the human brain [13]. When it learns something new, it commits that information to memory by increasing the synaptic weights between neurons. From breast cancer detection to the classification of satellite images, neural networks have many potential applications. This research reveals how a Neural Network approach might be utilized to analyze and optimize the dataset for crop yield prediction.

**Different layers in Neural Network**

The dominant form of artificial neural networks often consists of three layers: an input layer is connected to a hidden layer, which in turn is connected to an output layer; moreover, the hidden layer is attached to the output layer.[14]

 

- Input Activity The input section displays raw data input to the grid.
- The activity of each hidden unit is determined by the activity of the input unit and a weight is assigned to the connection between the input and the hidden unit.
- For the output unit to work properly, the hidden unit must be active, and the weights assigned to the hidden and output units must be of the same size.

This type of simple network is important because it allows you to create your own proxy for access to hidden partitions. Hidden partitions can change the weight of connection partitions and choose what is represented.

**Key Components of a Polymer-Based Recommender System**

1. *Polymer database:* A comprehensive collection of polymer data, including chemical structures, mechanical properties, thermal stability, conductivity, biocompatibility, etc., which forms the basis for the recommendation algorithms. This database might also include information on polymer blends, copolymers, and composites.
2. *Machine learning models:* Algorithms trained on the polymer dataset to predict properties and performance. These models often use supervised learning (e.g., regression models, neural networks) or unsupervised learning techniques (e.g., clustering) to identify patterns in polymer properties and recommend suitable polymers for specific applications.
3. *Feature extraction:* Processes that convert raw polymer data into meaningful features (like molecular weight, functional groups, crystallinity, etc.) that influence the properties relevant to a particular application, such as toughness, flexibility, or thermal resistance. These features are essential for accurate predictions and recommendations.
4. *Similarity analysis:* Techniques to find polymers with similar properties or structures. This component often uses algorithms like cosine similarity or distance metrics to identify polymers with attributes closely matching desired criteria, providing users with options that are structurally or functionally analogous.
5. *User interface (UI) and feedback system*: An interactive UI that allows users to input desired characteristics (e.g., biodegradability, mechanical strength) and receive recommendations. The feedback system lets users refine recommendations, enhancing the model's accuracy over time by learning from user preferences and selections.
6. *Evaluation metrics*: Methods to assess the performance of the recommender system, such as accuracy in predicting polymer properties, user satisfaction scores, and relevance of recommended materials. These metrics ensure the system is reliable and effective for end-users.

**Scope of Study**

A significant number of farmers persist in using outdated farming techniques, hence increasing the probability of achieving subpar crop yields. Although many areas of the nation have seen extensive modernization in agriculture, the bulk of agricultural activities are still conducted manually using basic and traditional tools. A significant number of farmers do not possess the essential tools to predict environmental conditions and other factors that impact production. The phenomenon of climate change has an adverse influence on the capacity of farmers to cultivate the essential sustenance required by society. Increasing climate change and increasing extreme events such as floods and droughts disrupt the growing season, limit water availability, facilitate the growth of weeds, pests and fungi, and can reduce agricultural productivity. The automation of traditional irrigation procedures has the potential to significantly increase agricultural production.

The proposed study aims to mitigate the risk of low crop yield by assessing the values of several factors that might impact the quality of the output, and thereafter making informed choices based on this data.

**Methodologies Employed to Evaluate the Performance of Recommender System**

- *Field trials and controlled experiments*: The system's recommendations (e.g., crop variety selection, fertilizer applications, irrigation schedules) are implemented in actual field trials.

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Results are then compared against control fields managed with traditional practices. Crop yield, quality, and resource use efficiency (such as water or fertilizer) are monitored to gauge the system's effectiveness.

- *Yield prediction models*: The recommender system may use yield prediction models based on machine learning or statistical methods to project expected outcomes. Comparing these projections with actual yields helps validate the accuracy and reliability of the system's recommendations.
- *A/B testing:* Fields or farms may be split into two groups: one using recommendations from the system and one using standard practices (the control group). Differences in yield, input costs, and sustainability measures are compared to assess improvements attributable to the system.
- *Data-driven performance metrics:* Key performance indicators (KPIs) like crop yield increase, input reduction (e.g., fertilizers, water), and cost savings are measured. Advanced analytics can also look at time-series data to track the cumulative impact of recommendations across seasons.
- *User feedback and satisfaction surveys*: Farmers' feedback on the practicality, ease of use, and perceived effectiveness of the recommendations is gathered. Surveys and interviews can provide insights into how the system influences farming decisions and satisfaction, which indirectly affects yield performance.
- *Economic analysis:* Cost-benefit analyses, including return on investment (ROI) calculations, assess whether the system's recommendations contribute positively to economic outcomes for farmers. This analysis considers both short-term and long-term financial impacts.
- *Comparative studies with similar recommender systems:* If available, the performance of the recommender system is benchmarked against other systems in the industry. This comparison helps highlight the system's unique advantages or areas for improvement.

## Problem Statement

The suggested system offers an intelligent crop recommendation system that would be very beneficial to farmers and other specialists in the field of farming. To get prompt and relevant data for making informed decisions on the cultivation of various crops, which may address multi-label classification issues. The main purpose of the current concept is to provide performance assessment to choose the most effective feature selection and machine learning algorithm for enhancing crop prediction frameworks. Our study aims to incorporate ensemble learning into a smart crop recommendation system to enhance the quality of recommendations.

## Research Objective

The study aims have been accomplished via conducting research investigations, focusing on several topics outlined below.

- Give positive recommendations to farmers that use IoT technology in Predictive Agriculture to enhance their crop output by accurately forecasting diverse soil variables.
- Enhance the crop recommendation method by using a multi-label classification approach. Additionally, statistical analysis and assessment will be conducted to determine the most effective feature selection and artificial algorithm.

## Literature Survey

In the field of data analysis and intelligence, Predictive analytics includes machine learning as an important factor in the process of efficient crop yield prediction. In this survey, we discussed on IoT-based framework for crop recommendation system.

- Gupta, A., et al. (2023) [15], focused on agricultural sector is characterized by its focus on data, precision, and enhanced intelligence. The advancement of IoT technology has led to the redesign of "smart agriculture" systems. This development in cutting-edge agricultural systems progressively enhances crop productivity, minimizes irrigation inefficiencies, and makes it more financially lucrative. Machine learning (ML) approaches fulfill the need to enhance the learning of the model by scaling it. This research presents a hybrid machine learning approach that incorporates the IoT to accurately forecast crop yields. This problem has three distinct steps: preprocessing, feature selection (FS), and classification. The database is first processed and then feature selection (FS) is done using correlation-based FS (CBFS) and variance inflation factor (VIF) methods. Finally, a two-level machine learning strategy for an IoT based smart farming system is proposed.

- Koshariya, A. K., et al. (2023),[16] discussed the use of modern technologies such as the Internet of Things (IoT) has led to increased efficiency and intelligence in the field of agricultural activities. Smart agriculture is an advanced farming system that provides information on factors such as weather and soil moisture to help grow crops and livestock. It combines sensors and the Internet to collect and share data with farmers. Researchers have developed algorithms that prioritize events and conserve energy. The main goal of the IoT network discussed in this chapter is to increase farm productivity and extend its life by using intelligent techniques such as machine learning algorithms to detect weather conditions and improve production in general.
- Ngo, V. M. et al. (2023), [17] suggested the use of an electronically agricultural record (EAR) to consolidate many independent databases into a single, unified database. Subsequently, we constructed data warehouse using Hive and Elasticsearch to effectively store and oversee agricultural Big Data. Ultimately, we used statistical techniques rooted in our data repository to extract pertinent information on fertilizers, shown by a case study. This statistical approach provides the optimal amount of fertilizer components such as nitrogen, phosphorus, and potassium for the ten most cultivated crops in the European Union (EU), taking into account various climatic and agricultural management variables.

### Research Gaps of Automated Agricultural System

- Existing automated agriculture systems do not meet the requirements of the suggested artificial intelligence approaches because they have not recorded and processed sensor values for different crop phases.
- Appropriateness of the intervals being mentioned for capturing field attributes. The proposed approach for assessing suitability requires modifying the farm monitoring system.

## DISCUSSION

After extensive analysis of the nature of our research and going through some research, we are familiar with the present research. Now we discussed methodologies to get optimal recommendation system.

### Precision Agriculture and Their Importance in Modern Farming

Precision agriculture is a farming management approach that uses technology to monitor, measure, and respond to the needs of crops and soil in a highly targeted way. By employing advanced tools such as GPS mapping, soil sensors, satellite imagery, and data analytics, precision agriculture allows farmers to make real-time, data-driven decisions on everything from planting and fertilizing to irrigation and pest control.[18]

### A. Importance of Precision Agriculture in Modern Farming [19]

1. *Increased efficiency:* By applying resources only where needed, precision agriculture helps optimize the use of seeds, water, fertilizers, and pesticides, leading to reduced input costs and minimized waste.
2. *Higher yields:* Targeted management of crops helps improve crop health, which can result in higher and more consistent yields.
3. *Environmental benefits*: Precision agriculture reduces the environmental footprint by minimizing excess use of fertilizers and pesticides, which can decrease pollution and prevent runoff into water sources.
4. *Adaptation to climate change*: The ability to monitor changing conditions and respond precisely is crucial in adapting to unpredictable climate patterns, helping sustain food production under shifting weather conditions.
5. *Economic viability*: By increasing productivity and reducing waste, precision agriculture helps farmers remain economically sustainable, even as costs of inputs and land use rise.

 

**Challenges [20]**

- *Data quality and availability*: High-quality, consistent, and comprehensive datasets are essential for building an accurate recommender system. However, agricultural data can be incomplete, inconsistent, or unavailable for certain regions or crop types. This lack of reliable data can hinder model training and reduce the system's effectiveness.
- *Data integration and standardization*: Agricultural data comes from various sources—satellite imagery, soil sensors, weather stations, and historical records. Integrating these diverse data types and standardizing them for processing can be complex, as each source may have different formats, scales, and accuracy levels.
- *Dynamic environmental conditions:* Environmental factors like weather, soil quality, and pest pressure are highly variable and can change rapidly. This dynamic nature makes it challenging for the recommender system to produce reliable, timely recommendations, as models must continuously adapt to new data.
- *Complexity of agricultural decisions*: Crop yield is influenced by numerous factors, including crop genetics, soil health, water availability, and pest management. Building a system that considers all of these factors without oversimplifying the recommendations requires sophisticated models and considerable computational power.
- *Farmer engagement and technology adoption*: Farmers may be skeptical of new technologies or may lack the technical expertise needed to use a recommender system effectively. Ensuring ease of use and providing sufficient training are critical but can require significant resources, especially in regions where digital literacy is low.

**Data Collection**

The data taken to analyze the effectiveness of various ML algorithms is sourced from various online resources and other government agencies. Also, we collect the data manually through sensor to get authenticated data. Multiple machine learning algorithms and methods for extracting features have been used to experimentally evaluate labelled data. The data includes crop as a class label attribute and various soil and climatic elements as input features for time series data [21].

**Feature Selection**

Using a lot of features in the ML model development can lead to the "curse of dimensionality," which can make the model less accurate and more difficult to understand. Not every feature is equally important to how well the ML model can predict.

So, feature selection is an important part of machine learning (ML) that is used to improve accuracy, cut down on the number of features used in model development, and make prediction even simpler and faster [19]. On the training dataset, different methods were used to choose which features to use. There are several ways for choosing features that are suggested by Python tools like PCA (Principal Component Analysis). Using PCA, you may decrease the number of variables in your dataset. Data on many variables (potentially many variables) might be valuable when you feel there is some duplication in the variables. in Figure 2, we can see the steps.

**Machine learning Classifier**

Choosing a dataset and splitting it up into training and test sets is a common first step in any classifier procedure. The first set is used to teach the system how to make predictions, while the second is used to test how well it did. Each set comprises about the same number of observations. The ability to predict an output is known as generalization, and it is achieved via training in machine learning. In other words, the system has to be able to adapt to new information rather than just memorizing values. Similarly, supervised and unsupervised learning approaches are extensively utilized in research today; As a consequence, the machine is given a set of objective outputs and is then charged with learning to generate the right output for every new input. Using artificial neural networks, we can sooth our output more.

 

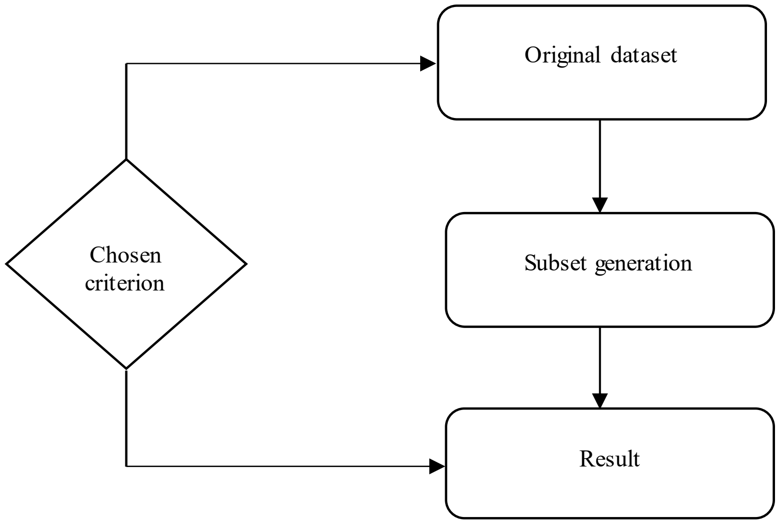


**Figure 2.** Steps for feature selection [22].

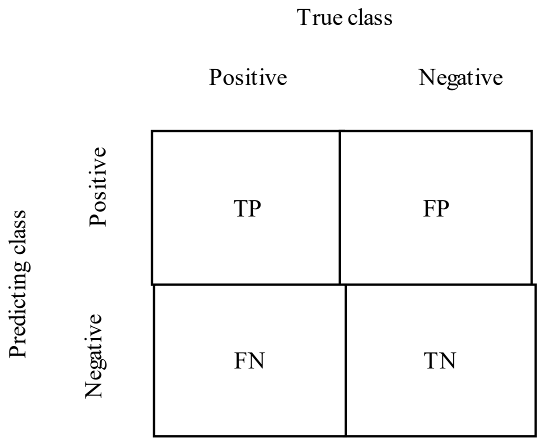


**Figure 3.** Confusion matrix for Mult-Lebel classification [20].

**Model Evaluation**

A classifier's effectiveness is often accessed via the use of a confusion matrix, as seen in the Figure 3. The expected to class is placed in a separate column from the actual class. The diagram elucidates the factors that contributed to the misinterpretation. A test result might exhibit the characteristics of both true and false simultaneously, which is referred to as True Positives. The accuracy of the classifier may be measured by analyzing the confusion matrix [23]. In this context, the true mistake rate is precisely calculated, serving as a measure of the classifier's accuracy and the probability of future cases being properly categorized. We can calculate specificity, sensitivity, precision and accuracy using confusion matrix to classify crops.

Using these explained steps above sections, we can construct an optimal recommender system to predict multi-label crop classification.

## CONCLUSION

The use of machine learning (ML) and neural network methods, which allow computers to acquire knowledge from existing datasets and further customize recommendations, is a notable advancement in Recommender Systems. We will place more attention on alternative recommender strategies and assess their effect, comparing them to all other approaches. Recommender systems still face significant obstacles in terms of scalability and latency, as well as emerging issues such as anonymity. The hybrid method has shown its ability to effectively address the bulk of current system issues. Recommender system has made significant progress in the domains of crop yield analysis. With the use of this model, we may conduct effective assessment of crop analysis and their indications, as well as address pertinent issues that need more examination in future research.

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