

SUSTAINABLE FERTILIZER USAGE OPTIMIZER FOR HIGHER YIELD

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Abstract: Agriculture is an important part of our daily life, but farmers face many problems such as increasing fertilizer costs, poor soil quality, changing weather conditions, and improper use of fertilizers. Using too much fertilizer can damage the soil and cause water pollution, while using less fertilizer than required can reduce crop growth and yield. Therefore, there is a need for a smart system that can help farmers use fertilizers in the correct amount.

This research proposes a Sustainable Fertilizer Usage Optimizer for Higher Yield using Data Analytics and Machine Learning. The system uses information such as soil nutrients (Nitrogen, Phosphorus and Potassium), soil pH, crop type, weather conditions, previous crop yield, and fertilizer usage. The collected data is cleaned and analyzed before applying suitable machine learning algorithms such as Random Forest and regression models. The system then recommends a suitable fertilizer and quantity according to the crop and soil conditions. The expected outcome is to reduce unnecessary fertilizer usage, decrease farming costs, maintain soil health, and improve crop yield. Overall, the proposed system aims to support smart, economical, and environmentally friendly farming.

Keywords: Sustainable Agriculture, Fertilizer Optimization, Machine Learning, Data Analytics, Random Forest, Crop Yield Prediction, Soil Nutrients, NPK, Precision Agriculture, Fertilizer Recommendation.

I. INTRODUCTION

Agriculture plays an important role in providing food and supporting the economy. In India, many people depend on agriculture for their livelihood. However, farmers face several challenges such as changing weather conditions, increasing fertilizer prices, declining soil fertility, and improper fertilizer usage. Fertilizers are necessary for healthy crop growth because they provide nutrients to plants. But applying fertilizers without knowing the actual requirement of the soil and crop can create problems.

When farmers use more fertilizer than required, it can increase their production cost and may damage soil quality. Excess fertilizer can also enter water sources and cause environmental pollution. On the other hand, if the required nutrients are not supplied properly, crop growth may become weak and the final yield may decrease. Therefore, using the correct type and quantity of fertilizer is important for both higher crop production and sustainable agriculture.

Modern technologies such as Data Analytics, Machine Learning, Internet of Things (IoT), and weather data can help solve this problem. These technologies can analyze large amounts of agricultural data and identify patterns between soil conditions, weather, fertilizer usage, and crop yield. For example, information about Nitrogen, Phosphorus, Potassium (NPK), pH, rainfall, temperature, humidity, crop type, and previous yield can be analyzed to provide better fertilizer recommendations.

The main motivation for selecting this topic is the problem of excessive and unplanned fertilizer usage. Many farmers still depend on traditional knowledge or general fertilizer recommendations. A data-based system can provide recommendations according to the actual conditions of a particular crop or field. This can help reduce fertilizer wastage and improve farming efficiency.

The scope of this research is to develop a smart fertilizer recommendation system that can analyze agricultural data and suggest suitable fertilizer usage. Machine Learning models such as Random Forest and regression algorithms can be used for fertilizer recommendation and crop yield prediction. The system can also be developed as a simple webbased

application so that farmers can easily enter their information and understand the results.

The main objectives of this research are:

- To develop a data-driven fertilizer optimization system.
- To recommend suitable fertilizer usage according to soil and crop conditions.
- To reduce unnecessary fertilizer application and farming cost.
- To support higher crop yield while protecting soil and the environment.
- To demonstrate how Data Analytics and Machine Learning can support sustainable farming.

II. LITERATURE REVIEW

i. Patil and Kumar (2020)

Patil and Kumar developed a Crop Recommendation System using a Decision Tree algorithm. Their system used parameters such as soil nutrients, pH, rainfall, temperature, and humidity to recommend suitable crops. The study showed that Machine Learning can help in crop selection. However, the system was mainly designed for a particular region and did not provide real-time recommendations.

ii. Kumar and Rani (2019)

Kumar and Rani studied crop yield prediction using Linear Regression, Random Forest Regression, and Support Vector Regression. Their research found that Random Forest performed well because it could handle complex relationships between agricultural parameters. However, their study considered a limited number of crops and did not provide real-time interaction with users.

iii. Agrawal and Singh (2021)

Agrawal and Singh developed a fertilizer recommendation system using Random Forest and Support Vector Machine. The system used soil NPK values and crop type to recommend fertilizers. It helped improve fertilizer efficiency and reduce overuse. However, the study had limitations related to explaining recommendations to farmers in a simple way.

iv. Zhang et al. (2020/2021)

Zhang et al. discussed the use of Data Analytics and Machine Learning for precision agriculture. Such systems can use soil and environmental information to provide nutrient recommendations. This approach is useful because fertilizer requirements can be different for different soil and crop conditions.

v. Patil and Kale (2021)

Patil and Kale highlighted the importance of IoT-based soil sensors in agriculture. Sensors can collect information such as soil moisture, temperature, and nutrient levels. This information can be used to provide updated fertilizer recommendations according to changing field conditions.

vi. Bongiovanni and Lowenberg-DeBoer (2004)

Bongiovanni and Lowenberg-DeBoer worked on site-specific nutrient management and variable-rate fertilizer application. Their work showed that fertilizer application can be adjusted according to the requirements of different areas of a field. This idea is useful for sustainable fertilizer management because it can reduce unnecessary fertilizer application.

vii. Lobell et al. (2015)

Lobell et al. studied the use of remote sensing and vegetation information for monitoring crop health. Satellite and drone images can provide information about crop conditions and can support better agricultural decisions. Such

technology can be used along with fertilizer optimization to understand crop health.

viii. Tilman et al. (2002)

Tilman et al. highlighted the environmental problems caused by excessive use of chemical fertilizers. Overuse can contribute to water pollution, greenhouse gas emissions, and longterm soil degradation. This shows that fertilizer optimization is important not only for increasing yield but also for protecting the environment.

- **Comparative Analysis of Previous Studies**

Previous studies show that Machine Learning, IoT, soil data, weather data, and remote sensing can be useful in modern agriculture. However, many existing systems focus on only one problem, such as crop recommendation, yield prediction, or fertilizer recommendation. The proposed research combines agricultural data analysis with fertilizer optimization to support a more integrated decision-making process.

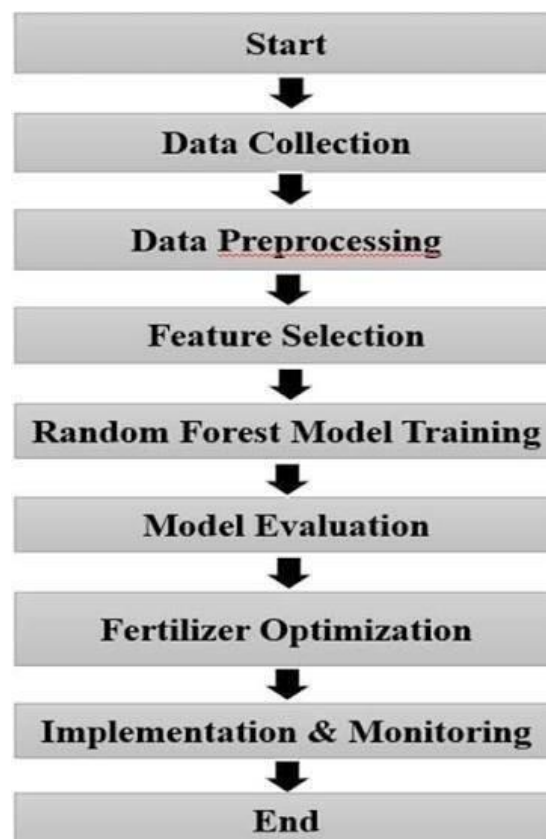
- **Research Gap**

Many existing approaches provide crop recommendations, yield predictions, or fertilizer recommendations separately. There is a need for a system that considers soil nutrients, crop type, weather, previous yield, and fertilizer usage together and converts these inputs into a practical fertilizer recommendation. The proposed research addresses this gap by focusing on fertilizer optimization while considering higher yield and sustainability.

- **Relevance to the Proposed Research**

Previous research provides a foundation for using agricultural data and Machine Learning for decision support. The proposed system combines data preprocessing, feature analysis, Random Forest and regression models, yield prediction, and fertilizer recommendation into a single framework for sustainable fertilizer management.

III. METHODOLOGY



Research Design

This study follows an experimental and quantitative research design. Agricultural data is used to develop and evaluate machine learning models for fertilizer recommendation and crop yield prediction. The system is designed to identify relationships between soil conditions, crop type, weather, fertilizer usage, and yield.

ii. Data Collection

The proposed system uses information such as Nitrogen, Phosphorus and Potassium (NPK), soil pH, crop type, weather conditions, previous crop yield, and fertilizer usage. Data may be collected from agricultural datasets, field records, soil testing, IoT sensors, and weather information where available.

iii. Research Tools and Techniques

Python is used for implementing the proposed system. Pandas and NumPy can be used for data processing, while Scikit-learn can be used for machine learning. Data visualization can be performed using Matplotlib. A simple webbased interface can be developed so that users can enter field information and receive recommendations.

iv. Data Preprocessing

The collected agricultural data is cleaned before model development. Missing values, duplicate records, inconsistent units, and incorrect entries are handled. Numerical features can be normalized or standardized when required, and categorical variables such as crop type can be encoded for machine learning.

v. Feature Selection and Engineering

Important features include NPK values, soil pH, crop type, rainfall, temperature, humidity, previous yield, and fertilizer usage. Feature selection helps the model focus on variables that are useful for predicting yield and recommending fertilizer. Additional derived features can be created from available agricultural information when appropriate.

vi. Machine Learning Model

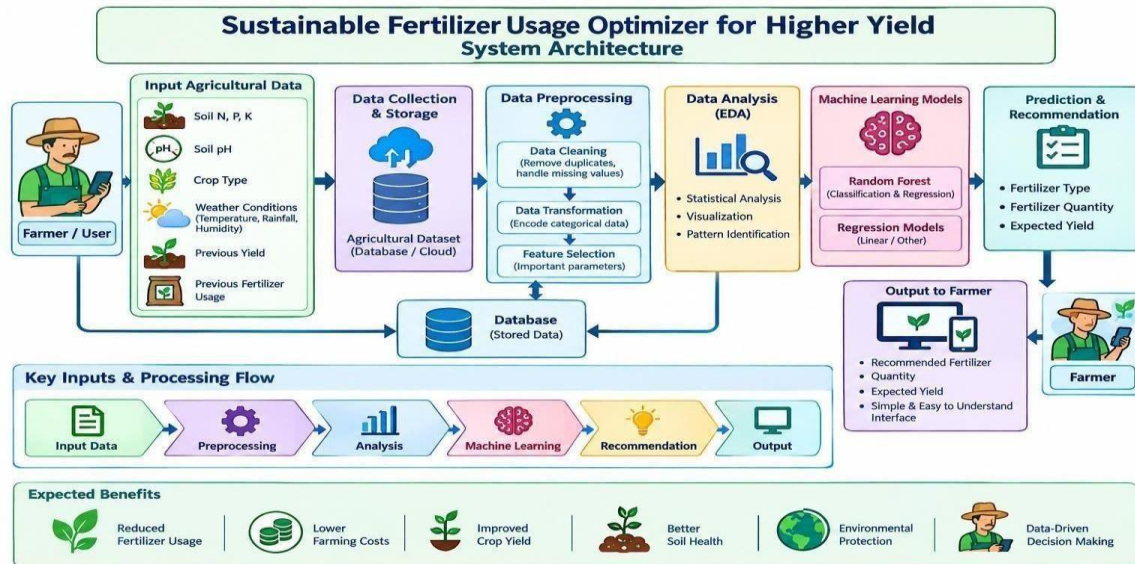
Random Forest and regression models are proposed for the system. Random Forest can be used to capture complex relationships among agricultural variables, while regression models can be used for crop yield prediction. The models are trained using historical data and tested on unseen data.

vii. Data Analysis and Evaluation

The performance of the proposed models should be evaluated using suitable measures. For yield prediction, metrics such as Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and R-squared (R^2) can be used. Recommendation quality can be evaluated by comparing recommended fertilizer usage with observed crop requirements and yield outcomes.

viii. Fertilizer Optimization and Recommendation

After analyzing the input conditions, the system recommends a suitable fertilizer type and quantity. The recommendation considers crop requirements, soil nutrient levels, weather conditions, previous yield, and fertilizer usage. The optimization objective is to balance expected crop yield, fertilizer cost, and sustainable nutrient use rather than simply maximizing fertilizer application.



IV. RESULTS

The proposed system is designed to evaluate agricultural data, identify relationships among soil, weather, fertilizer usage and crop yield, and generate a fertilizer recommendation. Since the supplied project material describes a proposed system and does not provide an experimentally validated dataset with measured model scores, numerical performance values are not fabricated here. The following results section defines the outputs that should be recorded after implementation and testing.

i. Model Performance

The Random Forest and regression models should be evaluated using MAE, MSE, RMSE, and R^2 for yield prediction. The model with better validation performance and stable behavior should be selected for deployment.

ii. Fertilizer Recommendation

The system should provide a fertilizer type and recommended quantity based on soil NPK, pH, crop type, weather conditions, previous yield, and fertilizer usage. The recommendation should aim to avoid unnecessary application.

iii. Yield Prediction

The system should estimate the expected crop yield for the supplied field conditions. Predicted yield can be compared with historical or test-set yield to determine the usefulness of the model.

iv. Optimization Output

The final output should present the recommended fertilizer plan together with the expected yield and, where data is available, an estimate of fertilizer saving or cost reduction compared with the existing practice.

Evaluation Metrics for the Proposed System

Metric	Purpose	Result Status
MAE	Measures average absolute prediction error	To be calculated after testing
RMSE	Measures prediction error with greater penalty for large errors	To be calculated after testing

R^2	Measures explained variation in yield prediction	To be calculated after testing
Fertilizer recommendation	Checks suitability of recommended type and quantity	To be validated
Yield improvement	Compares recommended practice with baseline practice	To be validated

V. DISCUSSION

The proposed fertilizer optimizer combines several agricultural variables instead of focusing on only one problem. The original study material identifies that Machine Learning, IoT, soil data, weather data, and remote sensing can support modern agriculture, while many existing systems focus on only crop recommendation, yield prediction, or fertilizer recommendation. The proposed approach therefore focuses mainly on fertilizer optimization for higher yield.

Random Forest is suitable for the proposed problem because agricultural data can contain nonlinear relationships between soil nutrients, weather conditions, crop type, fertilizer usage, and yield. Regression models can complement this approach by estimating expected yield. However, the final model should be selected only after testing it on a representative dataset.

The recommendation component extends the system beyond simple prediction. A useful system should translate the model output into an understandable fertilizer plan. The recommendation should balance yield, fertilizer cost, and environmental protection rather than encouraging excessive fertilizer use.

The study also has limitations. Model performance depends on the quality, size, and regional diversity of the agricultural dataset. Fertilizer requirements can vary by crop, soil, season, and location. Recommendations should therefore be validated with field experiments and agricultural expertise before large-scale use. The system should be treated as a decision support tool rather than a replacement for professional agricultural advice.

VI. CONCLUSION

This study presents a Sustainable Fertilizer Usage Optimizer for Higher Yield using Data Analytics and Machine Learning. The proposed methodology combines agricultural data collection, preprocessing, feature selection, Random Forest and regression models, quantitative evaluation, and fertilizer recommendation. The system is intended to recommend suitable fertilizer usage according to soil, crop, weather, and previous yield conditions. Its main goal is to reduce unnecessary fertilizer application, lower farming costs, support higher yield, and protect soil and the environment. Future work can include realtime IoT sensors, weather APIs, remote sensing, larger regional datasets, mobile applications, and field validation of recommendations.

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