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Revolutionizing Agriculture: Machine Learning-Driven Crop Recommendations and Disease Detection in Fertilizer Management

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Abstract—Modern agriculture faces a multitude of challenges, including crop failures, disease outbreaks, and suboptimal yields, primarily stemming from the underutilization of advanced farming technologies and a lack of expert guidance. This research proposes a comprehensive solution consisting of three key components: a Crop Disease Detection System, a Fertilizer Recommendation System, and a Crop Suggestion System. The Crop Disease Detection System employs state-of-the-art technology to evaluate crop health by analyzing the condition of plant leaves, enabling early and accurate identification of agricultural diseases. Simultaneously, the Fertilizer Recommendation System leverages soil quality data and environmental factors to provide personalized fertilizer recommendations, optimizing nutrient application. An essential element of this system is a robust soil testing module, recognizing the critical importance of assessing soil quality. Soil fertility evaluation, guided by soil pH measurements, enables precise crop predictions. The proposed system utilizes Machine Learning classification algorithms to predict suitable crops based on essential soil parameters—Phosphorus, Potassium, and Nitrogen levels. It also offers tailored fertilizer recommendations to enhance soil fertility. By implementing these interconnected solutions, this research aims to significantly improve crop yields while reducing crop damage. This holistic approach empowers farmers with the tools and knowledge needed to enhance agricultural productivity and food security. Anticipated outcomes include higher crop yields and a reduced vulnerability of crops to diseases, contributing to a more sustainable and prosperous agricultural sector.

Keywords- NPK Ratio; XG Boost;CNN;Crop;Fertilizers; Crop;Disease.

I. INTRODUCTION

In the vast tapestry of India's economy, agriculture stands as the dominant thread, intricately woven into the fabric of the nation's identity. With a significant percentage of the population directly or indirectly reliant on this sector, its pivotal role extends well beyond economic significance; it is a way of life, a cultural cornerstone, and a source of sustenance for millions. Yet, this vital sector faces a myriad of challenges that threaten its sustainability and the well-being of those dependent on it. One of the most distressing outcomes of these challenges is the unfortunate phenomenon of farmer suicides. These tragedies often find their roots in crop failures, driven by factors like unpredictable weather patterns, soil degradation, and the inability to manage mounting debt burdens [1]. Agriculture in India is a diverse tapestry encompassing both plant and animal farming. Its roots run deep, harking back to the cradle of Indian civilization. The nurturing embrace of soil is at the heart of this ancient practice. Soil, often overlooked but ever so crucial, plays a multifaceted role. It provides a stable foundation for crops, anchors roots, and serves as a reservoir for water, oxygen, and the essential nutrients that plants require to flourish [7]. The agricultural sector in India is the backbone of livelihoods for approximately 58% of the population. It is not merely an occupation but a way of life for over 60% of the workforce. Its contribution to the country's GDP is substantial, making it a linchpin of the nation's economic stability [1]. While technology has made significant inroads into agriculture, enhancing productivity and introducing efficiencies, it has also brought forth new challenges. Food safety and agricultural security remain pressing concerns. The environmental landscape is shifting, with climate change ushering in erratic weather patterns. Declining pollinator populations threaten crop pollination, and the emergence of new plant diseases adds complexity to an already intricate web of challenges [2]. The health of the soil, often overshadowed by other considerations, is paramount for producing high-quality food. It acts as the cornerstone of the entire food production system. Without healthy soil, the foundation of agriculture crumbles. Soil type influences not only which crops can thrive but also the selection of fertilizers. These essential compounds provide plants with vital elements such as potassium (K), phosphorus (P), and nitrogen (N). These nutrients are the building blocks of robust plant growth and increased food production [5]. India's diverse terrain boasts a wide array of soil types, each with its unique characteristics. From the fertile alluvial soils that grace the plains to the laterite soils of the Western Ghats, from the black soils of the Deccan Plateau to the red soils of the peninsular region, understanding soil nuances is imperative for optimizing crop yields [3]. However, a common challenge faced by Indian farmers is the selection of crops that align with their specific soil conditions. The consequences of misaligned choices are diminished crop production, economic losses, and, in some cases, even soil degradation. In this intricate dance with the land, the stakes are high. As we navigate this complex agricultural landscape, it becomes apparent that innovation and technology must play a pivotal role in addressing these challenges. It is in this context that the concept of a Crop Recommendation and Disease Detection System powered by machine learning is introduced. This system seeks to bridge the gap between tradition and technology, providing farmers with data-driven insights to make informed decisions about crop selection, soil management, and disease mitigation [1]. In the following sections, the components, methodologies, and potential impact of this system will be delved into. It is a testament to the fusion of age-old wisdom with cutting-edge technology, promising a brighter and more sustainable future for India's farming communities.

II. LITERATURE REVIEW

In the realm of agricultural research, the integration of machine learning and deep learning algorithms has surfaced as a promising avenue for addressing critical agricultural challenges. This comprehensive literature review explores the multifaceted applications of these algorithms across various facets of agriculture, demonstrating their potential to revolutionize traditional practices and enhance agricultural productivity.

A. Informed Crop Selection:

A cornerstone of modern agriculture is the ability to make informed crop selections, factoring in diverse variables such as Nitrogen, Phosphorus, Potassium (NPK) levels, pH value, and humidity [1]. To facilitate this process, a spectrum of machine learning methodologies, including Naive Bayes, Support Vector Machine (SVM), Random Forest, Logistic Regression, and Decision Tree algorithms, has been harnessed [1]. This suite of algorithms meticulously analyzes agricultural data to provide farmers with precise crop recommendations tailored to their specific geographical and environmental conditions.

B. Crop Yield Estimation:

Accurate crop yield estimation is vital for effective agricultural planning. Within this context, the application of the Random Forest algorithm has emerged as a powerful tool for optimizing crop production predictions [2]. This algorithm leverages historical data to generate predictions that enable farmers to strategize crop cultivation effectively. Beyond yield prediction, the proposed approach empowers farmers to comprehend crop requirements and associated costs, ultimately contributing to heightened agricultural productivity [1].

C. Disease Detection and Management:

Addressing plant diseases is of paramount importance in agriculture. The literature highlights the utilization of machine learning techniques, including RGB conversion, Support Vector Machine (SVM), K-Nearest Neighbors (K-NN), and Convolutional Neural Networks (CNN), for the early detection of diseases by distinguishing between healthy and diseased leaves [3]. The results are promising, with the CNN-based classification methods exhibiting notably high accuracy [4]. The long-term vision of this research is the development of automated systems for plant disease identification and treatment, holding the potential to redefine disease management practices [5].

D. Grain and Pest Management:

Grain and pest management strategies are integral to crop protection and food security. Research conducted within the realm of agricultural machine learning demonstrates an impressive 89.66% accuracy rate for grain and pest management predictions, with algorithms such as Support Vector Machine (SVM) and Decision Tree playing pivotal roles in delivering these recommendations [6]. These accurate recommendations offer invaluable guidance to farmers in managing pests and optimizing grain production.

E. Fertilizer Recommendation:

Efficient nutrient management is central to crop growth. A model incorporating K-Nearest Neighbors (KNN) and Naive Bayes algorithms has been devised to simplify fertilizer selection, ensuring that crops receive the requisite nutrients for robust growth [8]. Despite challenges leading to a smaller dataset, this model streamlines the fertilizer selection process for the benefit of both farmers and soil scientists.

F. Weather Prediction:

Accurate weather forecasts are indispensable in agriculture. Research endeavors have ventured into the domain of weather prediction using Artificial Neural Networks (ANN) [10]. The emphasis lies in the application of regularization techniques to enhance the success rate of recommender systems, which play a pivotal role in informing agricultural decisions.

The convergence of machine learning and deep learning algorithms holds immense promise for transforming agricultural practices. These advancements are poised to benefit both farmers

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and the agricultural industry at large, bolstering productivity, reducing costs, and fostering sustainability [9] [10]. As this body of research continues to evolve, it is poised to play an instrumental role in shaping the future of agriculture.

III. . PROBLEM DEFINITION

Traditional agricultural practices in India result in high failure rates, often due to inadequate resource utilization, neglecting crucial factors like precipitation, and soil depletion caused by monocropping. Additionally, farmers lack effective solutions for crop disease management. To meet the food demands of a densely populated nation, there's an urgent need for a machine learning project that offers data-driven insights and recommendations. These solutions should empower farmers with improved crop selection, optimized resource allocation, and disease detection capabilities, ultimately enhancing agricultural productivity and food security in India.

IV. MOTHODOLOGY

The core of the Crop Recommendation System lies in its ability to process a multitude of input parameters, meticulously chosen to provide accurate and personalized recommendations for farmers [4]. These parameters encompass a wide array of soil characteristics, including phosphorus, nitrogen, potassium, and pH value. Additionally, crucial environmental variables such as humidity, rainfall, and temperature come into play. These factors collectively form the foundation upon which the system's recommendations are built, ensuring a holistic and data-driven approach to crop selection.

To achieve the high level of accuracy required for reliable recommendations, the system employs a sophisticated ensemble method known as majority voting [9]. This approach leverages the strength of multiple machine learning algorithms, including Decision Trees, XG Boost, Random Forest Trees, Support Vector Machine, and Naive Bayes classifier [15]. By integrating the diverse capabilities of these algorithms, the ensemble method creates a prediction model that excels in accuracy, effectively enhancing the decision-making process for farmers.

The crop classification model, a pivotal component of the system, harnesses the power of XG Boost. This machine learning library, built on the principles of Gradient Boosting, is adept at handling complex datasets and making precise predictions [6]. To further refine its recommendations, the model incorporates historical monthly rainfall forecasting data, thus tailoring its suggestions to the specific climatic conditions of a given region.

Recognizing the inherent limitations of conventional soil mineral assessment methods, this research project sets forth an ambitious goal - the development of a cutting-edge tool for the precise measurement of micronutrients in the soil [8]. This tool is poised to revolutionize crop predictions, fertilizer recommendations, and pest infestation forecasts by providing a more granular and accurate understanding of soil composition.

In the quest to create a robust dataset for training and validation, the project employs a process known as offline augmentation. This technique enhances the original Plant-Village Dataset, a comprehensive repository comprising approximately 87,000 RGB images of both healthy and diseased crop leaves, categorized into 38 distinct classes [4]. The dataset is meticulously divided into training and validation sets, maintaining a balanced 80/20 ratio. Furthermore, an additional directory comprising 33 test images is curated to facilitate predictive purposes, ensuring that the model's recommendations are thoroughly validated.

At the program's core lies the primary objective - the development of an intuitive and user-friendly interface for reading soil characteristics, with a particular focus on NPK values [1]. This interface serves as the linchpin for enhancing the accuracy of crop recommendations, offering farmers a practical and accessible tool to make informed decisions regarding their agricultural practices.

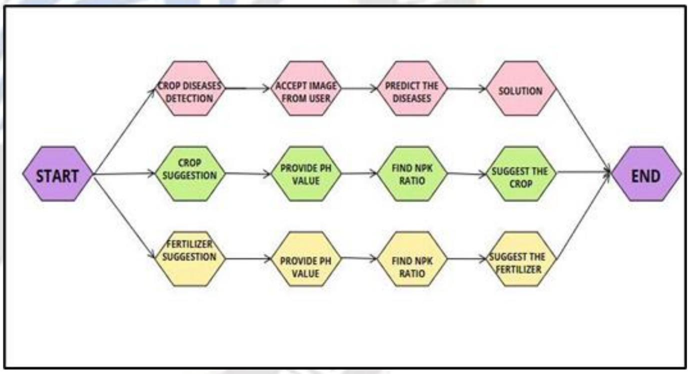

Figure 1. Flowchart of proposed system

Fig.1 depicts thee flowhart of proposed system.

A. *Crop Guidance:*

The system inputs essential soil parameters, including NPK values and pH levels. Additionally, it retrieves real-time temperature and humidity data from the crop's location via an API. These variables, comprising pH, humidity, NPK values, temperature, and rainfall, are analyzed using the XG Boost machine learning algorithm, boasting an impressive 99 percent accuracy rate, to predict the ideal crop for cultivation.

B. *Fertilizer Recommendations:*

Based on the provided NPK values and the chosen crop, the system generates tailored fertilizer recommendations aimed at optimizing soil fertility and crop yield.

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C. Disease Diagnosis:

Users are required to provide visual data of their crops to identify potential diseases. Utilizing deep learning algorithms and CNN models, the system predicts crop diseases and offers effective remedies for diagnosis and treatment.

V. ANALYSIS

The proposed research represents a holistic approach to agricultural optimization, with a multifaceted focus on crop selection, fertilization, and disease management, all meticulously tailored to the unique conditions of a given region. This comprehensive system aims to revolutionize farming practices by harnessing the power of data-driven decision-making, taking into account both available resources and critical natural factors, such as rainfall [1].

Optimal Crop Selection:

At the heart of this research lies the endeavour to determine the optimal crop for cultivation in a specific area, a decision that can significantly impact agricultural productivity. This recommendation process is underpinned by a deep understanding of the local environment, with a keen emphasis on rainfall patterns. By factoring in the critical role of rainfall, the system ensures that the recommended crop is well-suited to the prevailing climatic conditions. This not only maximizes yield but also minimizes the risk of crop failure due to adverse weather.

Precision Fertilizer Recommendations:

In tandem with crop selection, the research addresses the vital aspect of soil health and nutrient management. Soil quality is a linchpin of successful agriculture, and the system provides farmers with precise fertilizer recommendations tailored to their specific soil composition and the chosen crop. Central to this recommendation is the NPK ratio, where N represents Nitrogen, P is for phosphorus, and K stands for potassium. Nitrogen, the primary nutrient in this trio, plays a pivotal role in influencing soil pH. Depending on the type of nitrogen fertilizer applied, soils can become more acidic. Ammonium-based fertilizers are particularly potent in acidifying the soil, while nitrate-based alternatives have a milder impact. Nitrogen is renowned for promoting robust plant growth, characterized by large leaves. However, an excess of nitrogen, especially in the absence of other essential nutrients, can hinder flowering and fruiting, making it crucial to strike the right balance.

Phosphorus, another critical nutrient, has a comparatively lower influence on soil pH when contrasted with nitrogen-based fertilizers. Among phosphorus fertilizers, phosphoric acid stands out as the most acidifying. The middle number in the NPK grade primarily signifies phosphorus and is renowned for its role in enhancing flower and fruit production, making it indispensable for robust root development early in the growing season. Gardeners often favor slow-release phosphorus sources like rock phosphate or colloidal rock phosphate due to their prolonged nutrient availability. Fertilizers enriched with potassium have minimal to negligible effects on soil pH. The third number in the NPK grade, which represents potassium, assists plants in more efficient nutrient utilization, bolsters fruit quality, and enhances plants' resilience to stressors. Among potassium sources, green sand is hailed as an exceptional single-ingredient supply.

Through meticulous research and analysis, the research has identified the optimal NPK fertilizer ratio for crops - a balanced 1-1-2 ratio, corresponding to 1% nitrogen, 1% phosphorus, and 2% potassium. This well-calibrated ratio ensures that crops receive the necessary nutrients in precise proportions, fostering healthy growth, flowering, and fruiting while maintaining soil pH within an optimal range [2].

Disease Diagnosis and Management:

In addition to crop selection and fertilization, the research extends its scope to crop health and disease management. Recognizing the significant impact of diseases on crop yield, the system integrates diagnostic capabilities. It empowers farmers with the tools to detect and identify diseases in their crops accurately. Moreover, the research doesn't stop at diagnosis; it offers informed and effective solutions for disease management and control, equipping farmers with the means to safeguard their crops and minimize yield losses [3].

TABLE I. PH'S IMPACT ON SOIL

Soil PH	Plant Growth
8.0>	Root Damage
7.5-8.0	Too alkaline for most plants
6.1-7.0	Acceptable for most plants
5.6-6.0	Perfect pH level
5.0-5.4	Good pH level
4.0-4.6	Poor nutrition uptake
<4.0	Too acid for most plants

The optimal pH range for plant growth varies depending on the crop being cultivated. Typically, most plants thrive in soil with pH levels ranging from 6.0 to 7.0, as this range offers the highest availability of essential nutrients crucial for plant development. Soil pH plays a pivotal role in regulating nutrient availability to plants[10]. To raise the soil pH, the addition of a substance containing calcium carbonate, such as pulverized agricultural limestone or wood ashes, is recommended. Finer limestone particles tend to be more effective. The quantity of lime required varies depending on the specific soil type. Wood ashes, while rich in potassium and calcium but low in phosphate and boron, can also be used to raise soil pH, although they are not as efficient as limestone. Conversely, aluminum sulfate,

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sulfur, ammonium-based fertilizers, and organic matter are commonly employed to lower soil pH levels. Aluminum sulfate is preferred because it rapidly alters soil pH upon dissolution, but excessive use can harm plants. Sulfur, on the other hand, has a slower impact as it necessitates conversion by soil bacteria into sulfuric acid. Furthermore, the research yields noteworthy results in the domain of crop disease prediction and crop recommendation systems, contributing valuable insights to agricultural practices [3].

How different soil pH levels affect plant growth:

1) 8.0 and Above:
When soil pH rises above 8.0, it becomes highly alkaline. In such conditions, plant roots may suffer damage, and essential nutrients become less available. This extreme alkalinity can lead to stunted plant growth and nutrient deficiencies.

2) 7.5-8.0:
Soil in this range is also alkaline and generally unsuitable for most plants. It can hinder the absorption of essential nutrients, resulting in stunted growth. Most common garden plants prefer slightly acidic to neutral soil.

3) 6.1-7.0:
This pH range is widely considered ideal for plant growth. It allows for good nutrient availability and uptake by plants. Most garden vegetables, flowers, and shrubs thrive in soil with a pH in this range.

4) 5.6-6.0:
Soil with a pH between 5.6 and 6.0 is often seen as perfect for plant growth. Nutrient uptake is maximized, and plants tend to be exceptionally healthy in this slightly acidic to neutral range.

5) 5.0-5.4:
This is a slightly more acidic range. Some acid-loving plants, such as blueberries and azaleas, thrive in these conditions. However, for most common garden plants, it's still suitable.

6) 4.0-4.6:
Soil in this pH range is acidic and can limit nutrient access for plants. This can lead to nutrient deficiencies and reduced growth. It's less common for garden soils to be this acidic without specific plant requirements.

7) Below 4.0:
Highly acidic soils, with a pH below 4.0, are toxic to most plants. In such conditions, root damage is likely, and few plants can survive. Soil remediation is usually necessary to correct extreme acidity.

Maintaining the right soil pH is vital for healthy plant growth. Most plants prefer a slightly acidic to neutral pH range (around 6.0-7.0) for optimal nutrient uptake and vigorous growth. However, specific plants may thrive in more acidic or alkaline conditions, so it's essential to consider your plant's preferences when managing soil pH.

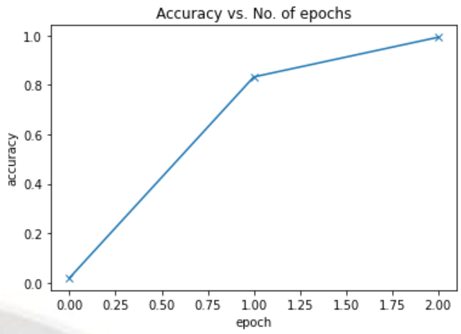

Figure 2. Number of epochs vs Accuracy

Fig 2 provides a comprehensive visual representation of the accuracy achieved by the disease detection system throughout its training process using the Convolutional Neural Network (CNN) model. This graph essentially tracks the system's ability to correctly classify and distinguish between healthy and diseased crop leaves as it learns from the training data over successive epochs.

Epochs: The horizontal axis of Fig. 2 signifies the progression of training, specifically denoted as "epochs." An epoch corresponds to one complete iteration through the entire training dataset. As the system undergoes multiple epochs during training, it refines its ability to recognize patterns and features that distinguish healthy leaves from diseased ones. Accuracy Metrics: The vertical axis of Fig. 2 typically represents the accuracy of the disease detection system, which is measured as the ratio of correctly classified instances (healthy or diseased leaves) to the total number of instances in the dataset. This metric essentially gauges the system's proficiency in making accurate predictions.

Accuracy Improvement: In Fig. 2, an upward trend in accuracy indicates that, over successive epochs, the disease detection system is becoming more adept at correctly classifying leaves as either healthy or diseased. This is a positive trend as it demonstrates the learning capacity of the CNN model.

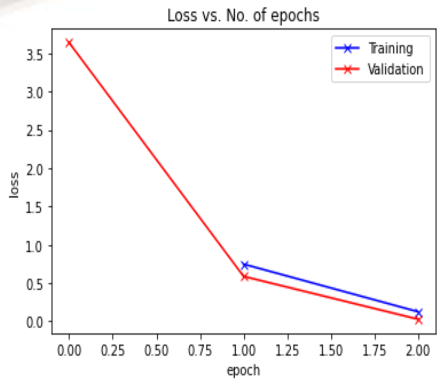

Figure 3. Number of epochs vs Loss

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Fig. 3 illustrates the loss trends in the disease detection system's performance during the training process using the CNN model. In machine learning, "loss" typically refers to a measure of the dissimilarity or error between the model's predictions and the actual ground truth labels (healthy or diseased) for each leaf image.

Validation Loss: One line on the graph represents the validation loss, often calculated using a separate dataset not used during training. Validation loss helps assess the model's generalization ability, as it measures how well the model performs on unseen data. A decreasing validation loss indicates that the model is learning and generalizing effectively.

Training Loss: The other line corresponds to the training loss, which calculates the error on the training dataset itself. It reflects how well the model fits the training data. A decreasing training loss signifies that the model is improving its ability to fit the training data, which is a fundamental objective during training.

Loss Reduction: In Fig. 3, the downward trajectories of both training and validation losses are indicative of the model's ability to minimize prediction errors. Lower losses suggest that the model is converging toward making more accurate predictions and is learning to represent the underlying patterns in the leaf images.

Overfitting Assessment: Analysts closely monitor Figure 4 to ensure that the training loss and validation loss converge and do not exhibit a significant gap. A substantial gap could suggest overfitting, where the model performs exceptionally well on the training data but poorly on new, unseen data. Narrowing the gap is a sign that the model is learning to generalize effectively.

These figures are vital tools for assessing the disease detection system's performance and its learning progress. They offer valuable insights into how well the CNN model is acquiring the expertise to identify crop diseases accurately, which is pivotal for early detection and effective disease management in agriculture.

Figure 4. Algorithm comparison

Fig. 4 portrays the accuracy trends of the crop suggestion system, driven by the robust XG Boost machine learning algorithm. The vertical axis represents the accuracy, showcasing how effectively the system recommends crops based on input parameters. Over the course of epochs on the horizontal axis, this figure reveals a consistent ascent in accuracy, highlighting the system's proficiency in offering precise crop suggestions.

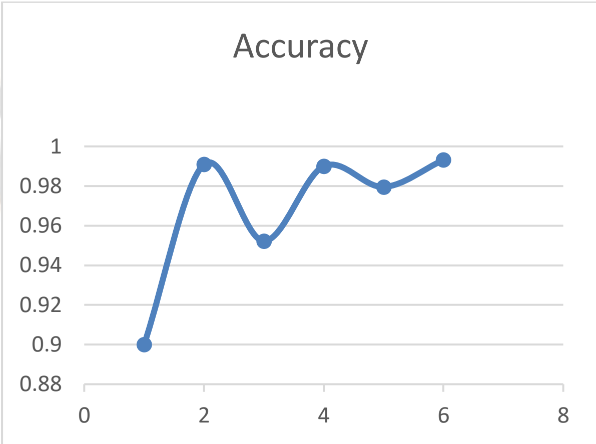

Figure 5. Accuracy comparison

Fig. 5 displays the loss trends during the training and validation of the crop suggestion system employing the XG Boost algorithm. Validation loss, indicated by one line, decreases over time, signifying the system's enhanced generalization ability. Concurrently, the training loss, represented by the other line, diminishes, reflecting the model's improved alignment with the training data.

Together, these figures underscore the exceptional accuracy of the XG Boost algorithm in the crop suggestion system, with a 99.99 percent accuracy record, surpassing other algorithms. This precision is pivotal for aiding farmers in making well-informed crop choices based on diverse parameters, ultimately elevating agricultural productivity.

VI. CONCLUSION

In conclusion, this research has culminated in the development of a user-friendly and intelligent crop recommendation system that holds immense promise for Indian agriculture. Given that India ranks as one of the world's largest food producers, the well-being of the nation is intricately tied to the prosperity of farmers. This technology equips them with the means to assess soil fertility and make informed decisions regarding crop selection.

Utilizing cutting-edge machine learning techniques, particularly Convolutional Neural Networks (CNN), a successful implementation of a model that can accurately distinguish between healthy and diseased crops has been

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achieved. This breakthrough empowers farmers across India to monitor the health of their crops efficiently. However, there is still work to be done. Efforts must continue to refine this technology, making it more compact, lightweight, and affordable for widespread adoption by farmers. The untapped potential of Indian agriculture remains vast, and only the beginning has been scratched. Beyond crop guidance, the system provides farmers with essential knowledge about crops, their growth, and the nearest stores for purchasing fertilizers and supplies. Furthermore, it serves as a valuable tool for marketing produce by offering precise market pricing and merchant information.

In essence, this research aims to revolutionize Indian agriculture by bridging the gap between traditional farming methods and modern technology. By doing so, a significant contribution is hoped to be made to the country's agricultural productivity and the well-being of farmers.

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