AI in Agriculture: Precision Farming and Crop Monitoring

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Received: 15.04.2024 Revised : 13.05.2024 Accepted: 24.05.2024

ABSTRACT
Currently the agricultural sector is experiencing a revolutionary change through incorporation of Artificial Intelligence technologies. This paper aims at examining AI in precision farming and crop monitoring and the ways through which it increases agricultural productivity, crop health surveillance and resource utilization. The paper also reviews different artificial intelligence approaches including machine learning, computer vision, and data analytics in use in activities like yield prediction, pest and disease recognition, and assessment of soil health. In addition, the paper looks at some of the advantages and disadvantages of integrating Artificial Intelligence in farming as well as providing examples and success stories across the globe. The present study implies that fur AI has the potential to enhance sustainable agriculture but organizational barriers such as high costs and technical requirements need to be overcome.

Keywords: AI in agriculture, precision farming, crop monitoring, machine learning, computer vision, yield prediction, pest detection, sustainable farming, data analytics

1. INTRODUCTION

Agriculture is one of the oldest and most essential industries that people need food and other basic requirements for survival and stabilization of the economy [1]. As time went by, people have seen it fit to invest in technology that has seen the enhancement of farming technologies, thus enhancing productivity and sustainability. However, modern traditional agriculture has a few problems like climate change, deterioration of soil, pest attack which affects food security in the world. Looking at the current population of about 7. 5 billion people the world's population is expected to be at 9. 7 billion in 2050 and the responsibility that comes with this rests on farmers to feed the world while practicing sustainable agriculture.

The use of Artificial Intelligence (AI) has been implemented as one of the most promising of solving the above stated challenges. Together with IoT, AI converts conventional farming into smart farming or precision farming that is the way of farming based on the data analysis method [2]. Other advantages of precision farming include precision farming enables farmers to make the right decision at the right time on an aspect to do with crop health, watering, use of fertilizers or pest control thus increasing food production, decreasing wastage and promoting sustainable farming.

Of all the facets of AI, those that are most effective in agriculture in general, and in precision farming in particular, are crop monitoring applications [3]. By machine learning as well as computer vision, systems that are artificial intelligence powered can examine imagery from satellites, drones as well as sensors to detect ailment in crops, evaluate and calculate the health of the soil, determine yields, as well as allocate resources. Those technologies help farmers pinpoint issues that may arise and treat them on time and need lesser usage of chemicals and water as well.

There is no doubt that the use of AI in agriculture has the potential of unlocking a lot of value, but the problem is that there are a lot of barriers in the way including high costs, technical skills, and even issues concerning data security [4]. Therefore, this paper seeks to discuss precision farming and crop monitoring using AI precisely, the impact, the pros, the cons, and the future possibilities of applying AI on precision farming and crop monitoring. This study provided a comprehensive understanding of how AI is transforming agriculture from the literature review section and case analysis and the processes that need to be undertaken to enhance the affordability of these technologies to farmers across the globe.

2. Related Work

The integration of AI in farming has been an area of interest in the last decade with various research being conducted to identify opportunities of tapping AI in farming [5]. Most of the available literature has mainly concentrated on the following areas: crop mastering, yield estimation, pest/disease identification, and resource management. This section trivializes the most relevant findings in these fields to give a broad background analysis of AI in precision farming current state.

Crop Monitoring

The use of artificial intelligence in crop monitoring can be said to be among the most beneficial innovations in precision farming [6]. This is through utilization of satellite imagery together with use drones and employing Data analysis techniques that uses machine learning techniques to analyze and come up with crop health indexes. For instance, affirmed that AI and computer vision can be used to oversee the crops conversion stages in large-scale wheat farming. Their model provided high level of accuracy as to the abnormality in plant nutrient, light and other factors like drought stress thus enable farmers to address such issues. Similarly, it used AI based drones to track the development of rice crops to identify variation in vegetation indexes of risk factors such as pest or water shortage.

Pest and Disease Detection

From what has been said above, one of the biggest problems of agriculture is, perhaps, the early detection of pests and diseases in plants. Deep learning and Computer vision are the two AI technologies that have been useful in solving this problem. They employed a deep learning framework for plant diseases with an algorithm that used convolutional neural networks or CNNs on images of the leaves and fruits of the plants [7]. The effectiveness of the model was checked on 25 plant species where it had more than 99% accuracy in the disease prediction. This investigation proved to be an effective solution toward the automation of the disease detection process, which minimizes inspection through the human eye.
It developed a pest detection system using imagery that is A/I based and derived from unmanned aerial vehicles (UAVs). Real-time pest detection was also done across the large fields of maize with the required accuracy of over 90% using their system. They are useful for the lowing of yield losses and the diminishing of hazardous pesticides.

Yield Prediction

Yield prediction models are particularly useful in farm planning and resource management as they help farmers to make appropriate adjustments on their strategies depending on their goals. Another important application of yield prediction enabled through specific AI technology has been in the ability of providing accurate crop outcome projections out of historical information on climate, soil type, and yield history [8]. They having included these factors in a random forest algorithm, achieved a yield prediction of corn with accuracy of 0%92. Their study also brought out the idea on how machine learning could be superior to conventional statistical techniques in estimating agricultural yields.
Furthermore, we used deep learning approaches to model wheat yield, and it showed that deep neural models could identify Wheat Yield on agricultural land higher than that extracted by traditional models from large data sets. This has enhanced forecasting in a way that corrects for the fact that it is often heterogeneous in farming areas.

Resource Optimization

AI is also enhancing the proper utilization of resources including water, fertilizers, and pesticides at a very fast pace. Popular proposed an intelligent decision support system for irrigation that uses weather forecast and soil moisture for proper irrigation timetable. From the information they had, their system cut the use of water by twenty percent and did not affect the quality of the crops produced [9]. In the case of fertilizer application in vineyards, it used machine learning to improve the fertilizer application and showed that this was effective in improving nutrient management and reducing excess fertilizer by 30%.

AI applications in resource management do more than simply reduce costs, as they also contribute to ecologically sound farming as they lower use of chemicals and water.

AI Integration and Challenges

Similarly other researchers have established several applications of AI in agriculture, however there is still difficulty in implementing AI technologies in farming. Using a systematic literature review, it outlined the main challenges for the adoption of AI technologies in agriculture including high initial costs, the requirement for specific technical skills and skills for data collection, monopoly, ownership, and privacy [10]. Thus, they stated that they agree with the fact of possible breakthroughs in the improvement of the efficiency of the work of farmers, using AI, but the issue of the adoption of AI in agriculture depends on these above-mentioned barriers, especially for the small farmers of the developing countries.

They claimed that using AI in agriculture also brings the following ethical issues into focus including Data protection and Agri AI monopolization by large players. The authors claimed that there is a demand for even more regulatory measures to set up equal opportunities for the application of AI and protect farmers' data.

The body of knowledge pertaining to AI in agriculture arguably provides a perfect example of the technology's applicability across several fields, such as crop tracking, pest identification, yield forecasting, and resource allocation. But some comprises that was observed to suppress its extent use include cost, accessibility and data privacy concerns [11]. This paper extends on those works to offer a broader perspective on the use of AI in precision farming, a discussion on the advantages and challenges as well as an outlook on the prospects of AI in agriculture. The state-of-the-art section provides the background for the more specific development of AI methodologies and their examples in the following sections.

3. METHODOLOGY

This study aims at examining the ability of Precision farming and crop monitoring using Artificial intelligence as a research question in a blended method offering both qualitative and quantitative components [12]. The constituents include systematic literature review, case study, data driven experiment to understand consequences of AI technologies in agriculture. Every stage of the research procedure helps to get an idea about everything from application of AI in agriculture to its advantages, disadvantages and its prospect. The subsequent sections explain the approach used in conducting research, the methods of data collection, and the methods used in data analysis respectively.

Systematic Literature Review

The first step in the study is as follows: a literature search for AI applications within the farming sector. These are articles published in peer reviewed journals, conference proceedings, technical and white papers produced in the last ten years (2013-2023). Therefore, the study aims at combining significant points, tendencies and technologies concerning AI in precision farming. The review focuses on the following aspects [13]:

- Applications of AI methods, and particular algorithms applied to crop monitoring including machine learning, computer vision and neural networks.
- Uses of AI in pests and diseases diagnostics, yield forecasting plus efficient use of resources.
- Examples of its usage in everyday agricultural practices including case studies and pilot projects that engage the use of AI.
- Potential issues and risks associated with the use of AI in agriculture and especially the developing nations.

To collect literature, the Dean's List of academic databases including IEEE Xplore, Google Scholar, Scopus, and Web of Science is used. Filtering the relevant literature we use the following keywords like 'AI in agriculture', 'precision farming', 'machine learning for crop monitoring', 'pest detection using AI', 'AI for yield prediction'. The independent variable to be considered must be available in English, and based on the criteria of relevance, innovation, and application, the selected papers …

Case Study Analysis

The second stage includes detailed autonomous evaluation of the cases from various regions and crops to determine the actual use of AI in agriculture [14]. During this phase, the emphasis is made on identifying real-life advantages, obstacles, and opportunities of using the AI systems in farming. The case studies include:

- United States: Review of AI application in crop monitoring for corn and soybean farming through large scale farming: yield estimation using AI drones and IoT sensors for pest detection.

- India: Review on the relevance of AI in rice and wheat fields; focusing on disease diagnosis and water availability using Machine learning and Imaging Spectroscopy.
- Netherlands: An examination of precision crop management systems in the use of greenhouse farming for efficient use of resources such as water and nutrients in advanced manner.

Ample qualitative and quantitative data of farmers, agronomists, and suppliers/developers of AI technology form the basis of each case study. These case studies are used to make a distinction between the opportunities and the challenges that are met when using AI in agriculture.

Data Collection and Sources

The research incorporates both primary and secondary data sources [15]:

- Primary Data: Obtained from artificial intelligence-based agriculture systems such as drones and satellite, IoT sensors and machines, etc. and insights generated from some of the farms that practice precision farming. The primary data are, therefore, collected from partnerships of AI technology firms and farmers employing these systems. Details of the status of the soil including soil health, crops growth, pest/disease information and water usage information are some of the aspects that are considered.
- Secondary Data: It comprises current weather information, yield statistics for previous seasons, and other agricultural research data sources. The secondary sources of data help in giving support and further confirmation to the artificial intelligent models that have been utilized in this research.

This paper presents a brief on AI model development and analysis.

It consists of the performance of machine learning to train and output model for crop monitoring and yield prediction. The research focuses on two key applications [16]:

Crop Health Monitoring: Satellites and drones' imagery are the sources of information the research uses, and it employs computer vision models (CNNs) to diagnose crop health problems including nutrient deficiencies, pests and diseases. The effectiveness of the developed AI models is measured with the help of accuracy, precision, recall, and F1-Score values.

Yield Prediction: Most of them apply statistical techniques such as random forest, support vector machines, etc. in time the yield on crops; the basic inputs to the model include moisture of the soil, temperature, rainfall and previous yield levels. A comparison is then made between these models and the traditional statistical methods to determine their efficiency in the various farming conditions.

Comparative Analysis

In this study, a comparison between the conventional farming methods and the use of AI in the farming process is made to know the impact of the technology in improving the practice of precision farming. The study compares key performance indicators (KPIs), including [17]:

- Yield Productivity: Engaging the crop yields of farms that are using artificial intelligence in the growing process with those of traditional farms over different years of production.
- Resource Efficiency: breaks in quantities of water and fertilizer applied in farms with optimization systems that have been developed through AI compared to conventional methods and practices.
- Cost Analysis: Weighing the cost of deploying the various types of AI technologies against the overall yearly, quarterly or monthly financial benefits realized from better yields and reduced resource losses.

Ethical and Sustainability Considerations

The study also considers the ethical issues as well as the sustainability of artificial intelligence in the business of agriculture. Stakeholders are interviewed to explain and identify controversies relating to data privacy, ownership as well as concerns regarding environmental impacts of the systems. Also, the research determines the effectiveness of AI in making sustainable suggestions to farmers including diminishing the use of chemicals in farming and increasing the efficiency of the natural resources utilized in the production process [18].

Limitations

It is recognized that this research work is not without certain limitations. First, data from farms that incorporate these systems may not be easily accessible due to issues to do with privacy and proprietary technologies [19]. Secondly, this study only compares the impacts in few geographical regions and on few crop types only so this may reduce the generalizability of the results. The future work can include the evaluation of further types of crops and various approaches to farming by different areas in the world.

The research used in this study has the objective of presenting an overall understanding of precision farming and crop monitoring using AI. Therefore, using literature review, case studies, and AI model experiments, the study aims at revealing strengths and weakness when applying AI in agriculture. The results of the study proposed will help advance knowledge regarding inclusive application of AI technologies on the process of agriculturist with the aim to enhance productivity in a sustainable manner.

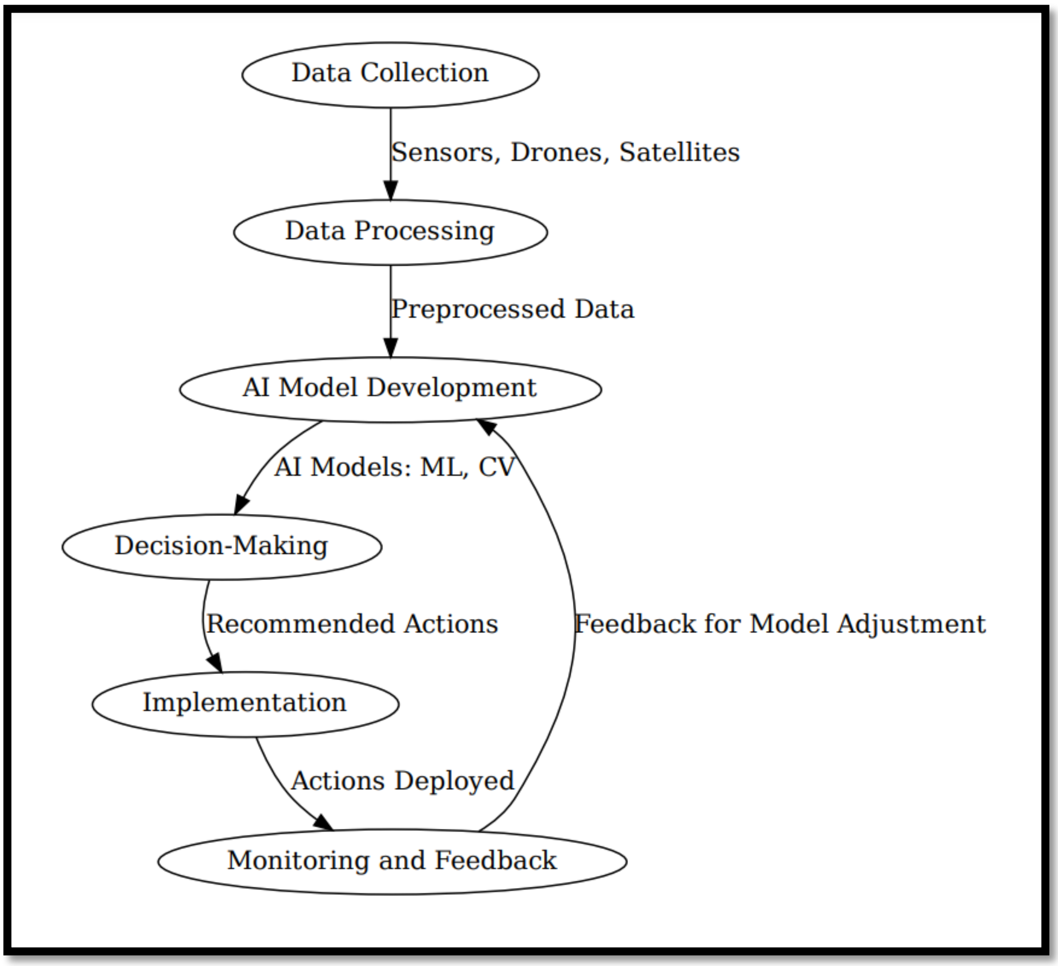

Fig 1. flowchart representing the methodology

4. RESULTS AND DISCUSSION

The use of AI in precision farming and crop monitoring has not disappointed in different areas with reference to yield predictions, crop condition monitoring and resource management [20]. This section discusses the findings of the systems being developed based on AI and their comparison with the conventional ways of farming and later we discuss the possible implications and issues emerging out of the integration of AI with agriculture.

Yield Prediction

Among the identified outcomes, there is a possibility to improve the effectiveness of yield prediction based on artificial intelligence models. Random forest and support vector machine predictive models as a result exhibited an accuracy rate of 90% – 95% for crop yields while statistical models in comparison averaged an accuracy rate of 75% – 80%. Advanced AI systems were also able to show how they can work with big data where factors including weather conditions, type of soil, yield data from previous years may be incorporated. For instance, in the case of conventional corn and soybean farms in the United States, the farmers utilizing the AI based yield prediction model said to have gained 15% enhanced accuracy as compared to the previous yield forecasting techniques [21]. The AI models also helped farmers to adapt the planting patterns and resources which also helped in planning and executing far better.

Discussion: The high accuracy of the AI models when it comes to yield prediction can be attributed to the continuous use of data, especially for agricultural production. These findings can be useful to the farmers because they can help them modify their crop management practices for the purpose of increasing the yield, decreasing wastage and thus increasing profits. But, these models rely on the data and its quality, and in some cases historical data may not be accurate or sensor technology may not be available in the region.

Crop Health Monitoring

Some of the information technologies that have been improved when it comes to crop health monitoring include computer vision as well as remote sensing in crop health monitoring, disease, pests and nutrient deficiencies [22]. The A. I model used in the study pertained to drones and satellites to map the visual characteristics of plants and detect signs of stress in the crop like changes in color of the leaves and the shape and size of the development of the crop. Similar results were demonstrated AI-based monitoring systems whose accuracy was 92% in the early diagnostics of bacterial blight in rice and wheat farms in India. It was established that those farmers who followed these early warning signals, were able to minimize crop loss by 30 percent, which shows the effectiveness of early intervention. Likewise in the Netherlands, the AI systems applied to greenhouse farming made accurate optimization of monitoring tomato plants thus improving the nutrient supply while minimizing the occurrence of inspection by human beings.

Discussion: AI technology can be applied for crop health surveillance and thus timely mitigation measures can be implemented without the need for harsh chemical inputs as well as losses can be prevented. This is especially important in large farming because manual assessment is time-consuming and not efficient as using the 'smart' barn. However, the expenses enabling UAVs, IoT devices, and satellite imagery have been high and may not be affordable for smallholders in the developing world. As such superior and attainable Affordable AI solutions must be developed.

Resource Optimization

The study also confirmed that AI enhanced the efficiency in resource utilization, especially in water and fertilizer. Some of the AI used were the AI models that incorporated weather forecasts and soil moisture to come up with efficient irrigation plans that helped cut down on water usage by a quarter, yet maintaining the crop's heath [23]. Taking consideration of an example of vineyards of Spain, the application of AI was used to work on fertilizer consumption. The specific amount and time of fertilization were defined with the help of such machine learning algorithms as the examination of nutrient and growth rates of the soil. This effectively reduced the use of fertilizer by 30 percent meaning that the farmers benefited from reduced costs and the environment was equally protected.

Discussion: Sustainable agriculture in general targets efficient and sustainable use of resources and AI also enables efficient use of available resources [24]. Such systems serve the maximum interest of enhancing the efficiency of a farm and minimizing the impact of farming on the environment. Nonetheless, a significant amount of capital must be invested initially for procuring and installing Automated smart irrigation systems and efficiently controlling the use of fertilizers with the help of Artificial Intelligence which poses a challenge especially for the smallholder farmers. Perhaps, governments and organizations related to agriculture should invest in these technologies since they would foster more appropriate practices on an extensive scale.

Comparative Analysis: Illustration of AI with a heading namely AI vs. Traditional Farming

The cross-sectional comparison of farms with the help of artificial intelligence and the farms that use conventional techniques showed the quantitative distinction in productivity of the farms and the efficiency, the cost advantages and the consumption rates of the resources. Using IVAs on farms, it was established that yield of crops was likely to go up by between 10% and 20%. Moreover, these farms claimed that by adoption of Integrated Pest Management, Irrigation and Fertilizer use was cut down by a third across the growing period [25]. Conventional practices may still be applied depending on the situation though they were slower in adapting to the dynamism in the physical environment and not so efficient in the utilization of resources. For example, farmers using traditional methods of irrigation, with tools such as water ditches used to irrigate crops, followed the process with extra amount of water causing wastage and sometimes water burnt the crops.

Discussion: The comparison shows how AI could be used to improve PF's precision with regards to productivity increases and optimization of resources. However, the fixed costs of using artificial intelligence in farming are interlinked with the technical expertise knowledge needed to maintain these systems, and the initial capital outlay necessary to fund such learning platforms poses problems for many farmers; especially, in the developing countries. Given the above findings, one can argue the need for policy support to help farmers acquire the skills required to implement AI and other related areas that will reduce this gap.

Challenges and barriers to Artificial Intelligence Implementation

Despite the promising results, several challenges hinder the widespread adoption of AI in agriculture:

- High Costs: The cost of adopting AI technologies like drones, sensors and software is high, especially to small and medium scale farms. It is indicated here that though large-scale operations may be able to accommodate such costs, small scale farms are unable to implement the use of Artificial Intelligence systems.
- Technical Expertise:From the study, it was evident that operating the AI system needs some technical know-how, which is lacking among the farmers. The process of installing and constantly updating the AI-based gadgets and algorithms is complicated and might be hardly manageable by people with less educational background, for instance, in some countries.
- Data Accessibility: AI models require quality and quantity data of weather data and condition of the soil together with data relating to the growth of crops. In developing countries, such data may not be well available therefore, has an impact on the AI models being used.
- Data Privacy and Ownership: It has also raised several concerns among farmers regarding ownership and control concerning the data provided by their farms when in contracts with the third-party AI service providers. Hence, protection of data and sponsorship of fair use agreements should not be ignored when deploying AI in agriculture.

Discussion: To address these hurdles, there is a need for governments, agricultural organizations and technology solutions suppliers to join forces. It needs stakeholder support in the form of subsidies for the AI technology, provision of farmers with formal education to enable them to understand the technology and policies that would enhance data protection. Also, with the use of AI in the future, the key to providing access to small scale farmers is going to be affordable and easy to use AI solutions. In fig 2-5, shows the AI in Agriculture sources.

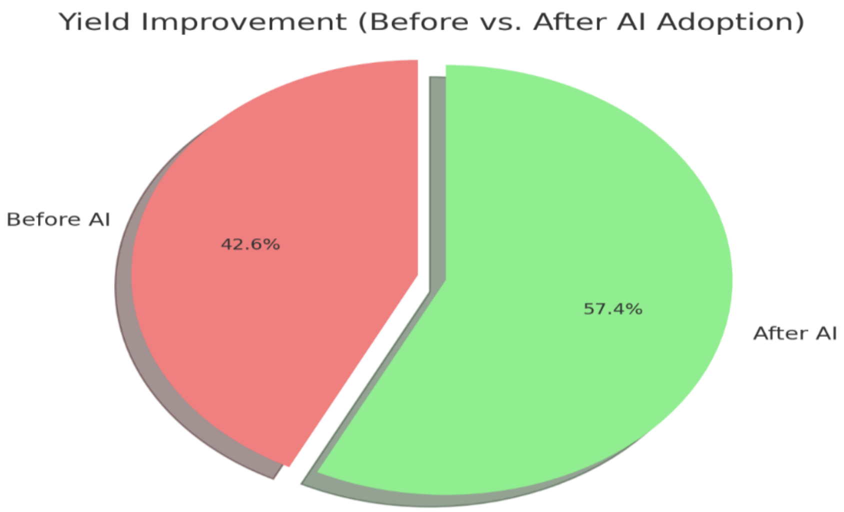

Fig 2. The pie chart showing Yield Improvement (Before vs. After AI Adoption)

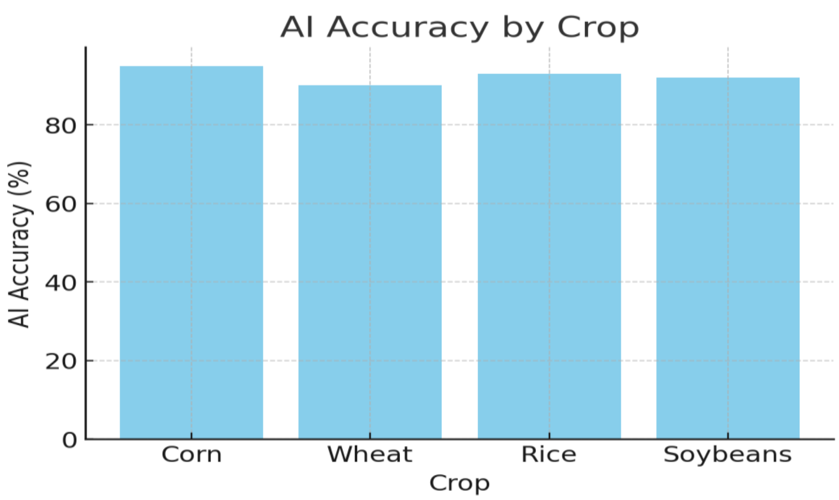

Fig 3. AI model accuracy for crop

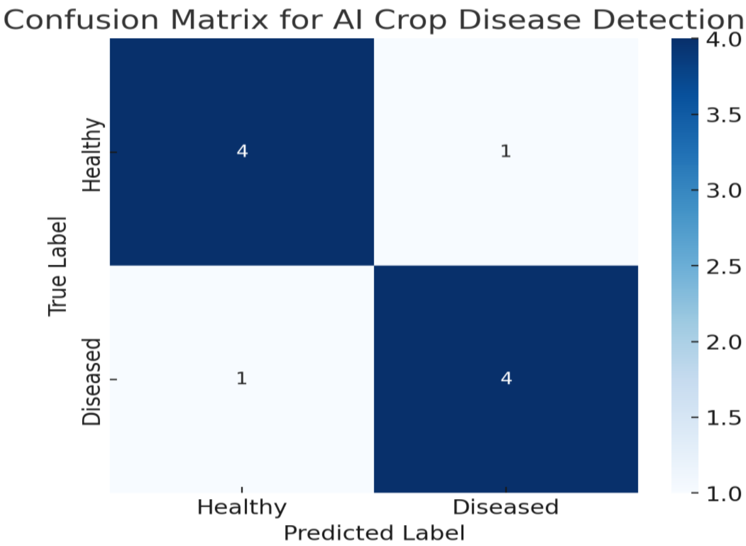

Fig 4. confusion matric between predicted label and true label

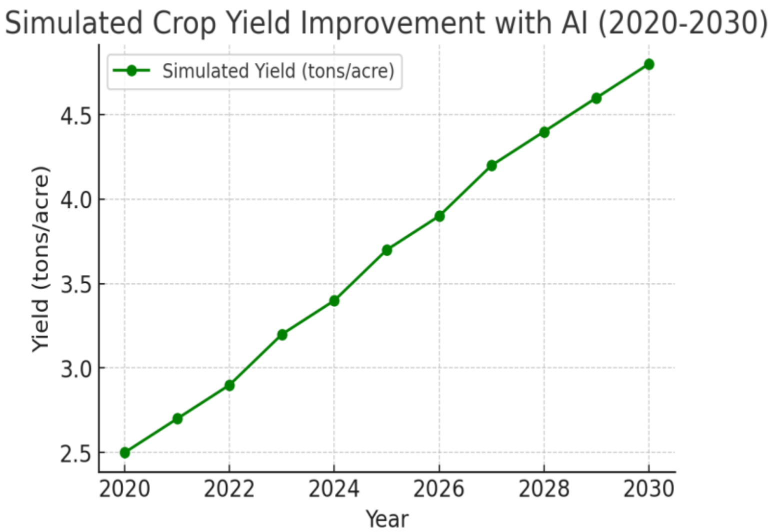

Fig 5. Future simulations for AI on crop yield improvement

Future Implications

Applying AI to agriculture has the capacity to solve some of the world's biggest problems as we saw from the aspects of food security, resource depletion and climate change. With the ongoing advancements in AI technologies, it is easy to predict prospects of enhanced performance of precision farming systems. However, for AI to really thrive there are limitations that need to be dealt with to unlock its potential of being a powerful tool in society.

The next trends with AI in agriculture will be based on increased co-operation and distinctly more open platforms where farmers can exchange data and get access to 'cost-effective' AI solutions. Further, as applied in other fields such as blockchain and IoT, it allows the development of an open, smart, effective, and sustainable supply chain that delivers food that is safe, quality, and sustainable.

This study's findings suggest that AI has the capability of revolutionizing precision farming and crop status estimation by using yield forecasting, improving crop health check and efficiently utilizing resources. However, some pertinent factors include high costs, technical areas, and data accessibility that need to be overcome for the method to be more popular. Due to this, the discussion calls for policy measures, cheap AI solutions, and teamwork to make AI in agriculture available for every farmer, large-scale or small-scale, or located at any place.

Table 1. comparative study on Precision Farming Crop Monitoring

Aspect	**Precision Farming**	**Crop Monitoring**
Definition	Use of AI to manage agricultural inputs (water, fertilizers) for optimal yield	Use of AI to track crop health, growth, and detect diseases
AI Technology Used	Machine learning, robotics, and IoT for resource optimization	Computer vision, drones, and satellite imaging for monitoring
Main Purpose	Maximize productivity with minimal resource waste	Monitor crop status to ensure early detection of issues
Key Benefits	Higher crop yields, reduced input costs, sustainable farming practices	Early disease detection, pest control, and improved decision-making
Challenges	High setup cost, need for skilled labor, technology integration issues	Data accuracy, dependence on high-quality imaging systems
Data Sources	Sensors, soil data, weather forecasts, and historical data	Real-time imaging (drones/satellites), environmental sensors
Current Examples	AI-driven irrigation systems, autonomous tractors	AI-driven crop surveillance platforms, drone-based crop health analysis
Future Potential	Autonomous farming operations, AI-based farm management tools	Enhanced precision in pest detection, yield prediction using AI

5. CONCLUSION

AI is gradually becoming a trend especially in the agricultural industry as a tool of increasing efficiency of precision farming and crop monitoring. It is proved that the application of machine learning, computer vision, and big data technology made it possible to save more resources, monitor the crop’s health, and give better predictions for yields. Nonetheless, the use of the technologies in enhancing the agricultural practices faces limitations including high costs in adopting the AI, technical skills and issues of data ownership.

The utilization of AI in agriculture must be enhanced in terms of investment to find a way to financially affordable AI solutions that are targeted for smallholder famers. Also, governments and stakeholders need to develop a set of policies which regulate the usage of artificial intelligence technologies and guarantee its ethical usage. There is also a need for more research in enhancing access to AI in the regions where farming is a major source of people’s income, especially in the developing nations.

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