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Artificial Intelligence in Sustainable Agriculture

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Abstract: ***Humans have been inventing machines to accomplish arduous and time-consuming tasks. Technology has advanced to enable the development of machines that perceive and acquire data, understand language, retain it as knowledge, deduce information, reason, and solve problems. The widespread deployment of artificial intelligence is a milestone in the history of the transformative aspects of modern technology. Agriculture is a vital sector that supports economic growth and human subsistence and automation in this sector is a global concern. A vast majority of people in India's agrarian economy depend on agriculture for their livelihood, so it is crucial to promote sustainable agricultural practices. Due to population growth, conventional farming techniques can no longer keep up with food demand. Various novel automation technologies are being established to meet these needs and provide employability in this field. Ensuring food security despite climate change and population growth is a challenge for Artificial Intelligence. Recent environmental changes and climate catastrophes have affected agricultural production, and it is crucial to leverage technology to mitigate these impacts. Using technology tools like AI, Unmanned Aerial Vehicles (UAVs) or drones, and sensors is an important step towards sustainable agriculture. These biosensor tools can help farmers monitor soil moisture levels, soil alkalinity, pesticide and toxicity levels, and identify diseases and pests that affect crop health. Biosensors can also help detect disease-causing organisms, enabling farmers to take preventive measures to ensure increased crop productivity. The paper aims to review technological innovations and suggest steps to integrate technology for the benefit of society through sustainable agricultural practices.***

Keywords: Agriculture; Artificial Intelligence (AI); Biosensor; Crop health; Data; Environment; Machine learning (ML); Sustainability; Technology.

I. INTRODUCTION

The combination of rising global population, increased urbanization and purchasing power are consistently posing an increased demand for food and other commodities. There is a great deal of pressure on farmers to raise production, while facing challenges such as financial constraints, limited land and other resources, non-availability of labor and unpredictable weather. As a society, we need to figure out ways to help farmers mitigate or at least cope with the risks they face. To address these issues, new automated ways are being developed to increase agricultural productivity, as traditional farming methods are unable to do so [1, 2]. Furthermore, the gradual loss in fertility of the topsoil calls for novel approaches to farming [3]. One of the most promising futuristic developments is the widespread use of artificial intelligence in sustainable agriculture. Agricultural sustainability refers to the ability of agricultural systems to adequately maintain productivity so as to satisfy the demands of the current generation without endangering the capacity of the next generations to satisfy their needs. Farming methods that minimize the negative impacts on the environment, society, and economy, while producing enough food to meet current and future demands are preferred [4]. Sustainable agriculture involves practices that conserve natural resources, minimizes the application of synthetic fertilizers and pesticides, and promotes the long-term health and resilience of ecosystems [5, 6].

II. IMPORTANCE OF AI IN AGRICULTURE

The agricultural industry is facing various challenges, such as climate change, population growth, and limited resources. The agricultural industry must incorporate novel innovations and cutting-edge technologies, such as artificial intelligence and machine learning (ML), to address these challenges [7]. AI and ML have the potential to revolutionize agriculture by providing farmers with valuable insights and improve efficiency. Al has several uses in agriculture, including prediction of crop disease, monitoring soil moisture content, modeling crop growth, evaluating pesticide requirement and assessing nutrient loss [8]. AI may help farmers make informed decisions about crop output, therefore it is crucial for effective and “smart agriculture”. AI tools’ efficiency and data dependability indicate the agriculture industry’s growth and potential.

It can aid farmers with processes such as deciding which crop to select, when to plant it, how much to irrigate, when to apply fertilizer, when to conduct pest management and which pesticide should be used, by leveraging AI data from ML [9]. AI can help to understand the response of seeds to varying conditions of weather and soil types [10]. Using this information can help to reduce the likelihood of plant diseases. (Fig.1)

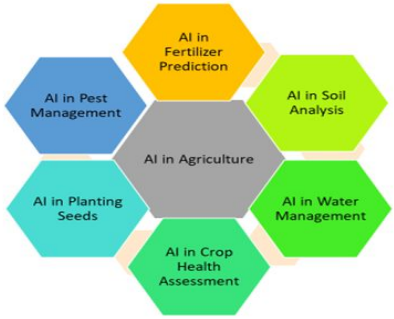

Fig.1 AI in Agriculture

A. AI in soil analysis

AI and remote sensing can enable large-scale monitoring of soil conditions [11]. This helps assess the soil quality, and its improvement can lead to high crop yields. Agriculture AI systems such as soil sensors, soil analysis, drones, or even smartphones can provide information and keep a check on soil's moisture, temperature, and overall state and compare this data with the parameters that have delivered the maximum crop yields. Additionally, farmers may save water and money while improving crop yields. AI may use datasets to assess the environmental impact of different fertilizers, their dosages, and types to determine the optimal amount for crop production and minimal environmental impact. They will make farming greener (12).

B. AI in fertilizer prediction

AI may use data sets to assess the adverse environmental impact of different fertilizers, their concentrations and types, to determine the optimal amount of fertilizer for enhancing crop production while minimizing its harmful effects. Artificial intelligence (AI) can analyze factors including soil-quality, weather patterns, crop type, and nutrient requirements to determine how much and what kind of fertilizer should be used in a given field. AI algorithms can identify the optimal fertilizer blend and application rate to maximize crop yields. It can also help in targeted fertilizer application [13]. Using AI in fertilizer prediction can also help reduce waste and environmental pollution. By minimizing over-fertilization, farmers can save money and reduce the amount of excess nutrients that run off into nearby water sources. Another approach is to use sensor technology and machine learning algorithms to monitor plant growth in real-time and adjust fertilizer application rates accordingly. For instance, sensors can monitor soil nutrient levels and plant responses to fertilizer, allowing for more precise dosage administration. AI has the potential to revolutionize fertilizer prediction effectively, efficiently, and economically which can lead to improved crop yields while promoting sustainable agriculture practices [14, 15].

C. AI in planting seeds

Due to climate change, farmers are having trouble knowing when to plant seeds. The use of AI tools could help farmers with smart seeding methods, speed up production, improve product quality, and decrease waste [16]. Automated tractors can be used to prepare the land for planting and harvesting. Using GPS, these tractors can operate unmanned. Drones can hence collect data and report on the condition of farms and crops [17]. Drones equipped with AI technology can be used to plant seeds in hard-to-reach areas or areas with difficult terrain with high precision and speed. This can help reduce labor costs and increase efficiency. Farmers can make a more educated decision about when to sow crops with the help of AI inputs which can further help farmers plan when to plant crops based on factors like weather and wind conditions. AI can be used to monitor the planting process in real-time and make adjustments as needed. The AI system can adjust the planting depth and spacing for each seed to ensure optimal growth. This can help ensure that seeds are planted in the best possible conditions, such as areas with higher nutrient content or better water availability, reducing the risk of crop failure [18, 19].

D. AI in weed control

The development of remote sensing techniques for locating, identifying, and managing various weed species in a field is made possible by advancements in AI-powered image recognition technology [20]. AI-powered machines such as robots, agri-drones etc., developed by many technology companies utilize data from cameras, laser sensors, and machine learning algorithms to detect, identify and target individual weeds, while allowing farmers to determine the most effective control methods for each weed, avoiding crop damage. The targeted area can be sprayed with the appropriate herbicide and weeds physically removed [21]. This reduces the amount of herbicides used and minimizes their impact on the environment. Robots driven by artificial intelligence can also be utilized to undertake weed management tasks like hoeing and manual weeding.

Thus, AI can help reduce the use of costly herbicides and other chemicals and improve weed control efficiently while reducing the need for manual labor [22]. Using AI, meteorological and soil records can be studied to predict where and when weed outbreaks can develop and also recommend the most effective herbicide for the situation. This can help farmers plan their weed control strategies, reducing the need for reactive treatments and increasing the effectiveness of crop management.

E. AI in pest and insect management

Artificial intelligence can identify and help with management of pest and insect populations, establish the types and doses of pesticides that should be used [23]. In addition, AI equipped drones may be employed to spray insecticides over fields thus enabling farmers to take proactive measures to prevent infestations [24]. By evaluating pest behavior, and crop type, AI algorithms can identify the most effective pest management strategies and reduce the use of hazardous pesticides. By creating AI models that can identify areas with a high risk of pest infestations one can predict when and where pests are likely to appear. To monitor insect populations in real-time, another method is to employ sensors and machine learning algorithms. Sensors can detect changes in temperature, humidity, and other environmental factors that may influence the behavior of pests. Machine learning algorithms can then examine these data to make predictions about the occurrence of insect outbreaks. In addition, AI can be used to control pests and parasites through the development of precision agriculture techniques. Drones equipped with cameras and machine learning algorithms, for instance, can be used to identify and target specific pest-infested areas. This allows for the precise application of pesticides and reduces the environmental impact of conventional pest control methods.

F. AI in water management

AI can help predict water demand for crops based on pre-existing data, current weather patterns, and soil moisture levels. Predictive analytics allows for the estimation of precipitation and evapotranspiration. Soil moisture, temperature, and other important information can be obtained from models trained with soil samples and other datasets. This information can help farmers plan their irrigation schedules and avoid over or underwatering their crops. Accordingly, farmers may save water and money while improving agricultural yields [25]. The delicate agronomic, climatological, and hydrological equilibrium is profoundly affected by how water is managed throughout agriculture. Daily, weekly, or monthly evapotranspiration estimates are now possible with the help of ML-based applications, enabling more efficient usage of irrigation systems [26]. Predicting the daily dew point temperature accurately helps in estimating evapotranspiration and evaporation and also in anticipating weather phenomena.

G. AI in crop health assessment and disease control

Machine learning algorithms are provided with input data of images and corresponding output labels which define the category or class of the image. These images are used to identify patterns and features that are indicative of plant diseases [27]. Once trained, these models can accurately and quickly analyze digital images of plants and classify them as healthy or diseased. This classification helps to improve the speed at which the disease is identified. It further enables the farmers to take timely action and prevent the spread of disease [28].

In addition to detection, computer vision models can also be used to classify different types of plant diseases, which can help farmers to implement targeted management strategies. For example, different types of plant diseases may require different treatments, so accurate classification can be crucial in managing diseases effectively. Increased efficiency and consistency in the production of high-quality crops can be achieved via the use of predictive analytics and improved farm and crop management systems. Using satellite images, drone images and meteorological data, the crop area can be assessed, and crop health can be monitored in real time. Real-time forecasting is possible when high-quality photos from drones and helicopters are used for field management [29].

III. PLANT APPS IN CROP HEALTH ASSESSMENT

Plant apps are mobile applications that employ AI and image recognition technologies to assess crop health. These applications enable farmers to identify crop diseases, nutrient deficiencies, and other problems using smartphones and tablets and are becoming increasingly popular. These apps use image recognition technology and machine learning algorithms to analyze photos of plants taken from smartphones similar to taking aerial images with the help of drones with high spectral cameras.

In order to use a plant app, the farmer takes a photo of a plant or a specific part of a plant (such as a leaf or a fruit) and uploads it to the app. The plant app uses image recognition technology to analyze the photo and compare it to a database of images of healthy and diseased plants. It is by comparison that the disease is identified, and analysis completed. Once the analysis is complete, the app provides the farmer with a diagnosis of the potential disease or pest, as well as recommendations for its treatment or prevention. Some apps currently being used are Agrio, PestId etc. Many such apps are also being developed by various educational institutes [30, 31].

IV. CHALLENGES

People across all industries are overcoming conventional challenges with the aid of AI technologies. AI applications are being used in sectors like finance, transportation, health care, and agriculture [32]. Artificial intelligence has the potential to revolutionize farming, but irrespective of the benefits of AI, technology providers still need to put in substantial effort to help farmers effectively deploy it.

1) The implementation of AI based solutions is an expensive proposition for small farmers. Moreover, there are additional costs in training and maintaining the technology. Farmers may need to modify their traditional farming practices and infrastructure to successfully implement precision farming technologies.

2) The use of AI for resolving agricultural issues can be challenging, as many owners of small farmland lack the infrastructure and capital to collect and share data.

3) Different types of plant diseases may require different treatments, so accurate classification can be crucial in managing diseases adequately.

4) There are challenges in using apps to capture diseased plants and diagnosing the disease accurately. For example, some diseases which don't manifest visually like the stem borer in sugarcane plants can go unnoticed by aerial image analysis.

5) There are other challenges associated with the drone technique, such as the need for high-quality and high-resolution images. Another challenge is procuring a high-resolution camera for accurate diagnosis.

6) There is also a requirement for specialized equipment and expertise. The complexity of the algorithms used for image analysis poses yet another challenge. There are maneuvering issues of drones due to high wind speed and adverse weather conditions which can lead to difficulty in using this technology. This can lead to limited area coverage of farm fields by the drones, posing yet another challenge, in addition to mandatory clearances for flying drones.

7) Despite various potentially impactful AI models, aiming to attain sustainability, (Fig.2) the ecological balance can get affected by extreme climate and environmental changes. This can further hamper crop yield and effective crop production.

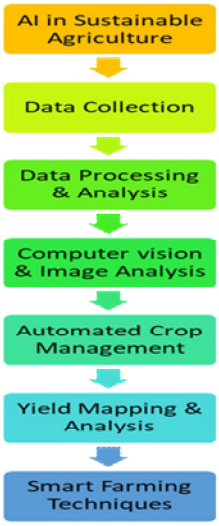

Fig. 2. Process flow chart of AI in sustainable Agriculture

V. CONCLUSIONS

Steps need to be taken to increase food production, so that we are well equipped not only to tackle adversity but also to circumvent it. Agricultural sustainability is closely related to environmental sustainability, so it is important to make the farmers aware of the technology at hand, its uses and implications. The regulatory guidelines for use of drone technology in farming are being deliberated upon worldwide, so that they can be effectively integrated with agriculture. These guidelines aim to ensure that drones are used safely and responsibly in agriculture. These AI and drone technologies can keep track of farm conditions, making agriculture less labor-intensive and more productive. The crop receives what it requires when field variability is recognized and considered. By using AI algorithms to analyze data on soil moisture, nutrient levels, and pest infestations, farmers can apply fertilizer, water, and pesticides more efficiently. Crop yields, fertilizer efficiency, and farm profitability can hence be increased. This represents progress towards sustainable agriculture since it conserves resources and lessens the adverse impacts of farming on the environment. Taking proactive steps to promote the adoption of technology and educating farmers would ensure that agriculture remains a sustainable and viable sector for the future.

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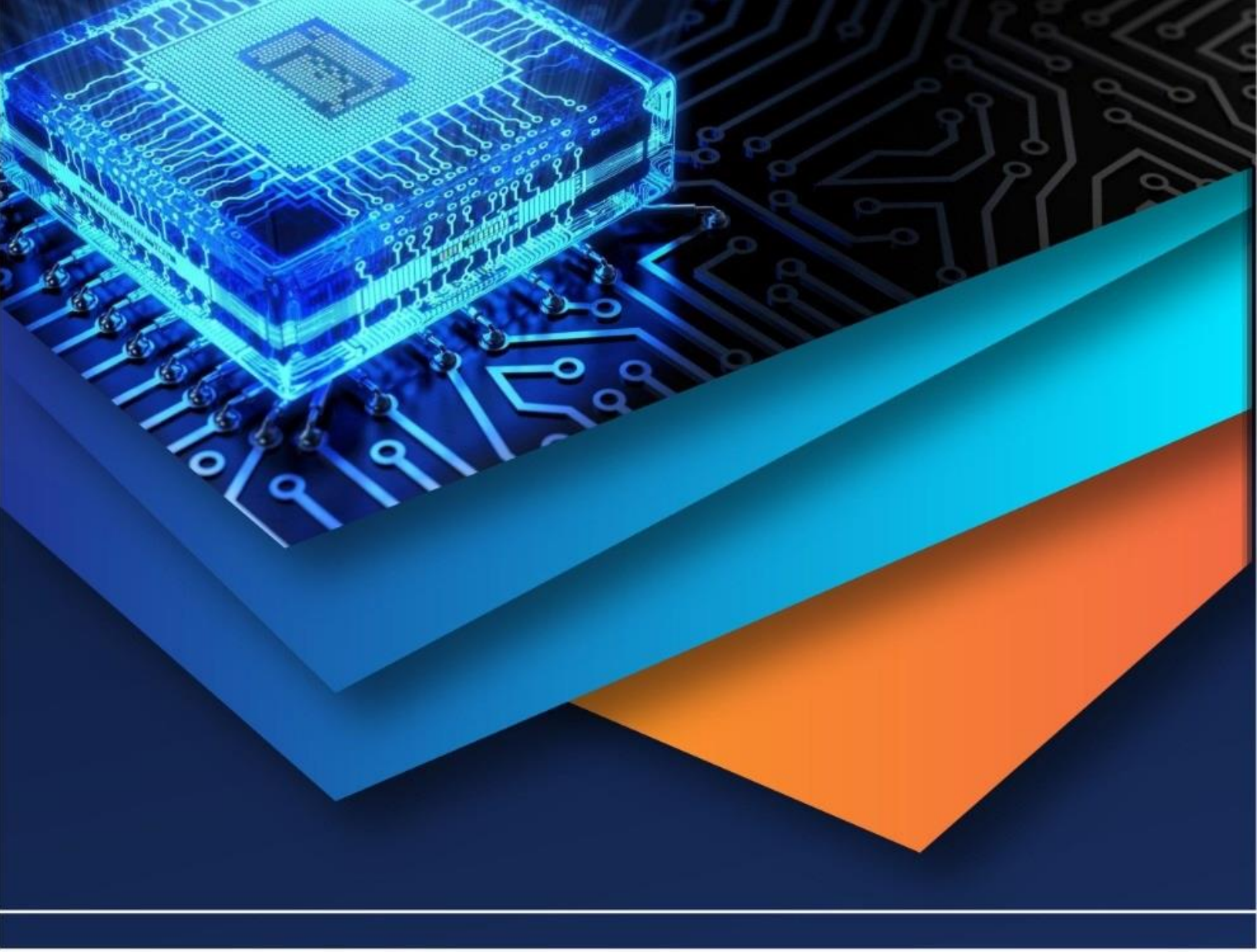

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