Smart Farming: The Role of AI in Agriculture

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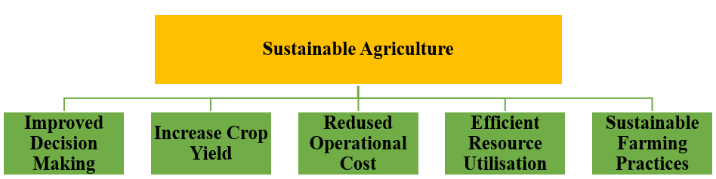
Introduction

Agriculture is the foundation of economic sustainability and plays a vital role in structural transformation and long-term economic growth (M.A. Kekan, 2013; B.F. Johnson et al., 1975), although its contribution varies across countries (R. Dekle, 2012). Traditionally limited to food and crop production, agriculture has expanded over the past two decades to include the production, processing, marketing, and distribution of agricultural and livestock products (M. Fan, 2012). Today, agriculture contributes significantly to income generation, GDP growth, employment, trade, and industrial development (O. Oyakhilomen, 2014; T.O. Awokuse, 2009). Technological advancements involving sensors, machinery, and digital tools have transformed farming practices by improving resource-use efficiency, reducing risks, and enhancing productivity. The rapid growth of Artificial Intelligence (AI) has been supported by universities and its increasing adoption in commercial, corporate, and government sectors. With the global population expected to reach 9–10 billion by 2050, food production must increase by 60–100% to ensure food security (Rockstrom et al., 2016). Challenges such as climate change, water scarcity, and food safety concerns require a shift toward sustainable agriculture. Digital technologies, including cloud computing, the Internet of Things (IoT), Artificial Intelligence (AI), machine learning, and deep learning, can support informed decision-making and sustainable agricultural practices (Ben R. et al., 2013).



Advancing Sustainable Agriculture through Artificial Intelligence

1. Data Science

Every day, farms generate a lot of data points. Farmers may now evaluate a variety of factors in real time, including weather, temperature. To help them make better decisions, they gather information on soil conditions or water usage on their farm. With the use of AI technology, farmers can use the data at their fingertips to produce healthy plants with less natural resource consumption.

2. Disease Diagnosis

Plant diseases have significant impacts on food security, economic stability, and environmental sustainability. Early disease detection is essential for effective management. AI-based image recognition systems can accurately identify plant diseases and enable field-level diagnosis using mobile devices such as smartphones (Peter *et al.*, 2021). AI tools that integrate big data and location-based science support agricultural research and help farmers and land managers make environmentally sustainable decisions. These technologies assist in selecting appropriate crop management practices and provide early warnings of pest and disease outbreaks (Peter *et al.*, 2021).

3. Plant Monitoring:

The most popular techniques for keeping updated on the health of plants are time-consuming and labour-intensive. AI is a useful tool for following and spotting possible issues with plant health or soil nutrient deficits. Applications are created to examine crop health trends in agriculture with the use of extensive research. Improved comprehension, soil health, pests, and plant diseases can all benefit from such AI-enabled solutions.

4. Management of Agricultural Production:

The agricultural supply chain is complex, involving food production, distribution, and consumption. Artificial Intelligence (AI) is increasingly used to improve crop rotation planning, planting schedules, water and nutrient management, pest and disease control, harvesting, marketing, distribution, and food security across the supply chain (Peter et al., 2021). AI offers significant opportunities to enhance agricultural research and decision-making by supporting the key components of the food system—production, distribution, consumption, and risk management. Its successful implementation largely depends on agribusiness adoption and the development of advanced tools for precision irrigation, nutrient management, and efficient crop production (Peter et al., 2021).

5. Predictive analytics:

Remote sensing technologies combined with Artificial Intelligence (AI) can accurately predict crop yields and estimate production under specific conditions. AI-based data analysis helps farmers optimize input use while conserving natural resources such as soil, air, and water.

Advanced systems integrating remote sensors with neural networks and machine learning can identify field variability and recommend site-specific management practices, improving productivity while reducing the environmental impact of fertilizers and pesticides. AI is transforming traditional agricultural systems by enabling higher food production with fewer resources. Researchers have increasingly adopted AI technologies to accelerate scientific discovery and enhance agricultural research. Numerous AI-based agricultural research initiatives have been undertaken to improve efficiency and innovation in the sector (O'Brien *et al*., 2021).

6. **Crop and Soil Monitoring:**

This employs deep learning and computer-assisted algorithms to interpret data from soil health and plant sensors, i.e., the PEAT pest and soil issues, based on the comprehensive study employing known as Plantix diagnostics. deficits in soil nutrients. Another illustration is Trace Genomics, which is a machine learning business that helps farmers assess soil degradation and offer soil analysis services. With a focus on preventing poor harvests and enhancing the capacity to produce healthy crops, this employs mechanical learning to offer farmers a knowledge regarding the strengths and limitations of their land. One example of using drones and a computer-driven crop analysis approach is Sky Squirrel technology. (Kale, S.S. and Patil P. S. 2019)

Areas of smart sustainable agriculture models

Soil: It is a fundamental resource for crop production, supplying essential nutrients that support plant, animal, and human life. However, soil quality can decline over time due to continuous cultivation and environmental factors. In arid regions, improper irrigation may lead to salinity and nutrient degradation, negatively affecting soil health. Internet of Things (IoT) sensors, such as moisture and nutrient sensors, can continuously monitor soil conditions. The collected data are analysed to assess soil health and optimize fertilizer application, thereby improving crop productivity and sustainable soil management (H. Cadavid *et al*., 2018).

Climate: This is a major factor in how well agricultural processes work. The weather is the only source of water and life support for many livestock and agricultural crops. Agricultural production can be negatively impacted by bad weather, particularly at crucial growth periods. Natural science and the development of agricultural plants and animals are influenced by climate elements, which include sunlight, temperature, rain, humidity, and wind. Storms, droughts, floods, hail, and hurricanes are examples of bad weather that can seriously harm fields and cattle.

Fertilization: Numerous nutrients, including potassium, calcium, phosphorus, and nitrogen, are naturally present in soil. Low nutritional value prevents plants from operating correctly and producing high-quality food. After the plants are harvested, fertilizers must be added to the soil to raise its natural level. Although chemical-based fertilizers were used since the dawn of agriculture, it is now widely recognized that improper management of their overuse can have negative environmental effects. In order to provide fertilizer using the right measures, farmers employ IoT sensors to read and evaluate samples of soil for basic testing. A key component of sustainable farming systems is fertilization.

Insects: These are defined as any living thing that damages or invades human constructions, animals, or plants. Large populations of pests can cause damage to agricultural products. IoT and AI technologies must be used to manage and keep an eye on these animals in order to prevent serious illnesses like malaria and other infections that affect plants and cattle.

Water and irrigation: There is growing pressure to maintain the availability of water supplies due to the rising global need for water in agriculture, particularly in Mediterranean nations. Thus, innovative and successful approaches should be the main emphasis of wise, sustainable agriculture operations.

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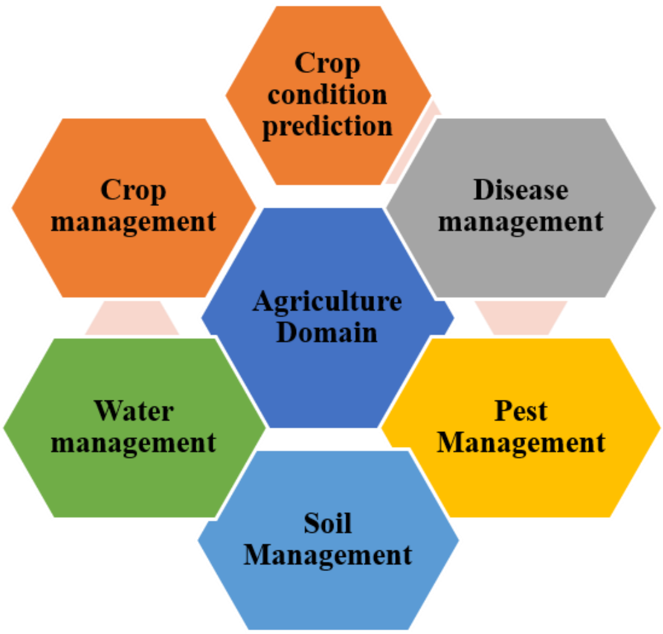
AI Technology's Applications and Uses in Agriculture

Robots

Agricultural robots are transforming modern farming by improving productivity, precision, and labour efficiency. They perform tasks such as fruit harvesting, autonomous tractor operations, sheep shearing, and weed control. Using technologies like artificial intelligence, computer vision, sensors, and cameras, these robots can identify and harvest fruits, carry out field operations autonomously, collect wool safely, and remove weeds effectively. By reducing labor dependence and increasing operational efficiency, agricultural robots contribute to higher productivity and more sustainable farming practices (M. S. Mir *et al.*, 2024).



Drones

Agricultural drones are important tools in precision farming, enhancing productivity and resource-use efficiency. They are widely used for soil and field analysis, crop monitoring, plantation activities, livestock management, and crop spraying. Equipped with advanced sensors and imaging technologies, drones can assess soil conditions, monitor crop health, detect livestock diseases, and support efficient planting operations. Agro-drones also enable precise application of fertilizers and pesticides, reducing input waste, saving time, and ensuring uniform coverage. These capabilities make drones a valuable component of modern sustainable agriculture (G. Sajjan *et al.*, 2025).

Summary

Artificial Intelligence (AI) and the Internet of Things (IoT) are playing an increasingly important role in modern agriculture by improving productivity, quality, and resource efficiency. These technologies support various agricultural sectors, including crop production, soil management, irrigation, weather forecasting, pest control, livestock management, and farm machinery. AI helps farmers analyze soil, crop, and weather data to select suitable crops, optimize input use, and improve yields. It can also predict weather patterns, crop seasons, and disease outbreaks, enabling timely decision-making. Additionally, AI-powered advisory systems and chatbots provide farmers with instant guidance and recommendations, supporting more efficient and sustainable agricultural practices while driving the growth of smart farming.

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