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Progress and Potential Drawbacks of Modern Agricultural Technologies: A Literature Review

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ABSTRACT

The production of agriculture has undergone new modifications as a result of agricultural technologies. These not only boost agricultural output but may also significantly raise the caliber of produced food, cut labor expenses, boost farmers' incomes, and achieve agricultural modernization. The use of precision agriculture (PA) is expanding due to the rapid socioeconomic changes that are occurring in certain developing nations. There are enormous ramifications for urbanization, energy consumption, and economic growth in certain developing nations when fundamental changes occur. The research status and current agricultural technology achievements are carefully summarized in this study. In-depth discussions of thirteen significant agricultural technologies are provided in this article. All significant technologies from developed countries are discussed so that under-developed and lower-developed countries will benefit from this paper. Finally, some fresh concepts for each technology are offered, and potential issues in establishing such sophisticated technologies are identified. The main objective of this review is to increase knowledge of modern agriculture and the development process in the agricultural field.

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Introduction

Agriculture is a particularly unique sector in terms of resources, production, consumption, knowledge, innovation, and the transmission of new technology. The challenge of applying innovations in agriculture cannot be seen simplistically and cannot be assumed to be solved if adequate financial resources are available (Dimitrijević, 2023). Many industrialized and developing nations' experiences over the last few decades have demonstrated that they have failed to modernize agriculture and rural development. There will be 9 billion people on the earth by 2050, which will cause the demand for food to increase by up to 102% (X. Wang, 2022), (Fukase & Martin, 2020). Consequently, agricultural production must increase by 60% to 70% to ensure the supply of raw materials for food, feed, and fiber (Eli-Chukwu, 2019). Each individual involved in the food system must commit to developing and enforcing procedures that will reduce the use of natural resources whenever it is practical to do so and recycle, reuse and repurpose them in all other circumstances. This is accurate despite the continued and escalating strain on the planet's resources. Implementing national and local plans and strategies for efficient resource management may be a way for government bodies to assist these activities. Sustainable farming practices are increasingly being used on a global scale (Eyhorn et al., 2019; Jhariya et al., 2021), which helps the agroecosystem meet current food demands while also ensuring that future generations can do the same with the limited resources they will have. These practices also emphasize the three basic pillars of sustainable development- environmental, social, and economic sustainability, as well as regional plans to effectively use resources.

Several factors, such as terrain, irrigation, soil types, nutrients present in the soil, and climate, influence crop quality and yield (Liliane & Charles, 2020). Farmers need cutting-edge technologies to increase food production on their limited land and resources to satisfy these demands. To boost crop yield, farmers must monitor their crops in real-time and take the appropriate action. This makes smart agriculture necessary. The remote monitoring of farms made possible by the Internet of Things (IoT) helps farmers get superior outcomes. The data required for analysis and decision-making is obtained through artificial intelligence (AI) and machine learning (ML). Sustainable agriculture requires advanced technology, including cloud computing, IoT, drones, remote sensing, and communication technologies (Khan et al., 2021).

Food security is becoming increasingly important since climate change threatens rural life and agricultural productivity, particularly for small farmers. Implementing climate-smart agriculture (CSA) is another way people respond to climate change's consequences (Bilali et al., 2020). Smallholder farming methods are not resilient to long-term climate change, are wasteful, generate inconsistent outcomes, and employ inefficient inputs. Thus, it is imperative to develop suitable agricultural technology to alleviate these limitations, boost output, and eliminate greenhouse gas emissions (Mbuli et al., 2021). An agricultural strategy known as "climate-smart agriculture" (CSA) uses climate change to advance agriculture while promoting development and guaranteeing food security. Thus, improving public extension services, basic services, and basic education in rural areas is necessary to increase CSA's creativity in research (Teklu et al., 2023).

Today's agriculture uses various advanced technologies due to the advancement of global information technology (Khan et al., 2021). All these technologies have reduced the suffering of the farmers in the agricultural fields and increased crop production. Farm automation, vertical farming, precision agriculture, blockchain, laser scarecrows, minichromosome technology, RFID Technology, real-time kinematic (RTK) technology, Artificial intelligence, agricultural robotics, drones, etc. are the contributions of this smart agricultural technology. In this article, I discuss the modern technologies of agriculture that make agriculture dynamic. The modern technologies with their future possibilities and disadvantages are briefly discussed, which is the nobility of this article. Academic people will get a brief overview of the current technological advancements and what is being thought of in the future in the agricultural field.

Modern Technologies

Farm Automation

Farm automation combines computer systems, agricultural machinery, electronics, data management and chemical sensors to improve equipment functioning and decision-making, reducing human input and error in the process (Tian et al., 2020). The technology's extensive adoption is being driven by fewer labor hours, higher yields, and more effective resource management. The farming process now includes a large amount of automation, which will only increase in the next years (Jha et al., 2019). Farmers are transforming how they cultivate their crops by using robotic harvesters, self-driving tractors, drones, seeding, and weeding. Robotics research is being prioritized by an increasing number of AgTech companies to develop self-driving tractors, drones, automatic watering, robotic harvesters and seeding robots (Rose et al., 2021). Despite the fact that these technologies are still in their infancy, an increasing number of conventional agriculture companies are integrating farm automation into their operations because one of their main goals is to do away with tiresome tasks.

These sensors may also be used to monitor soil quality and ensure crops are not harmed by drought or other environmental variables (Jaiswal et al., 2019). Farmers will be able to focus more on other elements of their company as automation increases, rather than typical human labor activities like watering, sowing, and harvesting (Rehman et al., 2022). Automation, like any other area, may help employees save time by reducing the need for individuals to participate actively in a process. Because of mechanization, most farmers today spend more time with their families than they did previously.

large adoption prices for robotic technology can be a significant barrier to entry for farmers (Hung et al., 2019), particularly in poor nations; technical faults and equipment failure can also offer large repair costs for such specialized equipment (Pradhananga et al., 2021). Automation in agriculture frequently results in substituting machines for human labor, which can result in job losses in the farming sector. This can potentially harm local economies and communities, particularly in places where agriculture is a key source of employment.

Vertical Farming

Since the 1950s, possibly even earlier, vertical farming has been a subject of science fiction (Rameshkumar et al., 2020). It is technically and economically feasible today, and it will be within the next ten years. Technology for vertical farms the practice of growing food in vertical stacks is known as "vertical farming," and it is a kind of urban agriculture. Three to eight tons of rice are typically produced per hectare (Kumar & Rajitha, 2019). However, farmers are not subject to this restriction while adopting vertical farming. Farm products are grown piled on top of one another in this enclosed, regulated farming type. In order to boost crop productivity in confined locations, the technology employs growing shelves that are positioned vertically.

The plants on the shelves are frequently either hydroponic or aeroponic (Atherton & Li, 2023), which are gardening techniques that grow plants in water and nutrient solutions and do not need soil (Mattson & Lieth, 2019). With emitters occasionally showering them with water and nutrients, aeroponics suspends the plant roots in the air. In order to produce healthier and larger crops, indoor vertical farms provide gardeners the ability to manage factors like light, temperature, water, and even carbon dioxide levels. Employing robots for planting and harvesting results in lower labor costs and a 70% decrease in water consumption (Shrivastava et al., 2023), which helps preserve energy. Farmers may use it everywhere to maximize their land's utilization and cultivate crops that would not be practical in their current places.

The fundamental problem is that high-density vertical farming necessitates expensive technology to replicate the sun since fruit and vegetables demand powerful, direct overhead lighting. Other difficulties with vertical farming include high beginning costs, a small selection of commercially viable crops that are inappropriate for tall field crops, significant energy consumption, and a high level of technical expertise. Figure 1A presents a common structure of vertical farming.

Precision Agriculture

A strategy for managing agricultural resources known as precision agriculture collects, analyzes, and offers insights and evaluates data to help farmers improve and increase soil quality and production (Cisternas et al., 2020).

In order to improve farmland and agricultural output in various crucial areas, including resource use effectiveness, productivity sustainability, quality, and profitability, precision agriculture data points are employed in management decisions.

This development in agricultural technology makes use of big data to support management decisions, enabling farmers to maximize production by regulating crop yield factors, including soil quality, moisture content, and microclimates (Bwambale et al., 2022; Radočaj et al., 2022). In order to improve crop health and make the most of agricultural resources, robotics, remote sensing, automation, robotics, and robotics technology are used. Government support would increase, and there would be a greater need for efficient agricultural health monitoring, promoting market expansion.

By reducing the need for tractors and other pieces of fossil-fuel-powered equipment, smart farming can help minimize greenhouse gas emissions. However, it may lead to a rise in the use of fertilizers and pesticides, both impacting global warming. Other drawbacks include the infrastructure required for precision farming being too expensive, the fact that it cannot be used in rural regions due to infrastructure issues, ownership issues, and other factors, and it does not include free-hand farming.

IoT in Agriculture

Using IoT, farmers can monitor their fields of crops from any location (Pyingkodi et al., 2022). Sensors monitor temperature, crop health, animal conditions, soil moisture, and other variables (Abioye et al., 2021) (Figure 1B). Thanks to IoT technology, automated irrigation systems with effective water resource management may be built (Jaiswal et al., 2019). IoT devices can help determine the proper amount of water for crops each season by capturing information about the crop, such as moisture and temperature.

We identified a few issues with IoT in agriculture, such as inadequate Internet access in farms, the fact that most farms are situated in rural areas where Internet connections may not be strong enough to support quick transmission speeds, expensive hardware prices, and disrupted cloud connectivity.

Blockchain and Food Traceability

The present food system has serious issues such as safety recalls, food fraud, food traceability, and supply chain inefficiencies that may be resolved using blockchain's capacity to track owner records and tamper with security (Demestichas et al., 2020; Sylvester, 2019). Its distinctive decentralized structure produces a transparent market, which guarantees verifiable goods and practices. In light of recent breakthroughs in blockchain applications, food traceability has become a hot topic in conversations about food safety (Sajja et al., 2023). The food sector is especially susceptible to errors that might have a negative impact on human lives since perishable food has a short shelf life.

Traceability is crucial for the food supply chain (Reddy et al., 2022). The current communication architecture of the food ecosystem makes traceability a time-consuming process because some parties are still keeping track of information on paper (Figure 2). Because of the nature of the blockchain, all parties in the food value chain may create and share data points in a safe manner, resulting in an open and accountable system (Bhat et al., 2021). It is possible to rapidly and unaltered record vast amounts of data using proprietary labels. The transit of food from farm to table may, therefore, be tracked in real-time.

One of blockchain's key drawbacks is its high energy usage (Awan et al., 2021). The system is incredibly energy-intensive to maintain a real-time ledger, and more energy is required to solve each new transaction. Lack of knowledge, inadequate transparency, ineffective value chains, and extremely constrained access to resources are other major problems (Farooq et al., 2023).

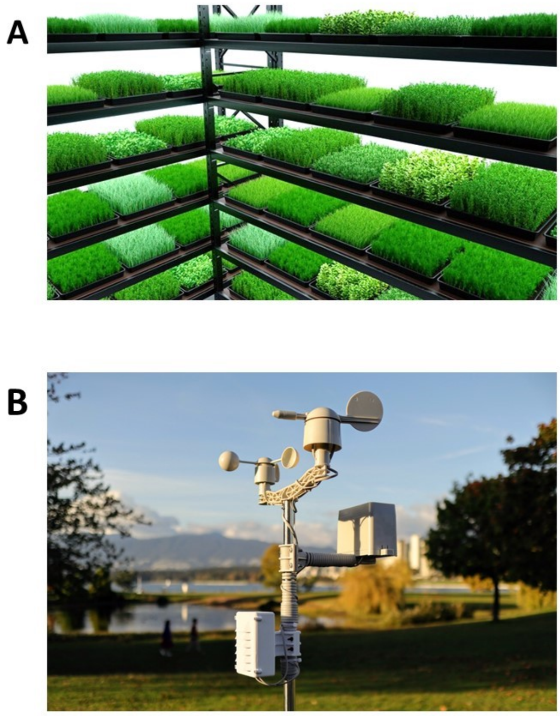

Figure 1. Vertical farming and IoT, (A) structure of vertical farming, and (B) IoT sensor in the agriculture field.

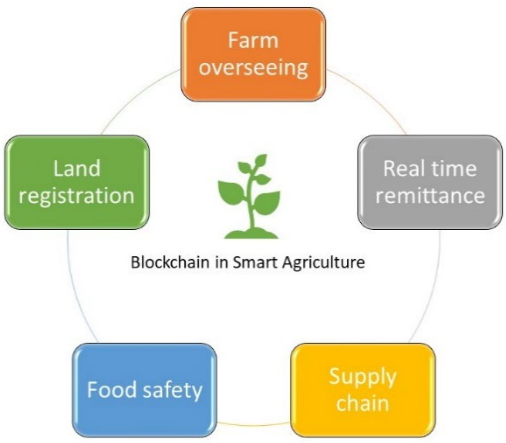

Figure 2. Circle of blockchain in modern agriculture.

A

B

Figure 3. Laser scarecrows and Satellite picture, (A) laser scarecrow on agricultural field and (B) Image of an agricultural land by a satellite

Laser Scarecrows

In an open field, birds or rodents may threaten crops. Farmers used traditional scarecrows to fend off hungry intruders in the past (R. N. Brown & Brown, 2021). However, modern farmers and ranchers use motion-detecting technology to prevent birds from stealing food.

After understanding that birds are sensitive to the color green, Prof. Brown from the University of Rhode Island collaborated on developing a laser scarecrow that produces green laser light (R. Brown, 2017) (Figure 3A). The light is invisible to humans in bright sunlight, yet it may travel 600 feet across a field to frighten birds before damaging crops. By reducing the number of birds around farms, preliminary tests have shown that laser scarecrows can minimize crop damage by up to 70% to 90% (R. Brown, 2017).

Minichromosome Technology

Due to the growing population and escalating food demand, farmers will need to boost agricultural production to maintain our current standard of living (Manida & Ganeshan, 2021). Therefore, losing entire crops to pests is a big issue as the world's population grows. Studies have raised concerns about genetically modified food in recent years, claiming that it may cause allergic responses or contain toxic substances (Islam et al., 2020; Krasnikova et al., 2019) that put people at risk for illness (Ji et al., 2019). Another problem is that the manufacture of GMO food has the potential to damage natural biodiversity (Mandal et al., 2020) or release poisons into the land (Nawaz et al., 2020). Fortunately, there is optimism in sight. Agricultural geneticists can use minichromosome technology to improve a plant's features without changing the genes in any manner. With the use of minichromosome technology, the risk of novel features segregating can be reduced by stacking genes next to one another on the same chromosome. Because minichromosomes only contain a limited amount of genetic material (Langner et al., 2021), this approach can be used to modify plants to be more pest- or drought-resistant without affecting the host's normal growth.

In brief, minichromosome technology enables genetic engineers to develop crops that depend less on toxic chemicals by using fewer insecticides, fertilizers, and fungicides. Another benefit is the ability to bio-fortify plants and raise their nutritional value. However, it has some downsides, such as connection drag, being labor-intensive, and taking a long time.

Radio Frequency Identification (RFID) Technology

RFID has long been a common use on many farms for the identification and tracking of animals (Yan & Li, 2019). It has also been used to control traceability in the food chain (Suresh & Chakaravarthi, 2022). By incorporating sensors into tags, it is possible to monitor the supply chain for perishable foods and develop new applications for irrigation, specialty crops, environmental monitoring, farm machinery, and agricultural equipment (Chew et al., 2020; Saha et al., 2022). These sensors offer data that is related to agricultural production. We now live in a world where a bag of potatoes may have a barcode that can be scanned with a smartphone to obtain details on the soil from which they were grown, although this may sound like something out of science fiction. It's not impossible to imagine a day in the future when farms may promote themselves and have devoted customers watch their harvests for purchase.

Real-Time Kinematic (RTK) Technology

RTK technology provides centimeter-level accuracy (Chen et al., 2022), enabling farmers to accurately map their fields (Mattivi et al., 2021) and permanently limit vehicles to the same lane (Freeland et al., 2019). Tractors can stay on track while traveling since their radio transmits accurate positional information to them. With less input, production is increased because this innovation improves soil health and productivity.

Artificial intelligence (AI)

Farmers can easily anticipate their crops using AI and data science technologies (Javaid et al., 2023). For instance, 3D laser scanning and spectrum imaging/spectral analysis can assist farmers in forecasting weather conditions and maximizing the use of the resources needed for pest management, fertilizer, and irrigation (Jha et al., 2019; Rehman et al., 2022). These can keep an eye on things like soil quality, plant health, temperature, humidity, and more. The goal is to use cutting-edge technology that can tell farmers more than the human eye can see to help them grasp what is occurring on the ground. Additionally, it is quicker in addition to being more precise.

Algorithms using remote sensors translate field perimeters into statistical information that farmers can comprehend and utilize to guide their decisions. Data processing algorithms adjust and learn based on the data they receive (Sharma, 2021). The algorithm's ability to forecast various outcomes improves with increased inputs and data collection. The objective is to provide farmers with the tools they need to use artificial intelligence to make better decisions in the field and ultimately produce better crops. However, using AI to grow our food might have unforeseen consequences, including increasing the danger of cyberattacks, environmental harm, labor exploitation, and the divide between subsistence and commercial farmers.

Satellite Imaging

Real-time crop photography is now possible thanks to advancements in distant satellite imaging (Zhang et al., 2020). These photos are not simply quick pictures from above; they have resolutions of at least 5 meters (Nguyen et al., 2020) (Figure 3B). With the use of crop photography, a farmer may inspect crops virtually, just as if they were in front of him or her. A farm may save a lot of time and money by even checking photographs once a week. This system may also be combined with crops, soil, and water sensors so that when danger thresholds are reached, farmers will be notified and given the relevant satellite photos.

Drones

Drones, also known as unmanned aerial vehicles, are becoming beneficial in managing crops and animals (Rejeb et al., 2022). Drones with sensors may be used by farmers, for instance, to track plant development, spot disease stress, irrigation (Figure 4A), check the temperature of the field, and spray pesticides or fertilizer where it is needed. They give farmers the ability to monitor crop health and evaluate the general state of their fields by offering real-time pictures, sensor data, and mapping capabilities. With the use of this data, decisions on the distribution of resources, the precise application of inputs, and the focus of interventions may be made using data. By boosting operational effectiveness, strengthening data collecting and analysis, and increasing access to essential services, drones' versatile applicability across several fields constitutes a substantial contribution. Different kinds of drones (Table 1) can work perfectly to protect field crops in the modern world.

Agricultural Robotics

One of the primary drivers for the widespread use and acceptance of agriculture robots is the need to fulfill the rising global food demand (Xie et al., 2022). Now that agricultural robots are available, many human-performed tasks in farming may be completed, boosting output and conserving a tremendous amount of resources (T. Wang et al., 2022). In today's agriculture, agri-robots are utilized for various tasks, including seeding, weeding, sorting, crop harvesting and packing (Figure 4B).

Certain drawbacks exist, such as the one-time larger investment required and the complexity of agricultural robots and other equipment, which necessitates training farmers before usage. Since agricultural robots need electricity, frequent power outages in rural regions limit their use and appeal.

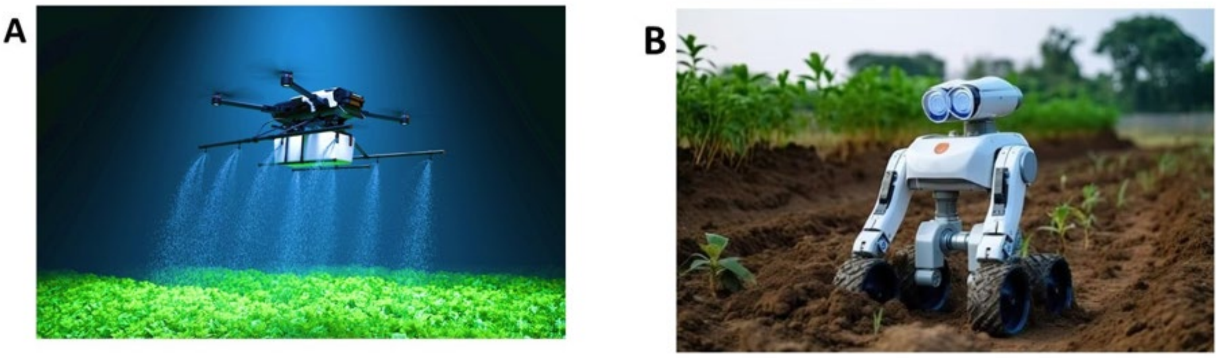

Figure 4. Drone and robot: (A) irrigation is done by a drone in the agricultural field, and (B) seedlings and soil are checked by a robot.

Table 1. Types of drones

Drones	Applications	Advantages	Drawbacks
Fixed wing	• Area survey • Structural inspection	• High speed • Long endurance • Large area coverage	• Landing • High price • Launching
Rotary wing (multi-copter)	• Inspection • Filmography • Photography	• Hovering • Availability • Low price	• Small payload • Short flight time
Rotary wing (helicopter)	• Inspection • Supply drops	• Hovering • Large payload	• High price

Conclusion and perspectives

Sustainable farming is a hot topic when worries about the environment and climate change are at an all-time high. Our expanding population and the developing shortages of land and water seriously threaten the survival of the human race. Innovation in modern agriculture is more important than ever. The entire industry is up against significant challenges, such as altering consumer preferences for sustainability and transparency, rising supply-side costs, and labor scarcity. These modern technologies will mostly shield against persistent agricultural issues. If farmers can produce enough crops, the world's population will have enough food for themselves.

Modern agricultural technology has made it possible to convert conventional farming into modern agriculture, which may be sustained and environmentally benign through wise resource management and utilization. This paper's main objective is to maximize production with the least input and minimize environmental damage, both of which are crucial for developing nations to meet the sustainability challenge. Some emerging nations are experiencing rapid socioeconomic transformation, opening up new opportunities for using contemporary tools in agriculture. Significant changes have far-reaching effects on urbanization, energy consumption, poverty alleviation, and economic development in some developing nations.

Declarations

Academic Contribution

Prodipto Bishnu Angon developed the idea and designed the structure. Prodipto Bishnu Angon and Pujan Aich collected the data, wrote the manuscript and prepared the final version.

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