**A Comprehensive Review on Recent Advances in Sustainable Agriculture**

**Abstract**

This article provides a detailed analysis of the Internet of Things' (IoT) use in agriculture, highlighting both its advantages and disadvantages. However, the Internet of Things (IoT) offers a great deal of promise to generate novel concepts that could progress modern agriculture and address many of the problems that farmers currently face. Smart irrigation, precision farming, crop and soil tracking, smart greenhouses, supply chain management, livestock monitoring, agricultural drones, disease and insect prevention, and farm equipment are some of the uses for IoT implementation in agriculture that this study takes into account. These innovative ideas have the potential to revolutionize farming practices, promote agricultural sustainability and production, reduce resource waste, and raise productivity. The study assesses the utility of each application and outlines the actions that need be made to improve its effectiveness. Important considerations include connectivity issues, cost control, data security and privacy, solution scaling, effective data management, and increasing knowledge and acceptance of IoT capabilities. Despite these challenges, IoT has a lot to offer the agriculture sector. The study highlights the importance of collaboration between farmers, IoT technology companies, academia, and government in order to address these issues and realize the full potential of IoT. This requires ongoing study, development, and adoption of IoT-driven solutions to keep agriculture viable as a substitute in the face of emerging problems like resource shortages and climate change.

**Keywords**

IoT, Precision farming, Smart irrigation, Agriculture, Crop monitoring

**Introduction**

Agriculture is the main source of a nation's income and has a big impact on its GDP [1]. Leaders in the world like the US and the EU make significant investments in new farming equipment. With the majority of people likely to live in cities by 2050, food productivity is predicted to need to rise by 70% in order to fulfill demand [2, 46]. Approximately 70% of all available water is being used for agriculture, which is a necessity for agriculture. However, food production is inadequate owing to environmental changes, and conservation of resources is necessary [3]. New farming methods are being developed in an effort to address this issue. Traditional agricultural methods, which have not integrated technological technology as well as other industries, have been superseded by modern farming techniques [4, 47]. New precision agriculture techniques and Internet of Things technology have completely changed farming in the computer age. Advanced farm management, waste reduction, and crop production can result from the application of IoT technologies in agriculture with little negative influence on the environment [5, 48]. “Agriculture is changing as a result of technologies including wireless sensor networks, radio-frequency identification, cloud computing, machine-to-machine communication, and data analytics. For instance, wireless sensor networks are capable of gathering information on meteorological parameters such as temperature, humidity, wind speed, and precipitation. They can also identify plant diseases, monitor food development, and figure out how to fertilize and water crops most effectively” [6, 7, 48].

Machine-to-machine communication allows for the implementation of tasks like watering and pest management, and radio-frequency identification (RFID) made it possible to track individual plants, animals, or pieces of equipment [8, 49]. For the storage and analysis of massive volumes of data gathered by sensors from different devices, cloud computing is important. Farmers can improve their operations and services by gaining fresh insights from further data analysis utilizing tools like machine learning [9, 50].

Farmers are now able to enjoy better livelihoods as a result of the shift towards farm mechanization [10, 51]. The type of crop being grown, however, determines how much farming is mechanized [11]. “While less field preparation is sufficient for some crops, such as pulses, extensive technology is used to prepare soils for crops like rice and wheat prior to harvest” [12]. “Mechanization has been essential in helping farmers in fast-developing nations like India overcome a variety of obstacles” [13, 52]. “Additionally, by making it easier to grow a variety of crop kinds, agricultural mechanization saves water, lowers the need for manpower, and increases farm profitability” [14, 53]. “Conventional irrigation techniques require a lot of work and are prone to weather variations. Crop yields can be hindered by inadequate precipitation, which is why irrigation systems have been developed to increase food output” [15, 54]. These watering systems, however, may utilize too much water, which could eventually cause a shortage. However, excessive water use from these irrigation methods may eventually result in water scarcity. Precision irrigation, or metered water use, has been used as a result of this worry and has revolutionized agriculture's environmental impact. It is a noteworthy invention in tackling the difficulties that farmers encounter [16, 55]. “Because precision agriculture maximizes resource utilization and reduces environmental impact, it provides substantial advantages. Precision agriculture uses cutting-edge technologies like IoT sensors and data analytics to help farmers make well-informed decisions regarding crop management, which results in more economical use of pesticides, fertilizers, and water. This enhances agricultural yields, lowers production costs, and encourages ecologically friendly farming methods, all of which eventually support agriculture's sustainability. By making it possible to gather, share, and apply extremely precise control methods, technological progress has significantly improved precision irrigation. The operator or an intelligent watering system, which is frequently available via a smartphone interface, receives the data from sensors that measure important factors including temperature, humidity, and soil moisture” [17, 56]. Agricultural practices have undergone a dramatic change as a result of the widespread use of precision watering. Several other IoT technologies, such as wireless sensor networks, radio frequency identification, cloud computing, machine-to-machine communication, and data mining, are also integrated into precision agriculture to improve a variety of agricultural processes. These technologies can be applied to individual plant or animal identification, plant disease detection, crop development tracking, nutrient input optimization, and the automation of agricultural tasks like pest management [18,19, 57]. Among the many advantages of precision agriculture are decreased waste, higher output, safer methods, and improved revenue generation for farmers. Additionally, by conserving water and decreasing the use of hazardous chemicals, it helps to minimize environmental damage [20, 58].

The Internet of Things has a big impact on farming and many other facets of human life. In order to facilitate communication between devices and systems, it consists of a network of networked objects that exchange data via the internet [21, 59]. IoT device adoption has been largely driven by the expansion of networked systems and organizations around the world. In the agriculture industry, where IoT integration has ushered in a new era of solutions for long-standing problems, this is never more evident [22, 60]. The use of IoT to construct a smart irrigation control system serves as an example. This device optimizes watering schedules by collecting data on soil humidity and current weather. This method reduces the amount of water used, which lowers the cost of cultivation [23, 61, 63]. A number of IoT concepts are examined in [24, 25, 62], “including sensor architecture and control systems used in agricultural environments. The conversation also covers cloud platforms designed for Internet of Things applications, real-time water demand forecast methods that use machine learning approaches, and coordinated irrigation software tools. By enabling farmers to make well-informed decisions, these advanced instruments eventually increase the quantity and quality of food produced. A gadget that uses Internet of Things technology to keep track of soil-plant-atmosphere interactions at the best possible spatial and temporal scales is detailed in” [24, 64].

This innovation offers a data-driven approach to farming in place of the conventional knowledge or labor-driven decision-making process. Nowadays, farmers can keep an eye on the health of their plants, the moisture content of the soil, and the weather in real time. Proactive monitoring allows for the early identification of any new problems, facilitating prompt action and guaranteeing the best possible plant growth. In order to improve agricultural productivity and handle the difficult effects of climate change, researchers have implemented a new and innovative wireless sensor network within an Internet of Things system [25, 65]. Data is collected on a number of variables, including soil moisture, temperature, humidity, and plant growth phases, using portable instruments. Following processing and analysis of this data, a cloud-based system provides farmers with real-time crop health and growth updates. Resources are conserved and food harvests are increased by helping farmers make well-informed decisions about irrigation systems, fertilizer application, and insect management. An IoT system for controlling mechanized farming across many communication platforms is proposed in [26, 66], which is similar to this. A robust, secure, and reliable system is created by integrating several variables, including data transmission speed, communication mode, security, range, latency, throughput, and power consumption. It is made up of sensors that monitor and control several activities, including watering, fertilization, harvesting, and pest control. It can be easily integrated into individual farmers' operations and allows flexibility to match their resources. From seeding to post-harvest cleanup, an Internet of Things (IoT)-based automated system is intended to simplify all facets of farming [27, 67, 68]. Soil moisture, temperature, humidity, and other environmental parameters are measured using sensors. In order to provide farmers with real-time recommendations on when and how to water, fertilize, and safeguard their crops, the gathered data is sent to the cloud for processing. The apparatus is also capable of controlling the systems in charge of fertilization, pest control, and irrigation. The system can be expanded to include more UAVs, cameras, farm bots, and other devices as needed. As a result, farming chores can now be fully automated, eliminating the need for daily human interaction. Farm production rises as a result of improved farming efficiency, which lowers labor expenses.

Comparing wireless sensor networks (WSNs) and Internet of Things (IoT) applications has completely changed the way farms gather and track data. These technologies have made it possible for farmers to use tracking devices to remotely monitor different aspects of their crops. This is a major shift from earlier approaches to data collecting and observation, enabling real-time surveillance and management of various farm regions [28, 69]. Through cloud-based analysis and processing of remotely acquired data, the IoT-based setup gives farmers insightful information to help them make decisions. Technological developments make it possible to create customized, self-installing landslide warning systems that may be deployed in dangerous locations without the need for user participation. These systems are capable of handling node failures and modifying communication links on their own for efficiency. Furthermore, an IoT management system concept has surfaced that can monitor a wide range of environmental elements, including soil, water, wind, and air, over vast distances [29, 70]. The Internet of Things (IoT) has made it possible for people to monitor the environment remotely by using inexpensive electronic devices and communication technologies. It also makes it possible to create and update detailed maps of noise, air quality, water pollution, current weather, and radiation levels in real-time, and outdoor factors can trigger data transmission to users, alerting them through messages or notifications from designated officers [30, 71]. Farmland operations have become more efficient and less labor-intensive, which has led to overall cost savings and improved organization. Incorporating IoT devices and wireless sensor networks into farmland offers the potential for improved operations, informed decision-making, increased efficiency, and ultimately higher yields in the agricultural industry [31, 72]. This study explores the various uses of IoT in agriculture, looking at how various IoT technologies can be used to solve the particular problems that the industry faces. Smart irrigation, precision farming, crop and soil monitoring, smart greenhouses, supply chain management, livestock monitoring, agricultural drones, and pest and disease control are just a few of the practical applications of IoT-based technologies that are explored in this subject.

**Sustainable approaches**

The Internet of Things (IoT) is a network of physical objects that are connected to one another and have sensors, software, and other technologies installed that allow them to trade and gather data online. Communication between these devices which can range from commonplace items to complex machinery and centralized systems enables remote process automation, control, and monitoring. By enabling precision agriculture methods and offering real-time data insights, IoT technology has the potential to completely transform conventional farming methods in the agricultural sector. In order to increase productivity and decrease human labor in the agriculture industry, scientists are increasingly using IoT-based products. These cutting-edge initiatives seek to use IoT solutions to boost agricultural quality and production [32, 33]. Agriculture is being revolutionized by IoT-based methods that increase productivity and efficiency. One notable breakthrough is the creation of automated farms that make use of wireless sensor technology. Plant care is made easier with this technology, which uses digital sensors connected to the Internet of Things to monitor and regulate important aspects of plant growth and health. The use of wireless sensor networks (WSNs) in the construction of polyhouse tracking systems is another creative endeavor. By using IoT innovation to precisely monitor and manage the polyhouse environment, these systems optimize growing conditions by integrating sensors for temperature, light, humidity, and carbon dioxide [34].

A WSN-based system that uses GPS and ZigBee protocols has also been developed by researchers to track farming characteristics like soil temperature, humidity, and water availability. The system's capacity to capture data efficiently and exhaustively allows farms to use this link to make informed decisions based on up-to-date and comprehensive data [35]. A Real-Time Crop-Tracking System has been created to address the unique requirements of rice farming. This strategy seeks to increase rice output and boost crop management by continuously monitoring important indices and giving farmers timely feedback. Since agriculture is one of the most fragile landforms that is impacted by environmental factors, a number of Internet of Things-based solutions have been developed to solve these issues. Better crop results are the result of these technologies' efficient monitoring and control of the environmental elements affecting rice agriculture [36]. It has been proposed to monitor agricultural parameters like temperature using low-cost Bluetooth devices. When combined with microprocessors, these gadgets can serve as weather stations, giving farmers vital environmental information to enhance agricultural productivity and management [37]. Farmers can make well-informed decisions based on timely and accurate information by using this technology to track field data in real time. Nevertheless, this technology's limited coverage area and requirement for constant mobile phone Bluetooth activation for continuous monitoring are its drawbacks [38].

Smart monitoring systems that farmers can utilize to better monitor and control the surrounding region can be constructed using further IoT technology. These systems improve the capacity to make well-informed agricultural decisions by offering extensive data and insights. For example, [39], researchers are developing a ZigBee-based smart sensor platform that can monitor temperature, humidity, sunlight, and pressure. There are numerous low-cost devices with dependable sensors and quick data communication capabilities that allow nodes to communicate easily and collect environmental data effectively. Furthermore, a lot of research is being done on how IoT-based technologies can improve irrigation management [40]. For example, a GSM-based irrigation tracking device has been developed, using the global system for mobile communication (GSM), which includes an Android app for measuring water levels, humidity, and temperature [41]. This economical wireless irrigation control solution neces knowledge of the commands required to start motors and modify crop settings. The Internet of Things has also transformed greenhouse monitoring. A GSM and field-programmable gate array (FPGA) system can be used to assess greenhouse factors including temperature and humidity [42]. This is a quick and low-cost tracking device that makes it simple to monitor the soil and crops in a greenhouse. Additionally, scientists are working hard to create adaptable and affordable greenhouse monitoring systems [43]. Fuzzy-control systems are useful because they make it possible to track several important greenhouse operation parameters. Similarly, scientists look forward to future developments in greenhouse tracking and control systems, tackling problems including wireless node clustering, electromagnetic interference mitigation, and standardization of WSN components [44]. Other IoT technologies used for greenhouses, crops, and animals have also made monitoring easier [45]. Numerous instruments have been created by researchers to assess the health of animals and identify frequent illnesses, whether they are caused by drugs or natural causes. These devices use the Internet of Things to collect vital data like body temperature, location, and heart rate. This makes it possible to identify problems early and provide help and intervention as soon as possible.

**Conclusion**

In conclusion, there are a lot of chances to transform farming methods through the use of IoT technology in agriculture. Farmers may improve efficiency, production, and sustainability through precision farming, smart irrigation, supply chain management, livestock monitoring, smart greenhouses, crop and soil monitoring, agricultural drones, and pest and disease control. The review's main conclusions emphasize how IoT technology has the potential to revolutionize agriculture. IoT makes precision agriculture possible by facilitating resource optimization and informed decision-making, which enables customized modifications to increase crop output while decreasing inputs. Additionally, predictive maintenance techniques and effective resource use result in cost reductions. Reduced environmental impact and resource conservation are two ways to create enhanced sustainability. Additionally, higher productivity and health monitoring result from better livestock management made possible by IoT. Better planning and decision-making are made possible for farmers by data-driven insights produced by IoT devices. Furthermore, supply chain optimization guarantees product quality and minimizes waste, while remote management gives farmers flexibility and convenience by enabling them to oversee and modify activities from any location. The substantial advantages of incorporating IoT technology into agricultural practices are highlighted by these important findings. Furthermore, research advances fueled by IoT innovation have the potential to create long-term plans for agricultural expansion. Using IoT technology in agriculture is becoming more and more necessary as a result of the problems caused by population expansion, climate change, and resource scarcity. By embracing the potential given by IoT, farms can eliminate risks, streamline operations, and construct a more stable food chain. In addition to addressing the demands of a growing global population, the IoT has the ability to alleviate the challenges facing the agriculture sector. To fully realize the potential of IoT in agriculture and capitalize on its advantages for farmers, consumers, and the environment, however, further study, development, and cooperation amongst stakeholders are needed.

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Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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