



Chapter 4

Artificial Intelligence and the Internet of Things– Enabled Smart Agriculture for the Modern Era


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ABSTRACT

The integration of artificial intelligence (AI) and the internet of things (IoT) with related to smart agriculture has changes in a new era of efficiency and sustainability in farming practices. This abstract provides an overview of AI-IoT-enabled smart agriculture and its importance in addressing modern agricultural challenges. In today's rapidly evolving agricultural landscape, smart agriculture, driven by AI and IoT technologies, has emerged as a transformative solution. This synergy combines AI's data processing and analytical capabilities with the real-time connectivity of IoT devices to create a dynamic and data-driven agricultural ecosystem. The convergence of AI and IoT in agriculture not only empowers farmers with real-time information but also helps meet the growing demand for food in a more sustainable and environmentally responsible manner. However, as technology continues to evolve, challenges related to data security, interoperability, and accessibility need to be addressed to ensure the widespread adoption of smart agriculture practices.

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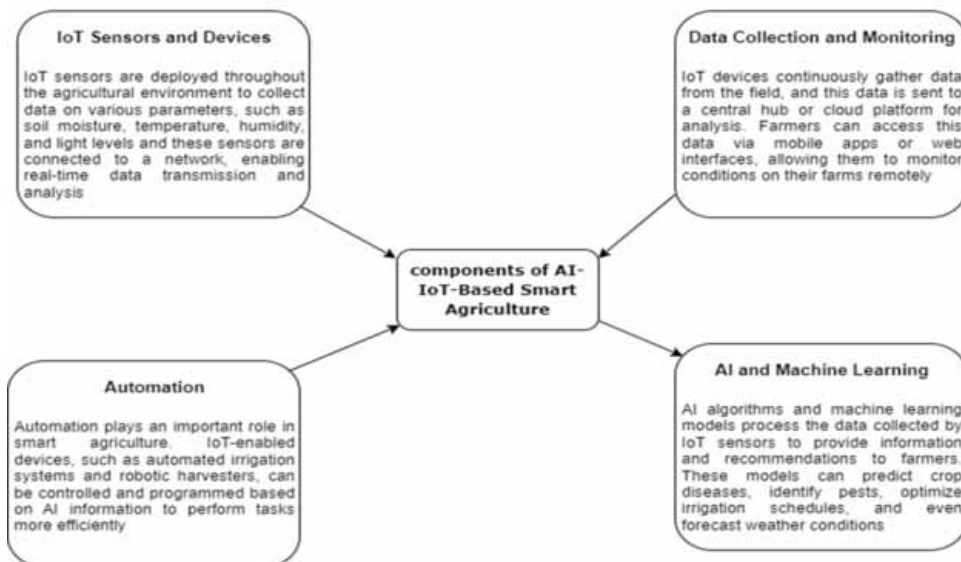
INTRODUCTION TO AI – IOT BASED ENVIRONMENT, SMART AGRICULTURE

In recent years, the integration of Artificial Intelligence (AI) and the Internet of Things (IoT) has revolutionized various industries, and agriculture is no exception. Smart agriculture, also known as precision agriculture, uses AI and IoT technologies to make farming more efficient, sustainable, and productive (Akkaş M. A. et al., 2017). This approach combines data-driven decision-making with real-time monitoring and automation to optimize various aspects of agricultural operations (refer figure 1).

Benefits of AI-IoT-Based Smart Agriculture as Increased Efficiency (AI-driven information help optimize resource utilization, reduce waste, and increase crop yields.), Sustainability (i.e., By minimizing water and pesticide use and promoting responsible farming practices, smart agriculture contributes to environmental sustainability), Improved Crop Quality (i.e., AI can help identify and address issues early, leading to higher-quality crops and reduced losses), Remote Monitoring (i.e., Farmers can monitor and manage their farms remotely, reducing the need for physical presence on-site), Data-Driven Decision-Making (i.e., AI-powered recommendations based on real-time data enhance decision-making and increase the chances of success).

In summary, AI-IoT-based smart agriculture is a transformative approach that holds the potential to address global food security challenges, reduce environmental impact, and increase agricultural productivity. As technology continues to advance,

Figure 1. Components of AI-IoT-Based Smart Agriculture



the adoption of these systems in agriculture is likely to grow, benefitting both farmers and the environment.

CHALLENGES IN TRADITIONAL AGRICULTURE

Traditional agriculture faces several challenges that can hinder its productivity, sustainability, and the livelihoods of those engaged in farming (Ananthi N. et al., 2017; Anastasi G. et al., 2009). Some of the key challenges in traditional agriculture include:

- *Limited Access to Resources:* Many small-scale traditional farmers have limited access to essential resources such as land, water, and seeds. This can result in reduced yields and economic hardship.
- *Climate Change:* Climate change leads to unpredictable weather patterns, extreme events, and shifting growing seasons. Traditional farmers often lack the resources and knowledge to adapt to these changes effectively.
- *Pests and Diseases:* Traditional farming practices may not always include modern pest and disease management techniques, making crops susceptible to damage and yield loss.
- *Soil Degradation:* Continuous cultivation without proper soil management can lead to soil erosion, nutrient depletion, and reduced fertility, impacting long-term agricultural sustainability.
- *Water Scarcity:* Water scarcity is biggest challenge in many regions. Traditional agriculture often lacks efficient irrigation systems, making farming highly dependent on rainfall.
- *Limited Access to Technology:* Traditional farmers may lack access to modern agricultural technologies, such as tractors, advanced machinery, and precision farming tools, which can improve productivity.
- *Market Access:* Traditional farmers may face challenges in accessing markets to sell their produce. Lack of transportation infrastructure, information, and market knowledge can limit their ability to reach consumers and obtain fair prices.
- *Labour Shortages:* Younger generations in rural areas are often migrating to urban areas in search of better opportunities, leaving traditional farms with an aging workforce. Labor shortages can hinder agricultural operations.
- *Limited Education and Training:* Traditional farmers may lack access to agricultural education and training, leading to outdated farming techniques and a limited understanding of modern best practices.

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- *Financial Constraints:* Access to credit and financing can be a huge barrier for traditional farmers, hindering their ability to invest in technology, inputs, and infrastructure improvements.
- *Land Tenure Issues:* Land tenure and property rights disputes can disrupt traditional agricultural practices, creating uncertainty and inhibiting long-term investments in farming.
- *Environmental Issues:* Traditional farming practices, such as slash-and-burn agriculture, deforestation, and overuse of pesticides, can contribute to environmental degradation and loss of biodiversity.
- *Rural Poverty:* Traditional farming communities often face higher rates of poverty due to limited income opportunities and challenges associated with subsistence farming.

Hence, addressing these challenges often requires a combination of government policies, investments in infrastructure and education, research and extension services, and the adoption of sustainable and climate-resilient agricultural practices. Transitioning to more sustainable and technologically advanced agricultural methods can help traditional farmers improve their livelihoods while mitigating the negative impacts of agriculture on the environment.

Limitations of Conventional Farming

Conventional farming, which relies on traditional agricultural practices, often faces various limitations that can affect its long-term sustainability, efficiency, and environmental impact. Some of the key limitations of conventional farming include:

- *Resource Intensive:* Conventional farming typically requires essential resources, including large amounts of water, synthetic fertilizers, and pesticides. This can strain local ecosystems and deplete natural resources.
- *Soil Degradation:* Continuous use of synthetic chemicals and lack of sustainable soil management practices can lead to soil erosion, reduced fertility, and long-term degradation of agricultural land.
- *Environmental Impact:* The heavy use of chemical pesticides and fertilizers can result in soil and water pollution, harm to non-target organisms, and adverse effects on biodiversity. Additionally, conventional farming often contributes to deforestation and habitat loss.
- *Water Pollution:* Runoff from conventional farms can contaminate nearby water bodies with chemical residues, negatively impacting aquatic ecosystems and human health.

- **Loss of Genetic Diversity:** Conventional farming tends to favor a limited number of high-yield crop varieties, potentially reducing genetic diversity and increasing susceptibility to diseases and pests.
- **Pest Resistance:** Overreliance on chemical pesticides can lead to the development of pesticide-resistant pests, making pest control more challenging and costly.
- **Resource Waste:** Conventional farming may result in the inefficient use of resources, such as excessive water use, leading to water scarcity issues in some regions.
- **Vulnerability to Climate Change:** Conventional farming may be less resilient to the effects of climate change due to its reliance on predictable weather patterns and traditional crop varieties.
- **Health Issues:** There are issues about the potential health risks associated with the consumption of crops treated with synthetic pesticides and fertilizers.
- **High Energy Use:** The production, transportation, and application of synthetic inputs in conventional agriculture require huge energy, contributing to greenhouse gas emissions and climate change.
- **Market Dependence:** Conventional farmers can be highly dependent on external markets and global commodity prices, making them vulnerable to price fluctuations and market dynamics.
- **Reduced Nutritional Quality:** Some studies suggest that intensive conventional farming practices may lead to reduced nutritional quality in certain crops.
- **Economic Pressure:** High input costs for synthetic fertilizers and pesticides can lead to financial pressure on farmers, especially small-scale and family farmers.

Hence, addressing these limitations often involves transitioning to more sustainable and environmentally friendly farming practices. Sustainable agriculture approaches, such as organic farming, agroecology, and regenerative agriculture, aim to reduce the negative impacts of conventional farming while promoting long-term ecological balance, resource efficiency, and economic viability for farmers.

THE NEED FOR TECHNOLOGICAL ADVANCEMENTS IN THIS SMART ERA FOR SMART FARMING/ AGRICULTURE

In the smart era, technological advancements are important for the agricultural sector, as they can address various challenges and meet the evolving demands of modern farming (Ande P. et al., 2017). Here are some key reasons highlighting the need for technological advancements in smart farming or agriculture:

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- *Increased Global Food Demand:* The world's population is continuously growing, leading to increased food demand. Agricultural technology can help meet this demand by increasing crop yields, improving efficiency, and reducing food waste.
- *Resource Efficiency:* Modern agriculture faces resource constraints, such as water scarcity and limited arable land. Technology, like precision irrigation systems and drought-resistant crops, can optimize resource use.
- *Environmental Sustainability:* Agricultural practices can have a major impact on the environment. Sustainable farming technologies, such as no-till farming and precision agriculture, can help reduce the environmental footprint of agriculture.
- *Climate Change Adaptation:* Climate change is causing shifts in weather patterns and increasing the frequency of extreme weather events. Advanced technology, including weather forecasting, climate modeling, and drought-resistant crop varieties, can help farmers adapt to these changes.
- *Data-Driven Decision-Making:* Big data and analytics enable farmers to make data-driven decisions. This includes predicting crop diseases, optimizing planting and harvesting times, and managing resources more efficiently.
- *Automation and Robotics:* Automated machinery and robotics can perform tasks like planting, weeding, and harvesting with greater precision and efficiency, reducing the need for manual labor.
- *Quality Control:* Technology can help maintain consistent quality in agricultural products, ensuring food safety and meeting consumer expectations.
- *Market Access:* Digital platforms and e-commerce solutions can connect farmers directly to consumers and markets, eliminating intermediaries and increasing profits.
- *Rural Development:* Technology can provide rural communities with access to information, education, and financial services, empowering them and improving their livelihoods.
- *Resilience:* Advanced technology can help farmers build resilience against challenges like crop diseases, pest infestations, and market fluctuations.
- *Diversification:* Technology allows for diversification in agricultural practices, such as integrating livestock and crop farming or incorporating agroforestry, which can enhance sustainability and income streams.
- *Monitoring and Traceability:* Technologies like blockchain can enable traceability in the supply chain, ensuring food safety and quality from farm to table.
- *Reducing Food Waste:* Smart farming practices, such as real-time monitoring of crop conditions, can help reduce post-harvest losses and food waste.

- *Knowledge Sharing:* Online platforms and mobile apps facilitate knowledge sharing and best practices among farmers, helping them stay updated on the latest innovations.
- *Government Support:* Governments worldwide recognize the importance of technological advancements in agriculture and may provide incentives and funding for farmers to adopt smart farming practices.

In summary, technological advancements are essential in modern agriculture to address global challenges related to food production, resource management, environmental sustainability, and economic development. Smart farming or agriculture uses technology to optimize agricultural processes, improve efficiency, and enhance the overall quality and sustainability of food production.

ENVIRONMENTAL AND SUSTAINABILITY ISSUES FOR SMART FARMING/ AGRICULTURE

While smart farming and agriculture technologies (Antony A. P. et al., 2020; Aqeel-ur-Rehman A. et al., 2014; L. Kanuru et al., 2021) provide many benefits, they also raise various environmental and sustainability issues. It is important to be aware of these issues to ensure that the adoption of technology in agriculture is done in a responsible and environmentally friendly manner. Here are some key environmental and sustainability issues associated with smart farming and agriculture:

- *Resource Intensiveness:* Some smart farming technologies, such as automated machinery and data centers, can be energy-intensive. The increased use of electricity can contribute to greenhouse gas emissions if the energy source is not sustainable.
- *E-Waste:* The rapid turnover of technology in agriculture can lead to electronic waste, including sensors, GPS devices, and other equipment. Proper disposal and recycling of e-waste are essential to prevent environmental harm.
- *Chemical Use:* While smart agriculture can help reduce the need for chemical inputs, it also relies on the use of certain technologies, such as drones and precision spraying systems, that may apply chemicals more efficiently. Careful management of chemical use and related to best practices are important to minimize environmental impacts.
- *Data Privacy:* Collecting and sharing data in smart farming can raise privacy issues. It's important to ensure that sensitive farm data is protected and used responsibly to prevent potential misuse.

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- *Digital Divide*: Access to smart farming technologies is not uniform, and the digital divide can leave some farmers with limited access to the benefits of these innovations. Bridging this gap is important for equitable and sustainable agriculture.
- *Monoculture*: Some precision agriculture practices may inadvertently promote monoculture, where a single crop is grown extensively. Monoculture can lead to decreased biodiversity and increased vulnerability to pests and diseases.
- *Overreliance on Technology*: An overreliance on smart farming technology may discourage farmers from using traditional and sustainable agricultural practices, potentially leading to a decline in indigenous knowledge and sustainable farming methods.
- *Loss of Rural Jobs*: As automation and robotics become more prevalent in agriculture, there is a issue about job displacement in rural communities. Supporting workforce transition and rural development is important for sustainability.
- *Data Security*: The security of farm data is essential to prevent cyberattacks or data breaches that could disrupt agricultural operations or lead to financial losses.
- *Waste Reduction and Recycling*: Smart farming can generate waste, such as used sensors and devices. Establishing recycling and waste reduction programs is essential to minimize the environmental impact of discarded equipment.
- *Sustainable Sourcing*: Considerations should be given to the materials used in smart farming technology, their sourcing, and their environmental impact. Sustainable sourcing and responsible supply chain management are important.

Hence to address these issues, it is important for consumers in the agricultural industry, including farmers, technology providers, governments, and environmental organizations, to work together to develop and promote sustainable smart farming practices. This can include the use of renewable energy, responsible data management, and the integration of technology with environmentally friendly and sustainable agricultural practices.

OVERVIEW OF AI AND IOT IN AGRICULTURE

AI and IoT are two transformative technologies that have found extensive applications in agriculture, collectively referred to as AI-IoT in agriculture. They provide innovative solutions to address various challenges and enhance the efficiency, productivity,

and sustainability of farming practices. Here is an overview of how AI and IoT are utilized in agriculture:

- *IoT Sensors and Devices:* IoT sensors are deployed in the agricultural environment to collect data on various parameters. These sensors can measure soil moisture, temperature, humidity, light, and even crop growth. GPS and satellite technology are used for precise location-based data collection and monitoring.
- *Data Collection and Monitoring:* IoT devices continuously collect real-time data from the field. This data is transmitted to a central platform, often cloud-based, where it is processed and analyzed. Farmers and agronomists can access this data through web-based dashboards or mobile applications.
- *AI and Machine Learning:* AI algorithms and machine learning models are applied to the data collected by IoT sensors. These models can predict weather conditions, detect crop diseases, and optimize resource management. Machine learning can analyze historical data to make predictions and provide recommendations, such as when to plant or harvest crops.
- *Precision Agriculture:* AI and IoT enable precision agriculture, which involves tailoring farming practices to specific field conditions. This includes precise irrigation, fertilization, and pest control based on real-time data. Drones and autonomous machinery are equipped with AI to perform tasks like crop scouting and precision spraying.
- *Crop and Livestock Management:* AI-IoT systems help manage crops and livestock more effectively. Livestock wearables and monitoring systems provide information about animal health and behavior. Crop management includes monitoring crop health, growth, and yield estimation.
- *Disease and Pest Management:* AI models can identify early signs of crop diseases and pest infestations, allowing farmers to take timely action. IoT sensors can be used to deploy automated pest control measures in response to detected threats.
- *Weather Forecasting and Climate Data:* IoT sensors provide real-time weather data for microclimates. AI can analyze this data to create more accurate short-term and long-term weather forecasts. Climate data analysis assists in managing the effects of climate change on agriculture.
- *Supply Chain and Traceability:* IoT is used for tracking and tracing agricultural products from farm to consumer, ensuring transparency and traceability in the supply chain. This technology can help in food safety and quality assurance.
- *Smart Irrigation:* AI and IoT enable smart irrigation systems that adjust water usage based on real-time weather data and soil conditions, reducing water waste and increasing efficiency.

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- *Market Access:* IoT and AI can connect farmers to markets, consumers, and suppliers through online platforms and e-commerce solutions, helping them access a broader customer base.
- *Education and Knowledge Sharing:* IoT and AI facilitate knowledge sharing and education through online platforms, enabling farmers to learn about best practices, new technologies, and market trends.

Note that the integration of AI and IoT in agriculture is helping farmers make data-driven decisions, optimize resource use, improve crop quality, and enhance overall farm management. It also promotes sustainability and environmentally responsible farming practices by reducing resource waste and minimizing the use of chemicals. This combination of technologies is an important step toward addressing the global challenges of feeding a growing population while ensuring the long-term health of our planet.

ORGANIZATION OF THE WORK

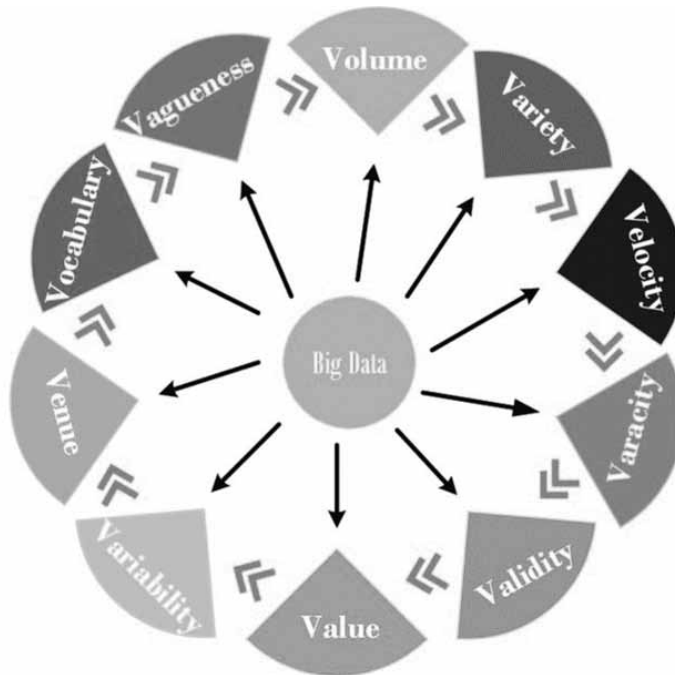
This work is summarized in 11 sections.

ESSENTIAL COMPONENTS OF SMART AGRICULTURE

Smart agriculture, also known as precision agriculture, relies on a range of essential components and technologies to improve farming practices, increase efficiency, and enhance sustainability (Ambildhuke G.M. et al., 2021; Deekshetha H.R. et al., 2022). These components work together to collect data, make informed decisions, and optimize various aspects of agricultural operations. Here are the essential components of smart agriculture as IoT Sensors and Devices, which can be summarized as Soil sensors, weather stations, and other IoT devices are deployed in the field to collect data on environmental conditions, including soil moisture, temperature, humidity, and light levels. IoT devices also include drones, unmanned aerial vehicles (UAVs), and autonomous machinery equipped with sensors and cameras for data collection and monitoring.

Data Collection and Connectivity: IoT sensors and devices continuously collect large amount of data (called big data) and transmit it to a central platform or the cloud for real-time analysis. Connectivity options may include wireless networks, cellular communication, and satellite technology. For big data characteristics can be found in figure 2.

Figure 2. Big data characteristics



- *Cloud Computing*: Cloud-based platforms are used to store and process the large amount of data collected from the field. Cloud computing allows for centralized data management, accessibility, and analysis from various locations.
- *AI and Machine Learning*: Artificial intelligence and machine learning models are applied to the collected data for analysis and decision-making. These models can provide information about crop health, disease detection, weather forecasting, and resource optimization.
- *Mobile Applications and Dashboards*: Farmers and agronomists can access data and receive recommendations through mobile apps and web-based dashboards. These applications provide real-time information on field conditions and enable remote monitoring.
- *Automation and Robotics*: Autonomous machinery, drones, and robotic devices can be used for tasks like planting, weeding, spraying, and harvesting. Automation enhances efficiency and reduces the need for manual labor.
- *Smart Irrigation*: IoT sensors and weather data are used to optimize irrigation schedules. Smart irrigation systems adjust water usage based on real-time conditions, reducing waste and conserving water resources.

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- *Crop and Livestock Management:* Livestock wearables, such as GPS-enabled collars and health monitoring devices, provide data on animal health and behavior. Crop management systems monitor crop growth, health, and yield, assisting in decision-making.
- *Precision Farming Equipment:* Precision farming equipment includes GPS-guided tractors, planters, and harvesters, ensuring precise field operations. These technologies allow for precise placement of seeds, fertilizers, and pesticides.
- *Weather Forecasting and Climate Data:* Real-time weather data and climate information are used to create accurate short-term and long-term weather forecasts. Climate data analysis helps in adapting to climate change impacts.
- *Supply Chain and Traceability:* IoT technology is used for tracking and tracing agricultural products from farm to consumer, ensuring transparency and traceability in the supply chain. This enhances food safety and quality assurance.
- *Market Access:* Online platforms and e-commerce solutions connect farmers to markets, consumers, and suppliers, facilitating access to a broader customer base.

Hence, these essential components of smart agriculture work together to provide farmers with real-time data, data-driven information, and automation capabilities, ultimately leading to more efficient, sustainable, and productive farming practices. Smart agriculture aims to address global food security challenges while reducing environmental impacts and promoting responsible farming practices.

EMERGING KEY TECHNOLOGIES IN AI-IOT AGRICULTURE

The field of AI-IoT agriculture is continually evolving, with emerging technologies playing an important role in transforming farming practices. These technologies have the potential to further enhance the efficiency, sustainability, and productivity of agriculture. Here are some key emerging technologies in AI-IoT agriculture:

- *5G Connectivity:* The rollout of 5G networks provides high-speed, low-latency connectivity in rural areas, enabling real-time data transmission and remote monitoring of agricultural operations. This is important for IoT devices and applications.
- *Edge Computing:* Edge computing involves processing data at or near the source (e.g., IoT sensors), reducing the need to transmit large amounts of

data to centralized servers. This can enhance the speed and efficiency of data analysis in agriculture.

- *Blockchain Technology:* Blockchain is being utilized to improve the traceability and transparency of the agricultural supply chain. It ensures that data related to the production, distribution, and quality of agricultural products is secure and tamper-proof (Tyagi Amit Kumar et al., 2019; Zeng Z. et al., 2020; Wang Q. et al., 2018).
- *AI-powered Computer Vision:* Computer vision technology, driven by AI, is increasingly used for visual data analysis in agriculture. It can identify crop diseases, monitor plant growth, and enable precision weeding, reducing the need for herbicides.
- *Genomics and Crop Breeding:* Advances in genomics and DNA sequencing are allowing for the development of crops with improved characteristics, such as disease resistance and higher yields. This technology aids in precision breeding and genetic modification.
- *Autonomous Vehicles and Robotics:* The development of autonomous tractors, drones, and robotic farm machinery is expanding. These technologies enhance precision farming, from planting to harvesting.
- *Biotechnology and CRISPR-Cas9:* Biotechnology, including CRISPR-Cas9 gene editing, allows for the development of crop varieties with desirable traits, such as drought resistance and improved nutritional content.
- *Hyper-spectral Imaging:* Hyper-spectral imaging enables the analysis of crops and soil at a more detailed level. It can provide information into nutrient content, water stress, and disease outbreaks.
- *Predictive Analytics and Machine Learning Models:* Advanced machine learning models and predictive analytics are being employed to forecast crop yields, identify optimal planting times, and anticipate pest outbreaks, aiding in decision-making.
- *AI-driven Robotics in Livestock Farming:* AI-powered robots and drones are being used to manage and monitor livestock, track animal health, and automate tasks like feeding and herding.
- *Vertical Farming and Controlled Environment Agriculture:* Vertical farming and controlled environment agriculture systems use IoT and AI technologies to optimize conditions such as lighting, temperature, and humidity, enabling year-round, high-yield crop production.
- *Sustainable Farming Practices:* Technologies that promote sustainable agriculture, such as regenerative farming practices and organic farming, are becoming more integrated with AI-IoT systems to minimize environmental impacts.

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- *Smart Pest and Disease Management:* AI and IoT are used to develop smart pest and disease management systems, which use predictive models to detect and mitigate threats, reducing the need for chemical pesticides.
- *Quantum Computing:* Quantum computing has the potential to revolutionize complex data analysis and optimization in agriculture, facilitating more precise resource management and decision-making.
- *Carbon Farming and Climate Resilience:* Technologies are emerging to support carbon farming practices, which sequester carbon in soils. IoT and AI help monitor and optimize these strategies.

These emerging technologies are poised to revolutionize agriculture by making it more efficient, sustainable, and responsive to the evolving challenges of feeding a growing global population and mitigating the impacts of climate change. As these innovations continue to develop, they hold the promise of further transforming the agricultural landscape.

APPLICATIONS OF AI-IOT IN MODERN AGRICULTURE

The integration of AI and IoT technologies in modern agriculture provides a huge range of applications that enhance productivity, sustainability, and decision-making. These applications span various aspects of farming and agribusiness. Here are some key applications of AI-IoT in modern agriculture (Zhang T. et al., 2018; Amit Kumar Tyagi and Poonam Chahal, 2020; Amit Kumar Tyagi and G. Rekha., 2020):

- *Precision Farming:* AI-IoT enables precision agriculture, optimizing the use of resources like water, fertilizers, and pesticides based on real-time data from sensors. This reduces waste and increases crop yields.
- *Crop Monitoring and Management:* Sensors and drones equipped with AI can monitor crop health, detect diseases, and provide recommendations for intervention. This leads to early disease prevention and improved crop quality.
- *Smart Irrigation:* IoT sensors and weather data are used to schedule irrigation based on soil moisture levels and weather forecasts, minimizing water usage and improving irrigation efficiency.
- *Weather Forecasting and Climate Data:* AI analyzes real-time weather data to create more accurate short-term and long-term weather forecasts, allowing farmers to make informed decisions about planting, harvesting, and resource allocation.

- *Livestock Monitoring:* Wearable IoT devices for livestock track animal health, behavior, and location. Farmers receive alerts on their mobile devices if an issue is detected, improving animal welfare and productivity.
- *Smart Pest and Disease Management:* AI-powered systems predict and detect pest and disease outbreaks. Drones and automated machinery can apply pesticides or control measures precisely, reducing the need for chemical inputs.
- *Market Access and Supply Chain Management:* IoT technology connects farmers to markets and consumers through online platforms and e-commerce solutions, improving market access and reducing the role of intermediaries.
- *Data-Driven Decision-Making:* AI analyzes historical and real-time data to provide farmers with information and recommendations on planting, resource management, and crop rotation, enabling informed decision-making.
- *Labor and Workforce Management:* IoT and AI help manage labor by optimizing tasks and schedules, reducing manual labor requirements, and increasing labor efficiency.
- *Food Safety and Traceability:* IoT and blockchain technology enable traceability in the supply chain, ensuring that food products are safe and of high quality from farm to table.
- *Smart Greenhouses:* AI-IoT systems control environmental conditions in greenhouses, adjusting temperature, humidity, and lighting to optimize crop growth and quality.
- *Crop Prediction and Yield Optimization:* AI models analyze historical data and current conditions to predict crop yields and recommend strategies for maximizing production.
- *Soil Health and Nutrient Management:* Sensors and AI models assess soil conditions and nutrient levels, helping farmers make data-driven decisions about fertilization and soil management.
- *Energy Efficiency:* IoT technology helps optimize energy use on the farm, reducing energy costs and the environmental footprint.
- *Rural Development and Education:* IoT and AI provide rural communities with access to education, financial services, and information, empowering them and improving their livelihoods.

These applications are transforming agriculture by making it more efficient, sustainable, and resilient to changing conditions. They help address the challenges of feeding a growing global population while minimizing the environmental impact of farming. As AI and IoT technologies continue to advance, their role in modern agriculture is likely to expand further.

BENEFITS, LIMITATIONS, AND IMPACTS TOWARDS AI-IOT BASED SMART AGRICULTURE ON TODAY’S SMART ERA

AI-IoT-based smart agriculture provide several benefits, but it also comes with limitations and has various impacts on modern farming practices in today’s smart era. Here is an overview of the benefits, limitations, and impacts of AI-IoT-based smart agriculture:

Benefits: Few Benefits towards AI-IoT based Smart Agriculture on Today’s smart era are discussed in table 1.

Limitations: Few limitations towards AI-IoT based Smart Agriculture on Today’s smart era are mentioned in figure 3:

Impacts: Now few major impacts AI-IoT based Smart Agriculture on Today’s smart era are:

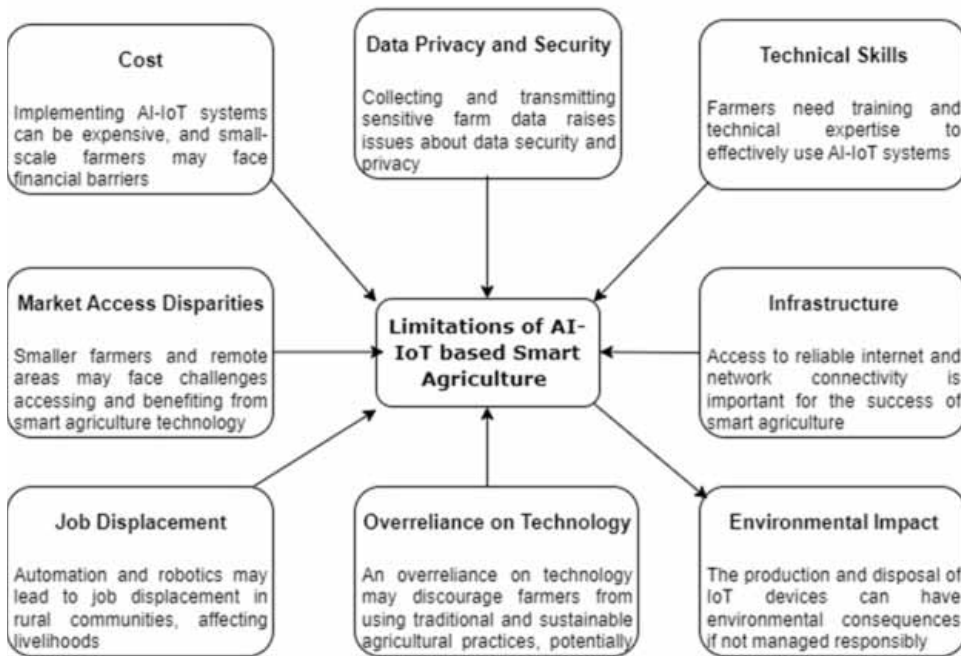
Economic Growth: Smart agriculture contributes to economic growth by increasing agricultural productivity and expanding market opportunities for farmers.

Environmental Sustainability: Reduced resource waste, lower chemical use, and sustainable practices lead to a more environmentally friendly and sustainable agriculture sector.

Table 1. Benefits towards AI-IoT based smart agriculture

Types	Discussion
<i>Increased Productivity</i>	AI-IoT technologies optimize resource use, enabling higher crop yields and livestock production, which is important for meeting growing food demands.
<i>Resource Efficiency</i>	Precise data-driven decision-making reduces resource waste, such as water, fertilizers, and pesticides, leading to cost savings and environmental benefits.
<i>Sustainability</i>	Sustainable practices, like reduced chemical use and precision farming, promote environmental responsibility and reduce the ecological impact of agriculture.
<i>Improved Crop Quality</i>	Smart agriculture practices result in higher crop quality by reducing disease incidence, ensuring optimal growing conditions, and timely harvesting.
<i>Remote Monitoring</i>	Farmers can remotely monitor their farms and make real-time decisions, reducing the need for physical presence on-site.
<i>Data-Driven Information</i>	AI-IoT systems provide data-driven information and recommendations, enhancing decision-making and overall farm management.
<i>Market Access</i>	Online platforms and e-commerce solutions connect farmers directly to consumers, improving market access and reducing the role of intermediaries.
<i>Labor Efficiency</i>	Automation and robotics reduce the need for manual labor, improving labor efficiency and reducing labor costs.
<i>Food Safety and Traceability</i>	IoT and blockchain technology enable traceability in the supply chain, ensuring food safety and quality assurance.
<i>Rural Development</i>	AI-IoT technology provides rural communities with access to education, financial services, and information, empowering them and improving their livelihoods.

Figure 3. Limitations of AI-IoT based smart agriculture



Food Security: Improved productivity and resource management contribute to global food security, helping meet the nutritional needs of a growing population.

Data-Driven Agriculture: The adoption of AI-IoT technology is shifting farming toward data-driven decision-making, improving efficiency and productivity.

Rural Empowerment: Rural communities gain access to technology, information, and financial services, empowering them and improving their living standards.

Global Connectivity: The integration of smart agriculture technologies connects farmers to global markets and enables international cooperation and knowledge sharing.

Innovation and Research: The development of AI-IoT technology drives agricultural innovation and research, resulting in more resilient and productive farming practices.

In summary, AI-IoT-based smart agriculture has the potential to address global food security challenges, reduce environmental impact, and increase agricultural productivity. However, it also faces challenges related to cost, data privacy, and the digital divide. The overall impact on agriculture and society is positive, with the potential to further transform farming practices and address the needs of the smart era.

CHALLENGES AND ISSUES RAISED TOWARDS AI-IOT BASED SMART FARMING/ AGRICULTURE

AI-IoT-based smart farming and agriculture provide several advantages, but they also raise several challenges and issues that need to be addressed to ensure responsible and sustainable implementation. Here are some of the key challenges and issues associated with AI-IoT-based smart agriculture, as mentioned in table 2.

Hence, these challenges and issues require a collaborative effort involving governments, farmers, technology providers, etc., in the agricultural sector.

Table 2. Challenges and issues associated with AI-IoT-based smart agriculture

<i>Types of issues</i>	<i>Description</i>
<i>High Initial Costs:</i>	The setup and implementation of AI-IoT systems can be costly, making it difficult for small-scale and resource-constrained farmers to adopt these technologies.
<i>Data Privacy and Security</i>	Collecting and transmitting sensitive farm data can pose data privacy and security risks. Unauthorized access, data breaches, and misuse of information are issues.
<i>Market Access Disparities</i>	Smaller farmers and remote areas may face challenges accessing and benefiting from smart agriculture technology.
<i>Regulatory and Legal Challenges</i>	The legal and regulatory framework for IoT and data privacy in agriculture may be lacking or inadequate, requiring important regulations and policies.
<i>Ethical Issues</i>	The use of AI and IoT in agriculture may raise ethical issues, such as the responsible handling of data, the treatment of animals in smart farming systems, and the ethical use of AI technologies.
<i>Consumer Acceptance</i>	Consumers may have issues about the use of technology in agriculture, affecting their perception of food safety and quality.
<i>Environmental Impact of IoT Devices:</i>	The production and disposal of IoT devices may have environmental implications if not managed sustainably.
<i>Overreliance on Technology</i>	An overreliance on technology may discourage farmers from using traditional and sustainable agricultural practices, potentially leading to a decline in indigenous knowledge.
<i>Job Displacement</i>	Automation and robotics in smart farming may lead to job displacement in rural communities, affecting livelihoods.
<i>Technical Skills</i>	Farmers need training and technical expertise to effectively use AI-IoT systems, which can be a barrier in regions with limited access to education and resources.
<i>Environmental Impact:</i>	The production, disposal, and energy consumption of IoT devices can have environmental consequences if not managed responsibly
<i>Lack of Connectivity</i>	In remote or underdeveloped rural areas, reliable internet and network connectivity may be lacking, limiting the effectiveness of IoT-based systems.
<i>Resource Scarcity</i>	Despite the efficiency gains, the expansion of smart agriculture could lead to increased demand for resources like water, potentially exacerbating resource scarcity issues.
<i>Digital Divide</i>	Despite the efficiency gains, the expansion of smart agriculture could lead to increased demand for resources like water, potentially exacerbating resource scarcity issues.
<i>Interoperability</i>	Ensuring that different IoT devices and systems can communicate and share data effectively is a technical challenge that needs to be addressed for strong integration.

CASE STUDIES IN SMART AGRICULTURE

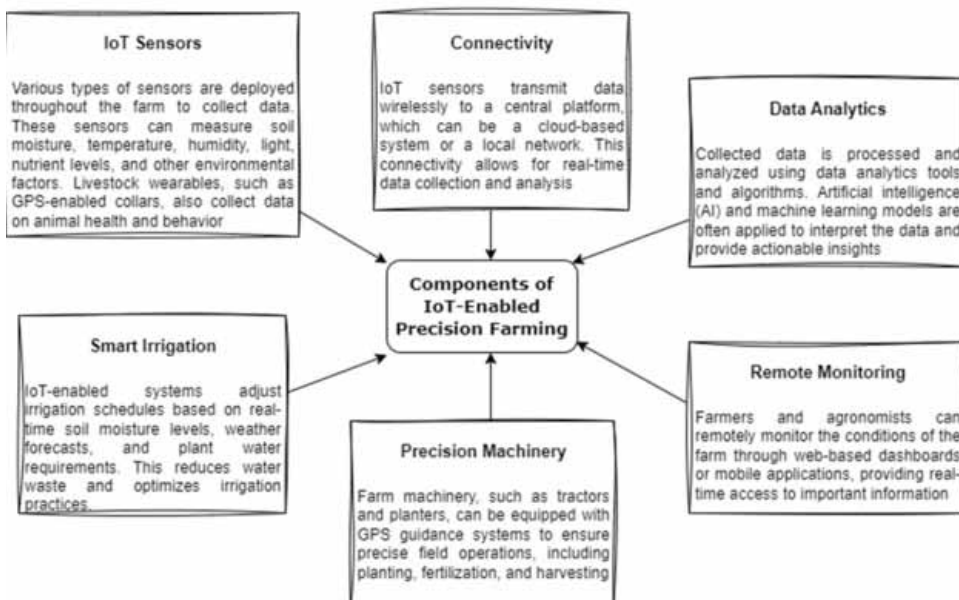
IOT-ENABLED PRECISION FARMING

IoT-enabled precision farming, also known as precision agriculture, is a farming approach that uses the Internet of Things (IoT) technology to optimize and enhance various aspects of agricultural practices. It involves the use of sensors, data analytics, and real-time monitoring to make informed and precise decisions about resource management, crop cultivation, and livestock operations. Here are the key components and benefits of IoT-enabled precision farming (refer figure 4):

Benefits of IoT-Enabled Precision Farming:

- **Resource Efficiency:** Precise data-driven decisions lead to optimized resource use, reducing waste and cost savings. This includes efficient use of water, fertilizers, and pesticides.
- **Increased Productivity:** Precision farming practices result in higher crop yields and improved livestock production, meeting growing food demands.
- **Sustainability:** Reduced chemical use, reduced environmental impact, and sustainable practices promote environmental responsibility in agriculture.

Figure 4. Components of IoT-Enabled precision farming



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- Improved Crop Quality: Early disease detection, optimal growing conditions, and timely harvesting result in higher crop quality.
- Data-Driven Information: Data analytics and AI provide information and recommendations for crop management, resource optimization, and decision-making.
- Market Access: IoT technology connects farmers to markets and consumers through online platforms and e-commerce solutions, improving market access and reducing the role of intermediaries.
- Labor Efficiency: Automation and robotics reduce the need for manual labor, improving labor efficiency and reducing labor costs.
- Food Safety and Traceability: IoT and blockchain technology enable traceability in the supply chain, ensuring food safety and quality assurance.

Note that IoT-enabled precision farming is transforming agriculture by making it more efficient, sustainable, and responsive to changing conditions. It addresses global food security challenges and minimizes the environmental impact of farming while enhancing productivity. This technology continues to advance, promising further improvements in farming practices in the future.

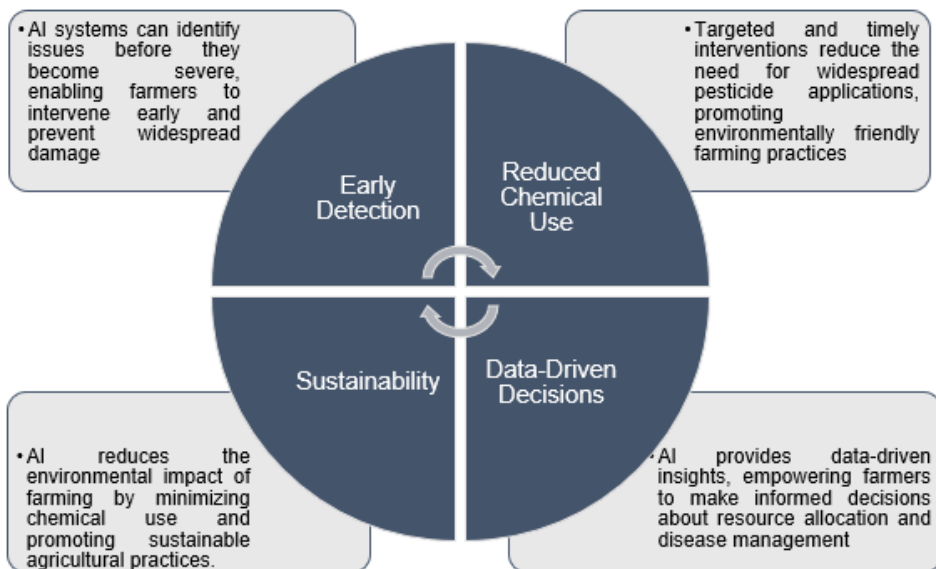
Ai-Based Pest and Disease Management

AI-based pest and disease management is an innovative approach in agriculture that uses artificial intelligence (AI) to detect, monitor, and manage pests and diseases affecting crops and livestock. This technology provides a data-driven and proactive solution to identify and address infestations and diseases, ultimately improving crop yields and reducing the need for chemical interventions. Here's how AI is applied in pest and disease management:

- *Data Collection:* AI systems gather data from various sources, including IoT sensors, drones, cameras, and remote sensing technologies. These sources provide information about weather conditions, plant health, pest presence, and disease indicators.
- *Image Recognition:* AI-powered computer vision algorithms analyze images of crops to identify symptoms of pests and diseases. These algorithms can recognize patterns, discolorations, or deformities that may indicate infestations or illnesses.
- *Machine Learning Models:* Machine learning models are trained on large datasets to identify and classify pests and diseases. These models can distinguish between different types of pests, their life stages, and various plant diseases.

- *Real-Time Monitoring:* AI continuously monitors crops and livestock in real-time, allowing for early detection of issues. This proactive approach enables farmers to take timely action to prevent the spread of pests or diseases.
- *Alerts and Recommendations:* AI systems provide alerts and recommendations to farmers based on the data analysis. These recommendations may include the need for targeted pesticide application, disease-resistant crop varieties, or other management strategies.
- *Predictive Models:* AI can forecast pest and disease outbreaks based on historical data, weather conditions, and other factors. These models enable farmers to take preventive measures before infestations occur.
- *Precision Application:* AI technologies can guide precision application systems, such as drones or automated machinery, to target specific areas with pest or disease problems. This reduces the need for broad-spectrum pesticides.
- *Data Integration:* AI can integrate data from various sources, including historical records, weather data, and sensor data, to provide a detailed view of the pest and disease landscape in the farming area.
- *Remote Sensing and Drones:* Drones equipped with AI can monitor large agricultural areas, collecting multispectral and hyperspectral data to identify crop health issues that may result from pests and diseases (refer figure 5).

Figure 5. Benefits of AI-based pest and disease management



Note that AI-based pest and disease management is a promising advancement in agriculture that helps farmers protect their crops and livestock while reducing the environmental impact of traditional pest and disease control methods. It contributes to more efficient and sustainable farming practices, ultimately benefiting both farmers and the environment.

Blockchain in Agri-Food Supply Chains

Blockchain technology is increasingly being adopted in agri-food supply chains to enhance transparency, traceability, and security. It provides a decentralized and immutable ledger that records every transaction and movement of goods from the farm to the consumer. Here are the key applications and benefits of blockchain in agri-food supply chains:

- a. Applications of Blockchain in Agri-Food Supply Chains:
 - Traceability: Blockchain allows every product in the supply chain to be traced back to its source. Consumers can scan a QR code or use a mobile app to learn about the journey of their food, including the farm of origin and processing steps.
 - Quality Control: Information about product quality, including temperature and humidity data during transportation, can be recorded on the blockchain. This data helps in maintaining product quality and safety.
 - Authentication: Blockchain ensures the authenticity of products by verifying the origin of items and detecting counterfeit goods. This is particularly important for high-value and premium products.
 - Supply Chain Visibility: All uses like from farmers to distributors and retailers, can access the same blockchain to view real-time data. This transparency reduces disputes and delays.
 - Smart Contracts: Blockchain supports the use of smart contracts, which automate and enforce agreements between parties. For example, a smart contract can trigger a payment to a farmer once the produce is delivered and verified.
 - Inventory Management: Blockchain can help manage inventory and reduce overstocking or understocking issues. Retailers and suppliers can access inventory data in real-time.
 - Food Safety and Recalls: In the event of a food safety issue, blockchain enables rapid tracing of the contaminated products to their source, allowing for more efficient recalls and reducing risks to public health.
- b. Benefits of Blockchain in Agri-Food Supply Chains:

- *Transparency*: Blockchain promotes transparency by making every transaction visible to all participants. This reduces information asymmetry and fraud.
- *Traceability*: Consumers can make informed choices based on the origin and quality of food products, promoting food safety and authenticity.
- *Reduced Food Waste*: Better inventory management and monitoring lead to less food waste, as products can be distributed more efficiently.
- *Efficiency*: Automation through smart contracts streamlines operations, reducing paperwork and administrative tasks.
- *Security*: Data on the blockchain is cryptographically secured and tamper-resistant. This reduces the risk of fraud and unauthorized changes to records.
- *Improved Collaboration*: All consumers in the supply chain can work together more effectively due to the shared and transparent information provided by the blockchain.
- *Enhanced Consumer Trust*: Knowing the source and quality of products builds consumer trust in the agri-food supply chain.
- *Regulatory Compliance*: Blockchain helps in complying with regulations, as it provides an auditable record of all transactions.

Hence despite these benefits, it is important to acknowledge that implementing blockchain in agri-food supply chains is not without its challenges. These challenges include the cost of infrastructure, interoperability between different blockchain networks, and the need for industry-wide standards and collaboration. As the technology matures and more agri-food supply chain participants adopt blockchain, it is likely to play an important role in ensuring the safety, quality, and transparency of food products from farm to table.

FUTURE INNOVATIONS TOWARDS AI- IOT BASED SMART FARMING/ AGRICULTURE

The future of AI-IoT-based smart farming and agriculture holds the promise of continued innovation and technological advancements. These innovations are essential for addressing the growing challenges of feeding a global population while ensuring sustainable and efficient farming practices. Here are some potential future innovations in AI-IoT-based smart farming and agriculture, as mentioned in table 3.

Hence, these future innovations in AI-IoT-based smart farming and agriculture will not only revolutionize farming practices but also contribute to addressing global food security challenges, reducing environmental impacts, and promoting

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Table 3. Potential future innovations in AI-IoT-based smart farming and agriculture

Types	Description
<i>5G and Beyond</i>	The rollout of 5G and the development of 6G networks will provide even faster and more reliable connectivity in rural areas, enabling real-time data transmission and remote monitoring of agricultural operations.
<i>Edge AI and Edge Computing</i>	Edge computing will become more prevalent, allowing data to be processed closer to the source (e.g., IoT sensors), reducing latency and enabling real-time decision-making on the farm.
<i>Swarm Robotics</i>	Autonomous robot swarms equipped with AI will perform various tasks such as planting, weeding, and harvesting, providing greater precision and efficiency in farming operations.
<i>Bioinformatics and Genomic Data</i>	Advances in bioinformatics and genomics will lead to more precise crop breeding and genetic modifications, resulting in crops with improved characteristics such as resistance to pests and diseases and better nutritional content.
<i>Quantum Computing</i>	Quantum computing has the potential to revolutionize complex data analysis and optimization in agriculture, facilitating more precise resource management and decision-making.
<i>Digital Twins</i>	Farms and agricultural environments will have digital twin representations, allowing for real-time simulation and optimization of farming operations.
<i>Hyper-spectral Imaging</i>	The use of hyper-spectral and multispectral imaging in agriculture will become more sophisticated, providing detailed data for crop health monitoring, nutrient management, and early disease detection.
<i>AI in Pest and Disease Management</i>	AI systems will evolve to provide more accurate and proactive pest and disease management solutions, reducing the reliance on chemical pesticides.
<i>Smart Biotechnology</i>	Smart biotechnology will enable crops to communicate their needs by responding to environmental cues, improving resource efficiency and adaptation to changing conditions.
<i>Carbon Farming and Climate Resilience</i>	IoT and AI will play an important role in supporting carbon farming practices and helping farmers adapt to the impacts of climate change.
<i>Agri-Food Blockchain Integration</i>	The integration of blockchain technology will further enhance transparency and traceability in the agri-food supply chain, increasing food safety and quality assurance.
<i>Decentralized Autonomous Organizations (DAOs):</i>	Decentralized organizations based on blockchain and AI will emerge to facilitate collaborative decision-making among farmers etc., in the agricultural sector.
<i>Open Data Platforms</i>	Collaborative open data platforms will allow for the sharing of agricultural data, research, and best practices, fostering innovation and knowledge sharing
<i>Sustainable Farming Practices</i>	Innovations will focus on regenerative and sustainable farming practices, emphasizing soil health, agroforestry, and organic farming methods.
<i>Personalized Farming Solutions</i>	IoT and AI will be used to monitor and protect ecosystems, ensuring that agriculture aligns with ecological conservation.
Environmental and Ecosystem Monitoring	IoT and AI will be used to monitor and protect ecosystems, ensuring that agriculture aligns with ecological conservation.

sustainable and efficient agricultural systems. The continued integration of cutting-edge technology is key to meeting the demands of the smart farming era.

SUSTAINABILITY AND ENVIRONMENTAL IMPACT

Reducing Agricultural Environmental Footprint

Reducing the environmental footprint of agriculture is important for mitigating the impact of farming on the environment and addressing global challenges like climate change, land degradation, and biodiversity loss. There are several strategies and practices that can help reduce the agricultural environmental footprint:

- *Sustainable Farming Practices*: Implement sustainable farming practices, such as precision agriculture, conservation tillage, and organic farming, to optimize resource use, reduce waste, and promote soil health.
- *Smart Irrigation*: Use precision irrigation techniques and IoT-based systems to reduce water usage and minimize water waste in agriculture.
- *Crop Rotation and Diversification*: Rotate crops and diversify plant species to enhance soil health, reduce the risk of pests and diseases, and improve nutrient cycling.
- *Integrated Pest Management (IPM)*: Adopt IPM strategies that emphasize biological control methods and targeted pesticide use to minimize the environmental impact of pest management.
- *Cover Crops*: Use cover crops to protect the soil, reduce erosion, and improve soil fertility, as well as enhance carbon sequestration.
- *Agroforestry*: Incorporate trees and other perennial vegetation into farming systems to sequester carbon, provide habitat for wildlife, and enhance soil health.
- *Renewable Energy*: Utilize renewable energy sources like solar panels and wind turbines to power farming operations, reducing greenhouse gas emissions.
- *Livestock Management*: Implement efficient livestock management practices using IoT technology to optimize feeding, health, and reproduction, thus reducing the environmental footprint of livestock farming.
- *Reduced Chemical Inputs*: Minimize the use of chemical fertilizers and pesticides by adopting natural and biological farming methods, including organic and biological farming.
- *Biodiversity Conservation*: Create and maintain natural habitats on or near farms to support biodiversity, including pollinators and beneficial insects.
- *Erosion Control*: Implement erosion control measures, such as terracing and vegetative buffers, to prevent soil erosion and protect water quality.

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- *Water Management*: Implement efficient water management practices through precision irrigation, controlled drainage, and monitoring to minimize water pollution and overuse.
- *Waste Reduction*: Reduce waste by optimizing resource use, reducing food loss and waste, and recycling organic matter into compost or energy production.
- *Sustainable Supply Chain*: Collaborate with supply chain partners to ensure sustainable and responsible practices throughout the entire agri-food supply chain, from farm to table.
- *Education and Knowledge Sharing*: Promote education and knowledge sharing among farmers about sustainable practices, new technologies, and best farming methods.
- *Environmental Certification*: Seek environmental certification for farms to demonstrate a commitment to sustainable practices and gain recognition in the marketplace.
- *Carbon Farming*: Implement practices that sequester carbon in the soil, such as agroforestry and cover cropping, to contribute to carbon neutrality.

Hence, reducing the environmental footprint of agriculture is a complex and ongoing challenge, but it is essential for protecting the environment, conserving natural resources, and addressing climate change.

Mitigating Climate Change Through Technology

Mitigating climate change through technology is an important aspect of addressing the global challenge of rising greenhouse gas emissions and their impact on the environment. Note that technology can play an important role in reducing emissions, enhancing energy efficiency, and promoting sustainable practices. Now will explain several ways in which technology can help mitigate climate change:

- *Renewable Energy Sources*: Transitioning from fossil fuels to renewable energy sources, such as solar, wind, and hydropower, reduces greenhouse gas emissions and reliance on carbon-intensive energy generation.
- *Energy Efficiency*: Implementing energy-efficient technologies in buildings, industries, and transportation systems can reduce energy consumption and emissions.
- *Carbon Capture and Storage (CCS)*: CCS technologies capture carbon dioxide emissions from industrial processes and power plants and store them underground, preventing their release into the atmosphere.

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- *Electric Vehicles (EVs)*: The adoption of electric vehicles, including EVs and plug-in hybrids, reduces emissions in the transportation sector and promotes cleaner mobility.
- *Smart Grids*: Smart grids use digital technology to improve the efficiency and reliability of the electrical grid, integrating renewable energy sources and reducing energy waste.
- *Energy Storage*: Advanced energy storage solutions, such as lithium-ion batteries and grid-scale storage, facilitate the integration of intermittent renewables into the grid.
- *Sustainable Agriculture*: Technology in agriculture, including precision farming and agroforestry, can reduce emissions and sequester carbon, making farming more environmentally friendly.
- *Green Building Design*: Building technologies that prioritize energy-efficient design and construction materials reduce emissions from heating, cooling, and electricity use.
- *Carbon Pricing*: Digital platforms and blockchain technology can enable carbon pricing and trading, incentivizing emissions reduction through market mechanisms.
- *Waste Reduction and Recycling*: Technology can improve waste management and recycling processes, reducing the environmental impact of landfills and incineration.
- *Climate Modeling and Prediction*: Advanced climate modeling and prediction technologies help us understand climate change impacts and plan adaptation strategies.
- *Sustainable Supply Chains*: Blockchain and IoT technology can promote transparency and traceability in supply chains, reducing waste and emissions.
- *Advanced Materials*: The development of advanced materials, such as carbon nanotubes and graphene, can lead to lightweight and energy-efficient products and structures.
- *Nature-Based Solutions*: Technology can support and monitor nature-based solutions like reforestation, wetland restoration, and carbon farming.
- *Circular Economy*: Digital platforms and sensors can optimize circular economy practices, reducing resource consumption and emissions associated with manufacturing and disposal.
- *Carbon Removal Technologies*: Innovations in carbon removal, such as direct air capture and enhanced weathering, can remove carbon dioxide from the atmosphere.
- *Remote Sensing and Monitoring*: Satellite technology and remote sensing data help monitor environmental changes, deforestation, and land use, facilitating better climate management.

- *Climate Adaptation*: Technology can support adaptation strategies, including early warning systems for extreme weather events and resilient infrastructure design.

Hence, mitigating climate change requires useful attempts/ efforts that combines technological innovation with policy initiatives and public engagement. By harnessing the potential of advanced technologies, the world can reduce greenhouse gas emissions, transition to a more sustainable and low-carbon economy, and take useful steps toward addressing the climate crisis.

SMART AGRICULTURE INITIATIVES BY GOVERNMENTS IN TODAY ERA

Governments around the world are increasingly recognizing the importance of smart agriculture initiatives to address food security, environmental sustainability, and the economic well-being of their agricultural sectors. These initiatives use technology and innovation to transform traditional farming practices into more efficient, productive, and sustainable systems. Here are some smart agriculture initiatives by governments in today's era:

- *Digital India's National e-Governance Plan (NeGP) (India)*: The Indian government's NeGP includes the "Digital Agriculture Mission" to promote technology adoption in agriculture, improve access to information, and enhance farmer income.
- *Agritech Innovation Fund (United Kingdom)*: The UK government has launched an Agritech Innovation Fund to support research and innovation in agriculture technology, with a focus on sustainable and efficient practices.
- *Agri-Food Strategy 2030 (European Union)*: The EU's Agri-Food Strategy 2030 aims to promote smart and sustainable agriculture by embracing digitalization, precision farming, and advanced technology in European farming practices.
- *Digital Agriculture Strategy (United States)*: The U.S. government is actively promoting digital agriculture strategies to enable precision farming, data-driven decision-making, and the development of IoT technologies in agriculture.
- *Smart Agriculture in China (China)*: The Chinese government has launched various initiatives under the "Smart Agriculture in China" program to promote the integration of digital technologies, AI, and IoT in agriculture.

- *AgTech and Innovation Precinct (Australia)*: Australia has established AgTech and Innovation Precincts to support and advance agricultural technology research, development, and innovation.
- *SmartAgriHubs (European Union)*: The SmartAgriHubs project fosters innovation and digital transformation in agriculture across Europe through a network of Digital Innovation Hubs.
- *National Agriculture Smart Service (NASS) (South Korea)*: South Korea's NASS program integrates IoT, AI, and big data to provide farmers with real-time agricultural information and support for decision-making.
- *Precision Agriculture and Digital Connectivity Initiative (Canada)*: Canada is investing in the development of high-speed internet and digital connectivity in rural areas to enable precision agriculture and technology adoption in farming.
- *Smart Agriculture Investment (Kenya)*: The Kenyan government has initiated several smart agriculture programs, including the promotion of digital marketplaces, weather information services, and mobile banking for farmers.
- *Agri-Tech Strategy (New Zealand)*: New Zealand's Agri-Tech Strategy aims to accelerate the adoption of agritech innovations, improve sustainability, and enhance the global competitiveness of its agricultural sector.
- *Digital Village Program (Indonesia)*: Indonesia's Digital Village Program integrates digital technology into agriculture, including IoT sensors, to provide farmers with real-time information and improve crop management.

Hence, these smart agriculture initiatives highlight the recognition by governments of the need to modernize and digitize the agricultural sector. They are aimed at enhancing agricultural productivity, ensuring food security, and promoting sustainable and environmentally responsible farming practices in today's era.

OVERCOMING ADOPTION BARRIERS TOWARDS AI-IOT BASED SMART AGRICULTURE

The adoption of AI-IoT-based smart agriculture faces several barriers and challenges, but these can be overcome with the right strategies and solutions. Here are some key barriers and ways to overcome them, mentioned as table 4:

Hence, overcoming these adoption barriers requires a coordinated effort involving governments, technology providers, financial institutions, farmers' associations, and local communities. By addressing these challenges, smart agriculture can become more inclusive and widely adopted, leading to increased agricultural productivity, resource efficiency, and sustainability.

Table 4. Barriers with solutions towards AI-IoT based smart agriculture

Barrier	Solution
High Initial Costs	Governments, NGOs, and financial institutions can provide subsidies, grants, or low-interest loans to farmers to help cover the initial investment costs. Cost-sharing partnerships with technology providers can also make adoption more affordable.
Lack of Technical Skills	Training programs and workshops should be organized to educate farmers on using AI-IoT technologies. Local agricultural extension services and tech companies can collaborate to provide training and ongoing support.
Limited Connectivity	Governments and telecommunications companies should invest in expanding network infrastructure to provide reliable internet connectivity in rural areas. Low-power, long-range IoT networks, such as LoRaWAN, can be used where traditional internet connectivity is lacking.
Data Privacy and Security Issues	Implement robust data encryption, authentication, and access control mechanisms to protect sensitive farm data. Develop and enforce data privacy regulations and standards specific to agriculture.
Resistance to Change	Awareness campaigns and demonstrations of successful AI-IoT implementations can help convince farmers of the benefits. Encourage early adopters to share their positive experiences.
Interoperability Issues	Promote industry standards and open APIs to ensure compatibility and interoperability between different IoT devices and systems. Encourage technology providers to adopt common protocols.
Environmental Impact of IoT Devices	Promote the use of energy-efficient IoT devices and encourage responsible disposal and recycling of outdated or non-functional devices. Invest in research and development to make IoT devices more sustainable.
Lack of Access to Capital	Microfinancing and crowd-funding platforms can be used to provide capital to small-scale farmers. Agricultural cooperatives and financial institutions should provide tailored financing options for smart agriculture projects.
Digital Divide	Efforts should be made to bridge the digital divide by providing technology access and literacy in rural and underserved areas. Mobile apps and SMS-based solutions can be deployed on basic smartphones to reach a broader audience.
Limited Awareness	Conduct awareness campaigns, workshops, and field demonstrations to educate farmers about the potential benefits of AI-IoT in agriculture. Engage agricultural extension services, universities, and tech companies in these efforts.
Small Land Holdings	Collaborative farming models and shared IoT infrastructure can be implemented to make smart agriculture accessible and cost-effective for small-scale farmers.
Lack of Local Language Support	Develop user interfaces and content in local languages to ensure that technology is accessible and understandable to all farmers.

CONCLUSION

AI-IoT-enabled smart agriculture is at the top of revolutionizing modern farming practices and addressing the complex challenges facing agriculture in the 21st century. This technology-driven approach uses the power of artificial intelligence and the Internet of Things to transform traditional agriculture into a more efficient, sustainable, and data-driven industry. The widespread adoption of AI-IoT-enabled

smart agriculture faces challenges, including cost barriers, limited technical skills, and data privacy issues. Overcoming these challenges requires collaborative efforts from governments, technology providers, financial institutions, and local communities. In this modern era, smart agriculture is not just a technological transformation but a necessity to address the increasing demand for food production, environmental sustainability, and the resilience of agricultural systems in the face of changing climates.

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