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Analysis of Long-Range Wireless Area Network Enabled Smart Agriculture for Sustainable Food Production

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Author's contribution

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ABSTRACT

Technology advancements and increased connection are bolstering the movement toward digital transformation in agricultural and food systems, which might lead to the proliferation of robots, fully automated farms and tractors, and spraying drones. The next-generation (4G) wireless network connection, known as 5G, will be necessary provide the massive data transmission volumes and low latency that may have many positive effects on IoT and blockchain applications in the agriculture and food industries. This study makes use of LoRaWAN (Long Range Wireless Area Network) for its energy-harvesting capabilities in remote agriculture monitoring. According to the findings of the experiments, LoRaWAN is the best technology to utilize in a system for monitoring agriculture when network lifespan and power consumption are important factors. Following application criteria, the experimental findings may be utilized to pick wireless technology for agricultural monitoring.

Keywords: Smart agriculture; 5G; internet of things; food; communication.

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1. INTRODUCTION

The agri-food business is adopting technology to create more sustainable food systems, and this includes the use of smart sensors, autonomous tractors, and spray drones. The Internet of Things (IoT), Big Data, Blockchain, Digital Twin, and real-time data analysis using AI-based algorithms are just some of the technologies used in this digital revolution. For instance, IoT is seen as a major game changer in the agri-food industry due to its capacity to significantly increase production and sustainability [1]. Better productivity across the food supply chain due to better utilization of automated field labor and real-time crop, product, and traceability data. For example, blockchain technology might improve the transparency of food information, the traceability of pesticide usage, and the location of items as they move through the supply chain from farm to fork [2]. Real-time information on crops, livestock, fields, soil, and environmental conditions (such as rainfall and temperature) is becoming more important to farmers. In extreme circumstances, such as completely automated temperature control systems in greenhouses, manned farm control is even no longer necessary, turning farms into cyber-physical management systems (CPMS). CPMS are in three stages, monitor, regulate, and provide data for computations and analytics of physical processes [3]. If fully autonomous and remotely operated robotic farms take use of a CPMS's technological capabilities, they might be part of the third stage of full-scale smart management of farms [4]. The technological prerequisite for this digital revolution is the exchange of data in real-time between sensors and digital tools or robotic equipment that aid the farmer in making decisions. Continuous data transmission, which is necessary for real-time data transfer, also calls for high-speed data connections. The availability and capacity restrictions of existing network communication technologies, such as 3G/4G, result in latency (delays in data transmission) and prevent efficient data transfer [5]. For the growing number of linked devices required for smart agricultural techniques, more bandwidth is required. A farmer who receives alerts from a smartphone app about high soil moisture levels based on information from soil sensors and alerts about heavy rain the same day from meteorological data analysis must decide fast which areas of a field do not need extra irrigation. Farming activities are immediately impacted by any loss of data connection between sensors, equipment, or data servers when situated in rural locations, just as they would be if they were located in an urban area. To help farmers in decision-making during routine agricultural operations, precision farming consequently requires real-time outputs from smart farming technologies coupled [6]. This calls for quick, dependable, and secure data flow between sensors and equipment. Smart farming relies on an extremely large number of Internet of Things (IoT) devices, which presents challenges for current 3G/4G networks. Given this newfound accessibility, the focus of this paper is on exploring the opportunities for digital innovation in agriculture and food production. More precisely, it will investigate the existing situation, find potential applications, and talk about the advantages and difficulties that must be overcome.

2. SMART AGRICULTURE METHODS

To improve farm output and quality, smart farming integrates conventional agricultural methods with information and communication technology (ICT). Utilizing innovative technologies in agriculture may help farmers increase crop yield and output while lowering labour costs and work hours. For all of these agricultural advantages, ICT encompasses a broad variety of components under digital and computer technologies. This include of GPS, drones, robots, sensors, and actuators, among others. A 5G network is the most recent addition to this list. Although many of these ICT technologies are currently being used by mobile networks to provide the aforementioned agricultural advantages, 5G's low latency, high bandwidth, and support for several sensors communicating at once will greatly increase the effect [7].

2.1 Precision Agriculture

5G is essential for maximizing the overall advantages of smart farming. Through precision agriculture, Cropin's current technological platform already helps to boost production and guarantee the efficient use of resources [8].

However, the introduction of 5G would facilitate the acceleration of the whole process via machine-to-machine services. These systems may operate more quickly because to 5G's real-time data transmission, which also enables rapid, reliable, data-oriented, and real-time decision-making.

2.2 AI-enhanced Machinery

AI-enhanced agricultural equipment is necessary for precision agriculture to be properly deployed [9]. Through mobile apps with AI integration, Smart Risk provides farmers with timely information on a range of environmental dangers and crop-damaging illnesses.

At the same time, ongoing agricultural monitoring utilizing AI-enhanced equipment may assist farmers in spotting dangers as early as possible. However, for artificial intelligence to function effectively, sufficient data is needed. By accelerating a vast quantity of data transmission, 5G will close the data availability gap that is currently present and improve AI performance.

2.3 Drone Sprayers

Reducing the use of agri-inputs that is not essential is a key component of precision agriculture. This is made easier by SmartFarm, which uses data collected from farms, satellites, drones, and sensors to monitor farms in 360 degrees. The use of 5G in these devices may help with effective crop monitoring, which is a task carried out and carried out by autonomous drone sprayers [10].

These drone sprayers, a relatively new piece of agricultural technology, have sprayers and scanners for both crops and weeds. In order to restrict the use of agrochemicals to just where necessary rather than blanket spraying, ICT-based systems may interface with IoT devices. Chemical usage that is limited and focused will result in lower input costs and contribute to reducing crop losses, soil erosion, and water pollution. Similarly, farmers may use drone sprayers equipped with AI and 5G to precisely predict the moment of harvest using color and size analyses.

2.4 Accurate Harvest Estimation

High-quality cameras using AI technology are used by agricultural drones to distinguish between healthy crops and weeds and ruined crops. They make this easier by recognizing variations in plant leaf texture and color [11]. As a result, these gadgets isolate plants and provide farmers the information so they may make adjustments.

With 5G, these gadgets can instantly send information to pursuing machines about possible weeds, damaged crops, and their position. With automated crop recognition and weeding, farmers can harvest quickly and efficiently while saving money.

2.5 Effective Irrigation

Farmers may better grasp the precise water needs by continuously monitoring their fields and crops. Through the use of soil probes placed 120 cm below irrigation lines, analysis of soil needs is feasible. The gadgets can track soil moisture, water salinity, and salinity trends due to the 5G connection. Smart Risk allows farmers to get this information on their phones so they can change watering plans accordingly [12].

Controlling the soil's moisture level will stop wasteful water use and ground- and surface-water depletion. Precision agriculture will also help farmers profit and produce higher-quality crops. Other stakeholders, such as suppliers of agrochemicals and agri-machinery, will also have access to an estimate of the potential output through Smart Risk, which will assist them choose sales and marketing strategies.

2.6 Livestock Tracking and Management

The advantages of 5G adoption in discovering precious livestock will become clear after you comprehend the significance of animals in sustainable agriculture [13].

Geolocation services and real-time connection made possible by 5G will help farmers learn about the health, fertility, and food consumption of their livestock. Additionally, it will assist farmers in lowering the total cost of livestock management programs and animal productivity.

3. IMPACT OF 5G-ENABLED SMART FARMING

The effects of smart farming have not yet been thoroughly investigated. However, farmers may anticipate the following advantages with the use of 5G in the future thanks to its qualities.

3.1 Faster Communication

Up to 10 Gbps of data speed will be available with 5G, making connection 100 times faster than with 4G. Real-time communication between stakeholders will be facilitated by increased speeds and dramatically decreased latency.

3.2 Machine-to-Machine Data Transfer

As was previously said, the speed and effectiveness of agricultural operations may be improved by direct information transmission between 5G-enabled equipment that doesn't need human creativity.

3.3 Reduced Costs

Farm owners may significantly boost income with a reduction in the need for labor, agri-inputs, and other resources. It can take longer for 5G to fully spread out and reach all distant locations. However, when it occurs, automation provided by this new agricultural technology will result in a reduction in the need for labour. Farmers may then concentrate their energies on tasks that need human thought, such as marketing and sales planning. To gain from 5G, farmers must be prepared to embrace its solutions for both their own needs and the environment.

4. 5G ECOSYSTEM'S EQUIPMENT AND TECHNOLOGY

The present research necessitates an environment that encompasses comprehensive 5G network coverage and rapid connection in order to investigate the prospective applications of 5G and Internet of Things (IoT) technologies within the agricultural sector. The effective deployment of data-driven decision-making relies on the integration of Internet of Things (IoT), minimising latency, and actively engaging stakeholders.

The 5G ecosystem is an embodiment of the IoT system architecture, which is a collection of many different technologies and pieces of equipment that work together in a seamless manner. Sensors collect data, which is then transported to a cloud architecture where decisions are made to carry out field activities in order to give insight for the end-user application. The system's components all function independently without any interaction between people or machines. These basic elements help to make the whole process streamlined and integrated. Fig. 1 shows the smart farming with 5G.

Sensors are crucial for the success of smart agriculture, as they collect and monitor environmental variables impacting crop output. Precision agriculture relies on reliable sensor data for targeted crop and soil management [14]. There are two categories of IoT sensors for monitoring applications: intelligent multifunctional imaging sensors, integrated into UAVs, railroads, and fixed components [15]; and specialized sensors placed throughout the field, tailored for specific use cases [16]. These sensors enhance the quality of data-driven decision-making, optimizing farming practices for higher yields and sustainable agriculture. Table 1 shows how sensors function and their applications. In order to quantify the energy consumption of different wireless technologies in agriculture, the suggested system incorporates a number of discrete hardware components. Each node uses a separate wireless technique to transmit the sensor data to the base station. A Series 2 2mW Wire Antenna XBee was utilized for Zigbee, a Dragino LoRa Shield for LoRaWAN, and a CC3000 WiFi Shield for WiFi. In Fig. 1, the system framework is shown.

5. COMMUNICATION TECHNOLOGIES

Smart agriculture is not possible without sensor technologies. Sensors are used to gather and keep track of a variety of environmental data and elements that might affect crop productivity. Obtaining precise sensor data for crop and soil-specific management is the foundation of precision agriculture [18]. The use of remote sensing like the Geographic Information System (GIS) and the Global Positioning System (GPS) are installed in nearly all of the equipment and vehicles for accurate and autonomous site-specific operations. There is a vast variety of IoT sensors available for monitoring applications, however they may be broken down into two main categories. Unmanned aerial vehicles (UAVs), fixed position components, and trains are all potential hosts for intelligent multifunctional image sensors [19]. Soil and fertilizer effect and biomass estimation, drought and water stress detection in plants, pest detection and management, weed detection, and greenhouse monitoring are just some of the many uses for these sensors when combined with deep learning [20]. Since the second kind of sensor may be placed anywhere on the playing field, it is the most common type of sensor employed. Uses for sensors and their operation are outlined in Table 1. IoT sensors are well-suited for smart agriculture for a number of other reasons as well, including their computational efficiency, affordability, range, resilience, memory, portability, and dependability.

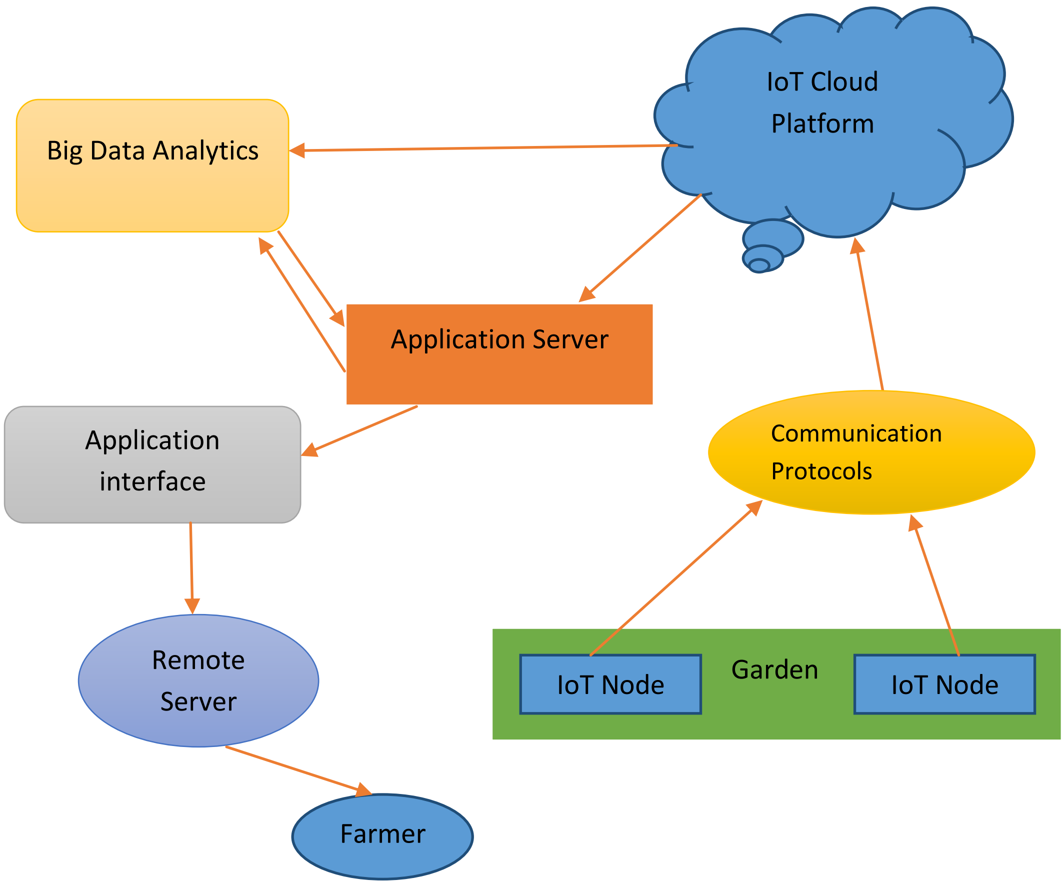

Fig. 1. Smart Farming with 5G

Table 1. Types of sensors [17]

Type of sensors	Functionality
Capacitive humidity	Electrodes coated in a hygroscopic dielectric substance may measure the electrical permittivity of the air to determine how humid it is.
Electrochemical	Electrode placement to detect a narrow range of soil ions
Imagery and remote sensing	Infrared (IR) cameras, digital cameras, multispectral cameras, and standard (visible light) cameras are used to create a digital picture.
Mechanical	Indicators of soil compaction may be found in the mechanical resistance of the soil.
Position	Obtaining coordinates (latitude, longitude, and altitude) through satellites of the Global Positioning System

6. AGRICULTURAL PRODUCTIVITY AND EFFICIENCY USING 5G

The introduction of 5G technology promises to revolutionize agriculture, enabling farmers to maximize their production while minimizing costs. With its lightning-fast speeds and low latency, 5G networks can enable the use of more accurate and efficient precision agriculture techniques, as well as enable more data-driven decision-making. By leveraging the power of 5G, farmers can increase the productivity of their operations and improve the sustainability of their farming practices. One way 5G networks can help improve agricultural productivity is by enabling precision agriculture techniques [21]. Precision agriculture is a set of techniques used to increase crop yields by optimizing crop management practices. By using 5G networks, farmers can access real-time data from their fields, allowing them to adjust their practices in response to changing conditions [22]. This can allow for more accurate decisions about planting and harvesting times, nutrient management, and pest control.

Another way 5G networks can increase agricultural efficiency is by enabling the use of autonomous machines. Autonomous agricultural machines are able to carry out tasks such as harvesting, cultivation, and spraying with little or no human input. By utilizing 5G networks, these machines will be able to communicate and share data with each other in real time, allowing them to coordinate their activities and work together more effectively. Finally, 5G networks can also be used to enable more data-driven decision-making. By leveraging the power of 5G networks, farmers can access and analyse large amounts of data in real-time. This information can be utilized to identify areas of their operations that can be optimized, allowing them to make more informed decisions about their farming practices and maximize their yields. In short, 5G networks offer a number of potential benefits to agricultural productivity and efficiency [23]. By enabling precision agriculture techniques, autonomous machines, and data-driven decision-making, 5G networks can help farmers increase their yields while minimizing their costs. As 5G networks become more widely available, it is likely that they will have a major impact on the future of agriculture**.**

The advancement of 5G technology is revolutionizing the way farmers are able to operate their businesses, providing them with much needed access to sustainable and climate resilient farming practices. 5G has enabled farmers to use data collected from their crops and other resources to make informed decisions about their land use and crop management. This has allowed them to reduce pesticide and fertilizer use, conserve water and energy, and select drought-resistant crops. 5G technology is also allowing farmers to access real-time weather data, including precise forecasts and soil conditions, enabling them to better manage their crops in order to maximize yields and reduce losses due to extreme weather events. By integrating 5G-enabled sensors and drones, farmers can have a better understanding of their land and crops, enabling them to adjust their practices in response to changing conditions [24].

5G has also enabled the introduction of precision farming, which uses advanced technology to monitor, control, and optimize crop production. Precision farming technology allows farmers to use data-driven insights to identify areas of their land that need particular attention, allowing them to reduce inputs and increase yields. In addition, 5G is enabling farmers to access real-time market information, helping them to maximize profits by selling their produce at the best price. With the introduction of 5G technology, farmers can now connect with buyers anywhere in the world, allowing them to access new markets and increase their profits [25].

The increased use of 5G technology in farming is also helping to improve food security and reduce food waste. By providing farmers with access to real-time data, they can better predict crop yields, enabling them to adjust production accordingly to avoid overproduction and reduce food waste.

As 5G technology continues to evolve, it will play an even bigger role in creating sustainable and climate resilient farming practices. By providing farmers with access to improved data and insights, 5G will help to ensure that agricultural production is more efficient and sustainable, helping to ensure food security and reduce the impact of climate change on agriculture.

7. EXPERIMENTAL PROCESS

In order to assess the viability of the proposed solutions, a testbed was built to examine whether or not wireless technology would be optimal for agricultural surveillance with energy harvesting. The only difference between the nodes for each system was how they communicated wirelessly. The tests were carried out in an outdoor setting where the solar panels on every node would get about the same amount of solar energy throughout the day. The remaining battery charge was determined by connecting probes from the power converter, measuring them on the Arduino, and sending the results to the computer serving as the destination. The Table 2 presents system parameters for three different types of wireless technology-based nodes used in agricultural monitoring applications: Zigbee-based node, LoRaWAN-based node, and WiFi-based node.

For testing reasons, nodes were set up to collect data on the battery charge every 1 Hz and send it out every 1 s. Keep in mind that these hours were chosen so that the systems would use more energy and shut down earlier as a result. Since genuine circumstances do not drastically change over a short period of time, times may be drastically reduced if the devices were put in an actual setting for agricultural monitoring. Before any of the nodes were put through their paces, their associated batteries were given a full charge. The Table 3 shows the summary results of the average current consumption and lifetime (in hours) for three different wireless technologies: Zigbee, LoRaWAN, and WiFi, based on the data from multiple samples.

Table 2. System parameter

Wireless Technology	Max Current Consumption (mA)	Min Lifetime (h)
Zigbee-based node	120	54
LoRaWAN-based node	80	70
WiFi-based node	260	22

Zigbee-based systems lasted 79.58 hours in the first testing, whereas LoRaWAN-based systems lasted just 152.56 hours and WiFi-based systems lasted about the same at 30.85 hours. In the second trial, the Zigbee-based system lasted 106.89 hours, the LoRaWAN-based system lasted just 230.98 hours, and the WiFi-based system lasted almost as long, 30.45 hours. The third experiment replicates the second and first, although this time there is less sunlight available and the nodes must rely on their battery power. The Zigbee-based system lasted 94.15 h, the LoRaWAN-based system lasted just 176.52 h, and the WiFi-based system lasted about the same, at 32.85 h. The use of LoRaWAN technology in remote agriculture monitoring significantly enhances battery longevity owing to its low-power and long-range characteristics. The method employs a spread-spectrum modulation approach, hence facilitating long-range communication with little energy consumption. This implies that LoRaWAN devices has the capability to transfer data over considerable distances while maintaining a prolonged battery life.

However, while building a system, other factors are often taken into account in addition to power consumption and device lifespan. Despite having a low power consumption, WiFi offers a substantially higher throughput, which enables a greater quantity of data to be exchanged between devices. The findings presented in this research may be utilized as a guide for choosing a wireless technology for an energy-harvesting agricultural monitoring system.

The successful integration of advanced technologies such as 5G and IoT in the agricultural sector necessitates a comprehensive evaluation of various factors. These factors include the preparedness of existing infrastructure, cost implications, scalability considerations, efficient data management practises, adequate training provisions, user-friendly interfaces, adherence to regulatory requirements, provision of connectivity in remote regions, and the establishment of long-term maintenance strategies. By addressing these aspects, the desired real-world impact can be effectively achieved. These crucial elements guarantee the smooth transfer of data, safeguard confidential data, empower farmers with important knowledge, and facilitate sustainable and effective farming methods.

8. FUTURE OF FARMING

Given this, we anticipate certain important agri-food business trends to pick up speed in the future.

Expect the enthusiasm around investments in sustainability initiatives to continue. The globe has not been doing enough to support less developed countries in coping with the impacts of global warming, according to a new United Nations report. There has been gross underfunding of climate adaption. Those shifts started in 2022 and will accelerate by 2023. Future contributions from the business sector are anticipated to reach unprecedented heights. Agriculture is being rapidly digitalized to increase food chain openness and visibility. One potential solution to agriculture's environmental impact and the approaching economic downturn in certain regions is the widespread use of digital technologies across the agricultural industry. We expect companies and governments throughout the globe to increase their technological investments in agriculture by using advancements in cloud computing, earth observation, remote sensing, data, and AI/ML models. This will aid the industry in solving existing agricultural problems while also opening up new avenues of opportunity.

This has the potential to greatly increase food output, increase profitability, and lower operating costs—all of which are vital in a recession. Maximizing the visibility and openness of the

Table 3. Summary results

Technology	Zigbee	LoRaWAN	WiFi
Average Current Consumption (mA)	67.52	27.56	172.48
Lifetime (h)	93.15	221.00	36.56
Sample 1 - Node Lifetime (h)	79.58	152.56	30.85
Sample 2 - Node Lifetime (h)	106.89	230.98	30.45
Sample 3 - Node Lifetime (h)	94.15	176.52	32.85

world's food systems will get a lot of attention. Knowledge from many different areas, including as data science, digital applications, GIS, agri-science, agronomy, AI/ML models, meteorological data, IoT, and drones, must be combined in order to give better visibility and intelligence across the agri-production lifecycle. In order to maintain the long-term viability of agriculture and, by extension, human civilization, businesses will need to use cutting-edge scientific and technological methods.

8.1 Enhanced Focus on Smallholder Farmer Empowerment [26]

Over the last several years, developing farmer-centric solutions has been a major emphasis for business actors, governments, and international organizations/development agencies. We anticipate that this tendency will intensify considerably between 2023 and later. 500 million of the projected 580 million farmers worldwide are small-holder farmers who are difficult to reach. Stakeholders in the global food system have acknowledged that training and enabling smallholder farmers at the grassroots level to adopt smarter, more effective, and sustainable agricultural practices is essential if agriculture is to undergo significant and lasting reform. Digitization and user-friendly, affordable, and widely available technology may help to a great extent with this. The Government of India's Kisan Drones initiative, which uses drones to digitize land records, spray pesticides to increase production, and analyze crops, is an excellent example of how to make technology more accessible to small farmers. The boardroom discussions of agribusinesses will be dominated by farmer empowerment at the local level in the next year.

8.2 Building Food Self-Sufficiency and Reducing Food Wastage [27]

To feed their people, nations will make determined efforts to increase their food production's autonomy and self-sufficiency. The Covid-19 pandemic of the last two years and the geopolitical upheaval of 2022 have acted as wake-up calls, highlighting the need of nations creating their own self-sufficient food system. By increasing the productivity, efficiency, predictability, and sustainability of their food supply systems, governments will speed up the wider use of data and technology to assist the growth of their economies [28].

As the world struggles with food insecurity and economic uncertainty, eliminating food waste will rise in importance. At various stages, from the field through packing, storage, and distribution, one-third of the food produced worldwide today is either lost or wasted. The use of technology will become more important in the fight against food waste. Soil sensors, for instance, may support soil health monitoring to stop crop loss in the field. With the use of digital tools, producers may get real-time notifications that can help them cut down on loss throughout the growing process and track the lifetime of their crops. End-to-end traceability of food items and commodities is made possible by IoT-enabled integrated agricultural systems and digital dashboards, resulting in less food waste across the supply chain. There will be a significant decrease in food waste throughout the agricultural value chain as a result of the broad use of digital crop monitoring and smart supply chain models.

8.3 Regenerative Agriculture to Reduce Soil Degradation [29]

In the next few years, we anticipate increasing expenditures in soil protection and biodiversity. The foundation of productive agriculture is healthy soil. Soil degradation must be halted and soil health must be preserved and restored for regenerative agriculture to become a reality. Farmers need to be guided by data when deciding how to utilize water, pesticides, and agrochemicals, and when considering regenerative agriculture practices that may improve soil health [30]. New efforts and investments will be made by policymakers, agrochemical corporations, technological actors, and NGOs to protect the soil.

9. CONCLUSION

The significance of 5G and its successful uses in agriculture are discussed in this review, along with any problems and their fixes. It also discusses the ecology of 5G, the usage of UAVs and their numerous kinds and advantages, as well as the advantages and disadvantages of various communication protocols for agricultural applications. With several case studies of major food industry players, we also highlighted how 5G may be used in various smart agricultural approaches, such as precision agriculture, greenhouse farming, and urban farming. In addition, we covered several popular 5G agricultural applications. Consider crop sampling and geospatial and temporal mapping as the initial step in smart agriculture for any developing nation like Pakistan where farmers face significant upfront costs. After providing an overview, we draw the conclusion that Pakistan's agriculture is taking a number of steps to address issues including climate change, water shortage, and food poverty. Artificial intelligence and the use of cutting-edge information technology, which are largely lacking in projects established locally. Research and development in the disciplines of inter-agriculture and information technology should be first funded by Pakistan and other poor countries to secure long-term food security regardless of climatic situations.

COMPETING INTERESTS

Author has 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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