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APPLICATION OF DIGITAL TECHNOLOGIES FOR ENSURING AGRICULTURAL PRODUCTIVITY

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Annotation:
Over the decades, agro-food security has become one of the most critical concerns in the world. Sustainable agro-food production technologies have been reliable in mitigating poverty caused by high demands for food. Recently, the applications of agro-food system technologies have been meaningfully changing the worldwide scene due to both external strengths and internal forces. Digital agriculture (DA) is a pioneering technology helping to meet the growing global demand for sustainable food production. Integrating different sub-branches of DA technologies such as artificial intelligence, automation and robotics, sensors, Internet of Things (IoT) and data analytics into agriculture practices to reduce waste, optimize farming inputs and enhance crop production. This can help shift from tedious operations to continuously automated processes, resulting in increasing agricultural production by enabling the traceability of products and processes. The application of DA provides agro-food producers with accurate and real-time observations regarding different features influencing their productivity, such as plant health, soil quality, weather conditions, and pest and disease pressure. Analyzing the results achieved by DA can help agricultural producers and scholars make better decisions to increase yields, improve efficiency, reduce costs, and manage resources. The core focus of the current work is to clarify the benefits of some sub-branches of DA in increasing agricultural production efficiency, discuss the challenges of practical DA in the field, and highlight the future perspectives of DA. This review paper can open new directions to speed up the DA application on the farm and link traditional agriculture with modern farming technologies.

Keywords. Digital agriculture, Internet of things Digital technology, Big data, Smart farming.

Introduction

Over the decades, increasing demands for supplying agro-food products have influenced agriculture patterns worldwide. Additionally, changing human lifestyles and increasing human population and urbanization have directly impacted the production and consumption of agro-food products. The financial value of strategic plants and the scarcity of natural resources for agriculture have spurred plant producers and agriculture researchers to discover new ways to overcome the food crisis. Thus far, various modern technologies and efficient strategies have been implemented in the agro-food sectors.

However, reports indicate a need to find and/or improve the current agro-food tools to overcome the hunger problem and demand-supply gap by increasing production efficiency. Therefore, on a global scale, "the question of whether the scientific discoveries are able to sustainably and effectively feed everyone by 2050" is the primary concern regarding the future of the agro-food sector. The implementation of digital technology can provide "versatile technology that will revolutionize food production in most critical areas around the world". Generally, Digital Agriculture (DA) is currently understood as using modern tools, data monitoring and analytics, and data-driven solutions in agriculture to improve and/or optimize farming systems, increase crop quality and yield, reduce waste, and manage pest and disease pressure.

By using DA, agricultural producers, and researchers are able to use information and communication technology (ICT) by collecting data, which are achieved from satellites, sensors, connected objects, smartphones, storage, and data transfer protocols (3G/4G/5G coverage, low-speed terrestrial or satellite networks, clouds). DA could be used across different agricultural ecosystems and at different levels of its production, whether on the farm (optimization of cropping operations), in support services (new agricultural advisory services based on automatically collected data), or more broadly at the territorial level (water management). It also can be used in the value chain (enhancing inputs such as seeds, improving harmony between production and the market).

The general understanding of what is meant by "digital technologies in agriculture" is primarily focused on expanding data gathered "in the field," the contribution of artificial intelligence, connectivity protocols and automation. Many operations, including planning farming operations, financing, reporting, monitoring numerous operations, and performances, are simplified by digital technologies. Digital technologies in agriculture have been deployed in various segments of farming, including farm equipmentation, animal handling facilities, agronomy, and communication. Interestingly, DA widely covers diverse aspects of the agro-food sector from basic application, like using mobile device to get technical assistance and monitoring the farms, to a more comprehensive implementation, like using satellites and Global Positioning System (GPS) to predict the weather conditions and mapping the fields.

At the advanced level, specialized Farm Management Information Systems (FMIS) and Farm Management Software (FMS) help producers to control their farm or nursery from a centralized platform, including tasks such as crop rotation, planning, inventory management, and financial tracking. The first history of DA dates back to the mid-20th century, when computers were used to analyze data of farms and satellites were used to monitor crop growth. Nonetheless, DA finds its own way in the 21st century, when the powerful and affordable computing systems and technologies, including GPS, smartphone, drones, and sensors, are becoming increasingly available. Precision Agriculture (PA), which was developed in early 1900s, is the basis of DA. More recently, new technologies of DA, such as Internet of Things (IoT), Artificial Intelligence (AI), and blockchain were introduced. IoT, AI, wireless sensors, robotics, mechanization, sensors and data analytics have the potential to boost productivity, improve the utilization of water and other farm resources. These technologies can aid in fostering resilience and long-term sustainability in crop and livestock production.

Based on the current understanding of DA implementation and its potential applications across various food production systems, the following research questions are relevant:

• which digital technologies have been used in agriculture?

• how these technologies can affect the agricultural industry in regards to sustainable food production?

• what is the adoption status of these technologies?

• what are the challenges of deploying these technologies in agriculture?

The objective of this review is to elaborate the potential advantages and obstacles of using DA, and to clarify ways in which these technologies can be leveraged to support agricultural sustainability, efficiency, and productivity. To the best of the author's knowledge, this review is a comprehensive documentation of DA as a potentially reliable approach to improve agricultural outcomes and to address global agro-food issues.

Materials and Methods:

The following sources of information was used for literature review: Scopus (https://www.scopus.com/), Springer Link (http:// link.springer.com/), Science Direct (http://www.sciencedirect.com/) and the National Agricultural Library (https://www.nal.usda. gov/). Google Scholar (https://scholar.google.com/) was also used to extend the research for potentially useful publications that were not indexed in the sources mentioned above.

This study chose to use the most prominent databases of academic research, such as Scopus, due to their extensive coverage of global and local academic journals and their reliability. These databases were selected because they contain essential metadata and allow for easy data extraction compared to other databases. Scopus was searched using the following key search terms:

- ✓ “digital agriculture,
- ✓ precision technologies,
- ✓ digital farming,
- ✓ precision agriculture,
- ✓ intelligent agriculture,
- ✓ digital agriculture technologies.”

Each search was documented in a table containing the keyword used, the source, and the number of publications found. An initial review was conducted to identify potentially relevant publications for this research by evaluating the abstracts of each publication. The decision to include or exclude a publication as potentially relevant was made after each review.

After the partial review of potentially relevant publications, an in-depth analysis of each publication was conducted by reading the entirety of the publication to determine whether it addressed any of the research questions. The relevant information from the publication was extracted where applicable. Threats to validity The methodology used in this study followed the standard procedures of a literature review, which involves a search strategy, record extraction, and result reporting.

This type of review is suitable as a research method when the aim is to provide a broad view of research in various fields on a particular subject and to analyze research advancements or compare research on the topic across disciplines. This approach can be applied to investigate themes, theoretical perspectives, or particular issues within a research field or discipline, aiming to identify new ideas or approaches as well as theoretical perspectives or issues. A good review must be independently replicable, which gives them greater scientific value.

The presented literature review is susceptible to threats to validity because the search was conducted using only five online repositories. It is possible that additional relevant publications may have been missed by not exploring other sources. If this literature review is replicated, it is possible that different publications may be found. This difference would result from different personal choices during the screening and eligibility steps, but it is highly unlikely that the overall findings would change.

The fundamental components of DA from cell phone to blockchain technology.

To identify problems and enhance agricultural productivity by effectively utilizing available resources, PA uses the available data collected from various sources, such as satellite photos and mobile sensing platforms. Simultaneously, smart and digital agriculture utilize robotics, wireless systems, mobile applications, and IoT-based automation to detect, assess, and control the condition of the soil, water supplies, and weather fluctuations on croplands to increase field efficiency and minimize expenses. In the field of automation, the deployment of smart irrigation, water loss control, and continuous identification of soil nutrient levels in remote places have all benefited from wireless sensors and IoT devices.

The adoption and use of DA technologies vary across different regions of the world, and there are several factors that influence this variation. In Europe, there is a relatively high level of adoption and use of DA technologies, particularly in countries with a high level of agricultural production, such as France, Germany, and the Netherlands. The European Union has also been promoting the adoption of PA practices through its Common Agricultural Policy. In North and South America, the adoption and use of DA technologies are relatively high, and the United States, Brazil, and Canada being among the leading countries in this area. These countries have been early adopters of PA practices and have been investing in research and development of new technologies. In Asia, the adoption and use of DA technologies are growing rapidly, and China being a leading country in this area. The Chinese government has been promoting the use of PA technologies to increase crop yields and reduce environmental impact .

In Africa, the adoption and use of DA technologies are still relatively low, due to various factors such as limited access to technology and infrastructure, and low levels of investment in research and development. However, there are initiatives aimed at promoting the use of DA technologies in Africa, such as the African Agricultural Technology Foundation's Digital Agriculture Services project. Overall, the adoption and use of DA technologies vary across different regions of the world, and are influenced by factors such as access to technology and infrastructure, government policies and initiatives, and investment in research and development.

Significant technological advancements in digital agriculture. Because of digitalization, farmers can now manage their farms and agricultural operations more efficiently from a distance. Agriculture sensors, actuators, and gadgets will all be connected in the near future by IoT, enabling automatic real-time interaction, controlling, and decision-making. This can reduce the need for human labour, which in turn, increases productivity and revenue. Cloud-based farm management tools like SmartFarm and Agrovi strive to combine this information from various sources and incorporate it into their decision-making processes. The combination of these factors provides farmers with data for dynamic management planning that was previously only available to large-scale megafirms.

UAV-based remote sensing is considered as the application of unmanned aerial vehicles (UAVs), to collect images and information of the earth's surface (in this report referring to agriculture field) from above. This technology is equipped with different types of sensors such as radar, lidar, thermal, multispectral, hyperspectral sensors which facilitate the capture of high-resolution data from water bodies, vegetation, land, and man-made as well as natural features. Compared to photos obtained from satellites, the datasets collected by drones that are integrated with high-resolution imaging sensors can provide farmers with higher precision. UAV-based remote sensing is primarily used to observe soil characteristics and crop stress. This generates valuable information that can be used to develop decision support systems for smart pest control, fertilization, and irrigation management. There is a wide variety of UAVs, for instance fixed wing (planes), single-rotor (helicopter), hybrid system (vertical take-off and landing), and multirotor (drone). Among these, drones (multi-rotor technology) which are lifted and propelled by four (quadrotor) or six (hex-rotor) rotors, have become increasingly popular in the agriculture sector due to their mechanical simplicity in comparison to helicopters, which rely on a much more sophisticated plate control mechanism.

Remote sensing not only improve productivity, but also protect the environment, since it can allow farmers to find a better match between crop growth and water/nutrient uptake. There are many discussion regarding the traditional use of remote sensing, but very little discussion about its combination with other technology. Recently, UAV-based remote sensing has become more popular due to the advances in sensor system and availability of low-cost drones which makes it a valuable agriculture tool for plant-producers, scientists, and researchers.

Table 1 Shows the pros and cons of UAV based remote sensing in agriculture

Advantage	Disadvantage
Improved crop monitoring: It can provide detailed information on crop health, growth patterns, and stress, allowing farmers to detect issues early and take corrective action.	Battery and flight time: At the moment, lithium-ion batteries are being used because their capacity is larger than that of conventional batteries. But an increase in battery capacity increases the drone weight.
Better resource management: It can help farmers optimize the use of resources such as water and fertilizer, reducing costs and minimizing environmental impact.	Technical complexity: The data generated by remote sensing technology can be complex, which can make it difficult for farmers to interpret and apply to their operations.
Increased productivity: By providing detailed and timely information, it can help farmers make more informed decisions, leading to higher yields and improved profitability.	Data quality: The quality of remote sensing data can vary, depending on the equipment used and the conditions in which the data was collected, which can lead to uncertainty around the effectiveness of the technology.
Efficient land use: it can help farmers identify areas of their land that are underutilized or overused, allowing them to make better use of their resources and maximize productivity.	Limited access: Limited access to reliable and high-quality data can be a challenge for many farmers, particularly in developing countries or remote areas.
Accurate mapping: It can provide accurate mapping of agricultural land, allowing farmers to better understand their land and make more informed decisions about planting, harvesting, and other activities.	Privacy and security concerns: There may be concerns around the privacy and security of data collected through remote sensing technology, particularly as it relates to sensitive information

Notwithstanding the advancement in the UAV-based remote sensing application, the adoption UAV-based remote sensing into the agro-food sector is slow due to issues such as :

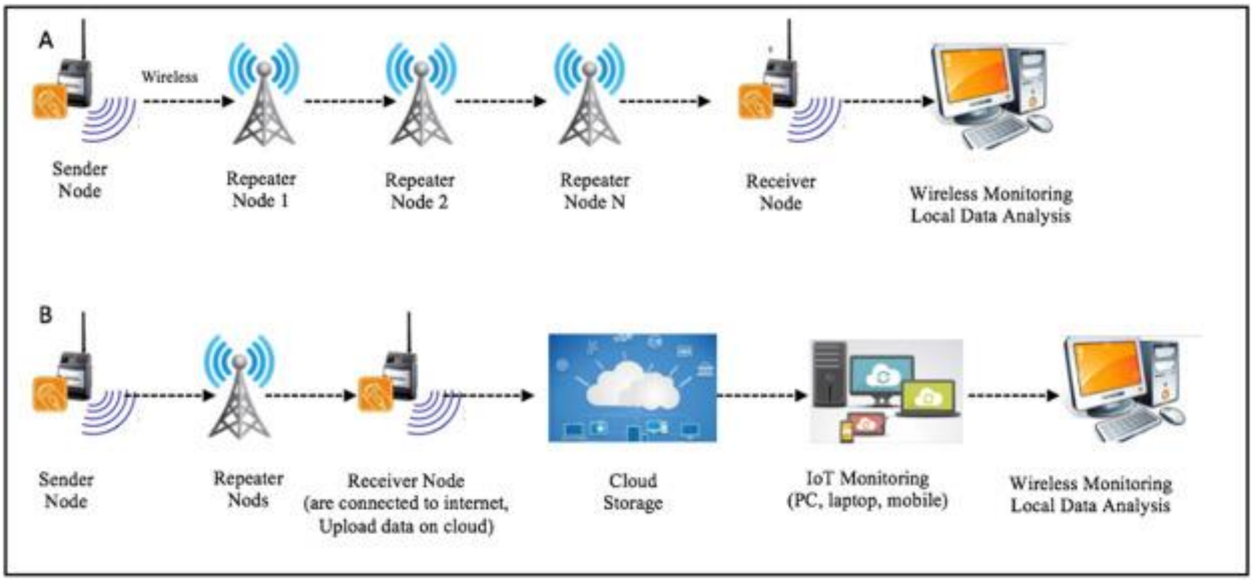
• cost: the cost of acquiring and maintaining remote sensing equipment can be high, which can be a barrier for many farmers.
• complexity: the data generated by remote sensing technology can be complex, which can make it difficult for farmers to interpret and apply to their operations.
• standardization: there is a lack of standardization for data collection and analysis, which can make it difficult to compare data across different sources or technologies.
• data quality: the quality of remote sensing data can vary, depending on the equipment used and the conditions in which the data was collected. this can lead to uncertainty around the effectiveness of the technology.

• access: limited access to reliable and high-quality data and internet connection can be a challenge for many farmers, particularly in developing countries or remote areas.

• privacy and security: there are concerns around the privacy and security of data collected through remote sensing technology, particularly as it relates to sensitive information such as crop yields and land use.

Overall, these issues have slowed the adoption of remote sensing technology in agriculture, but efforts are underway to address these challenges and increase the adoption of this technology.

An IoT-based automation system comprises sensor nodes, several repeaters, and receivers that are interconnected across the field to increase the productivity and profitability of digital agriculture through a better understanding of the interactions between soil, crop, and weather. Data access is limited in a wireless monitoring system because the receiver node saves data on a local host. In contrast, the receiver node in IoT-based monitoring systems uploads data to a web server so that any client device connected to the internet may access it. Measurements obtained from a multitude of wireless sensors are input into a traditional Decision Support System (DSS) or crop growth model, powered by AI algorithms, through the utilization of internet connections and cloud-based streaming systems in large-scale agriculture, with the end goal of maximising both production efficiency and profitability. IoT gadgets have shown to be useful for enhancing agricultural resource management and boosting output sustainability. Represents field measurement and data collection using wireless sensor networks and devices, and demonstrates IoT monitoring and cloud-based data analysis. The range of the distance between the sender and the monitoring device in wireless sensor networks is usually between 1-m to 100 km. However, this distance becomes unlimited when using IoT and cloud-based data analysis.



A) Schematic demonstration of field measurement and data collection using a wireless sensor network and
B) IoT monitoring and cloud-based data analysis.

To ensure continuous data collection, large-scale farms require careful consideration of factors such as number of sensor nodes, repeater sites, power usage, operating frequencies, and distance between transmitters and receivers . Developing an IoT architecture and successfully implementing its transmitters and receivers in the field can be intrinsically challenging. Most gateways utilize single-board computers equipped with ARM processors, while most software applications are intended for x86 processors. This results in compatibility concerns and unexpected behaviours . WiFi, Bluetooth Low Energy (BLE), LoRaWAN, SigFox, NB-IoT, and LTE are the radio protocols that have the most widespread application for IoT .

There are different types of WSNs, which are categorized depending on the environment where they are deployed. These include Terrestrial Wireless Sensor Networks (TWSNs), Wireless Underground Sensor Networks (WUSNs), Underwater Wireless Sensor Networks (UWSNs), Wireless Multimedia Sensor Networks (WMSNs), and Mobile Wireless Sensor Networks (MWSNs). In agricultural applications, TWSN and UWSN are widely used. In TWSNs, the nodes are deployed above the ground surface, consisting of sensors for gathering the surrounding data. The second variant of WSNs is its underground counterpart, WUSNs, where sensor nodes are planted inside the soil. In this setting, lower frequencies easily penetrate through the soil, whereas higher frequencies suffer severe attenuation. Therefore, the network requires a higher number of nodes to cover a large area because of the limited communication radius. Many research articles are available in the literature that discuss the use of WSN for different outdoor and indoor applications, such as irrigation management, water quality assessment, and environmental monitoring. These studies have focused on developing WSN architectures that are simplified, low cost, energy-efficient and scalable. Yet, various factors associated with WSNs need further attention, such as minimum maintenance, robust and fault-tolerant architecture, and interoperability.

Adoption of automated processes using wireless sensing and IoT in DA comes with several challenges. Many farmers may not be aware of the potential benefits of wireless sensing and IoT devices, making them unwilling to invest in these technologies. Wireless sensing and IoT devices may be complex and require specialized knowledge to set up and use effectively, which can be a barrier for many farmers who may not have access to technical support. Additionally, some farmers may not have access to the necessary infrastructure, such as reliable internet connectivity, to support wireless sensing and IoT devices.

There may be concerns around the privacy and security of data collected through wireless sensing and IoT devices, particularly as it relates to sensitive information such as crop yields and land use. Furthermore, regulatory barriers may also prevent the use of wireless sensing and IoT devices in agriculture, such as restrictions on the use of certain frequencies for wireless communication. Addressing these adoption issues is critical to ensure effective and widespread adoption of automated processes using wireless sensing and IoT in DA. This can be achieved through increased awareness and education, addressing cost and infrastructure challenges, ensuring data privacy and security, and establishing standard protocols and regulations to support interoperability and data compatibility.

Big data Analysis:

Rapid developments in IoT and cloud computing technologies have increased the magnitude of data immeasurably. This data, also referred to as Big Data (BD), includes textual content (i.e., structured, semi-structured, and unstructured), and multimedia content (e.g., videos, images, audio). The process of examining this data to uncover hidden patterns, unknown correlations, market trends, customer preferences, and other useful information is referred to as big data analytics (BDA). Big data is typically characterized according to five dimensions defined by five Vs, which are: (1) Value, (2) Volume, (3) Velocity (4) Variety, and (5) Veracity. The paradigm of BD-driven smart agriculture is comparatively new, but the trend of this application is positive as it has the capacity to bring a revolutionary change in the food supply chain and food security through increased production.

Agricultural BD is usually generated from various sectors and stages in agriculture, which can be collected either from agricultural fields through ground sensors, aerial vehicles, and ground vehicles using special cameras and sensors; from governmental bodies in the form of reports and regulations; from private organizations through online web services; from farmers in the form of knowledge through surveys; or from social media. The data can be environmental (weather, climate, moisture level), biological (e.g. plant pest/disease, plant nutrient), or geo-spatial depending on the agricultural domain and differs in volume, velocity, and formats. The gathered data is stored in a computer database and processed by computer algorithms to build relational assessments of seed characteristics, weather patterns, soil properties, marketing and trade operations, consumer behavior, and inventory management.

A summary of the tools and services used to decipher BD in agriculture is given in Table 2. Machine learning, cloud-based platforms, Modeling and simulation are the most commonly used techniques. Particularly, machine learning tools are used in prediction, clustering, and classification problems. Whereas cloud platforms are used for large-scale data storing, pre-processing, and visualization. There are still many potential areas that are not adequately covered in the existing literature, where BDA can be applied to address various agricultural issues. For instance, these include data-intensive greenhouses and indoor vertical farming systems, quality control and health monitoring of crops in outdoor and indoor farms, genetic engineering, decision support platforms to assist farmers in the design of indoor vertical farms, and scientific models for policymakers to assist them in decision making regarding the sustainability of the physical ecosystem. Most systems are still in the prototype stage.

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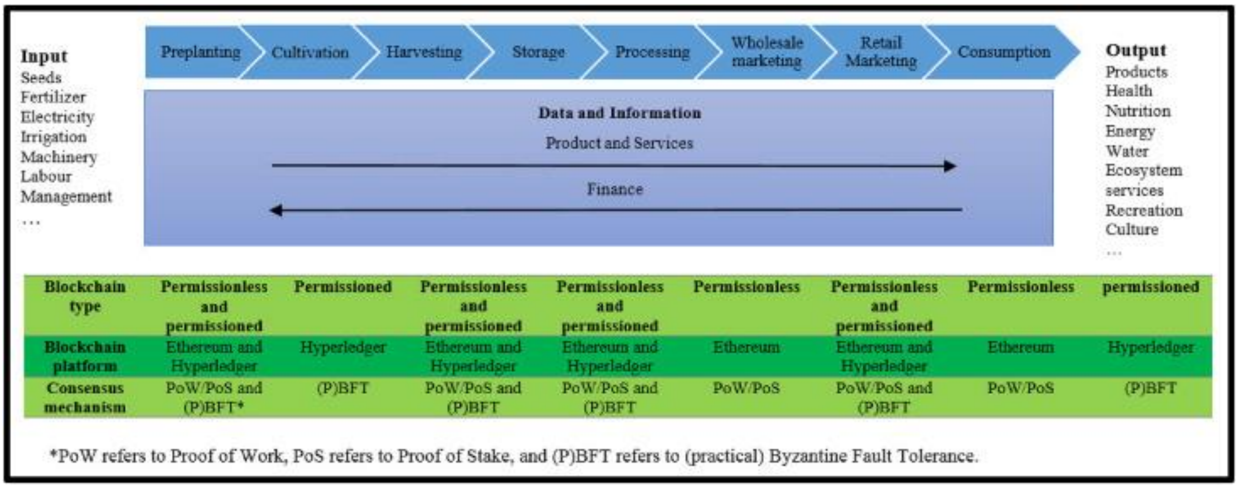
Table 2 Big data tools and services in agriculture.

Service category	Tools and techniques used	Big data source	Farm type	Maturity level
Water and environment management	Crop Modeling and simulation, geospatial analysis	Weather station, historical databases	Open-air	Conceptual
Crop management	Clustering, prediction, and classification. Support vector machine.	Sensor, historical, and farmer data.	Open-air	Conceptual
Irrigation management	Cloud based application. Cloud-based platform, and web services	Sensor data industry standards	Open-air Hydroponics	Conceptual, prototype

The adoption of BDA in DA has been steadily increasing in recent years. Many agricultural companies and organizations are now using advanced analytics and machine learning techniques to extract insights from large and complex datasets, such as weather data, soil samples, and satellite imagery. These insights can help farmers make more informed decisions about crop management, such as when to plant, irrigate, and harvest, as well as identify potential issues such as disease outbreaks and yield losses. They can also support a more efficient use of resources, such as water, fertilizer, and energy.

Smart agriculture. Agro-food systems are supported by data and information on natural resources that sustain all types of farming. Illustrates the flow of data and information, the flow of products from input to output through various value-adding stages, and the flow of money from output to input. It shows how and what type of blockchain is used on different kind of platforms (Ethereum or Hyperledger) along with various consensus mechanism might be suitable to collecting data and information at different stages in crop agro-food systems.



Data and information flow along the food value chain.

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Multiple actors and stakeholders produce and manage data and information depending on their capacities and needs. Utilizing ICT, IoT, and a variety of contemporary data collection and analysis tools, such as Unmanned Aerial Vehicles (UAV), sensors, and machine learning, are critical components of smart agriculture. Creating a comprehensive security system that facilitates data use and management is a crucial component of smart agriculture. Traditional methods manage data in a centralized manner and are vulnerable to cyber-attacks, inaccurate data, data distortion and misuse. For instance, data from environmental monitoring is typically managed by centralized government agencies with special interests.

They can influence decisions made in relation to data. Environmental monitoring data, for example, is generally collected by centralized government entities with special interests. They can influence data-driven decision-making. Throughout the entire value-added process, from seed to sale, of producing an agricultural product, various actors and stakeholders generate data and information that can be stored using blockchain technology. This guarantees that all recorded data are immutable and that the data and information are transparent to all parties involved. Unlike methods, which rely on "security of obscurity," blockchain technology produces security through decentralization.

The combination of IoT and blockchain technology has led to the development and implementation of several smart agricultural schemes. For example, a lightweight blockchain-based architecture for smart greenhouse farms is proposed by Refs. IoT sensors in greenhouses function as a local, private blockchain that the owner centrally controls. A smart agricultural framework based on blockchain and IoT is proposed by Lin for large scale implementation. The primary purpose of the platform is to build trust between parties utilizing blockchain. Agents involved in the selling of plantation products can access the data recorded in the blockchain using mobile devices. For application at the local and regional levels, Ref. suggest a blockchain-based ICT e-agriculture model in which each actor has a piece of real-time water quality data kept in the blockchain. Additionally, farm organizations are utilizing blockchain to improve their farming practises and make it smarter. For example, Taiwan's agricultural irrigation groups use blockchain to store data collectively and improve communication with the public.

Summary of findings:

The goal of this review was to describe the cutting-edge digital technologies that are being integrated into the agricultural industry and to forecast the future direction of DA. Upon extensive analysis, it can be concluded that certain technologies such as big data and analytics, wireless sensor networks, and cyber-physical systems have not been extensively studied in the agro-food domain. The high cost of implementing complex and advanced technologies in the agriculture sector during the early stages of adoption could be one of the primary reasons for this gap. The findings of this review also demonstrate that IoT has gained significant traction in farms. This is primarily attributed to the diverse range of functions that IoT offers, including monitoring, tracking, tracing, agriculture machinery, and precision agriculture.

Although, IoT is a significant area of focus in DA, very few studies have taken into account aspects such as data security and reliability, scalability, and interoperability in the development of intelligent agricultural systems. Our analysis indicate that the majority of use cases in the agricultural sector are still in the prototype stage. This is likely due to the fact that agricultural processes involve living organisms such as animals and plants, as well as perishable products, which make developing systems more challenging compared to non-living systems. Nonetheless, agriculture has been relatively slow to adopt technological advancements due to the complex and multi-disciplinary nature of the industry.

Digitalization of agricultural systems is complicated due to variation in plant or crop species and growth conditions. This emphasizes the necessity for significant research and development efforts in specific areas to guarantee successful implementation of DA in both developed and developing countries.

The potential of blockchain technology to assist the agricultural industry was also examined. The application of blockchain technology can benefit the agricultural sector by providing immutable and irreversible storage of data. Moreover, blockchain technology can enhance credibility and contribute significantly to the sustainable agro-food industry. While blockchain has the potential to ensure food traceability, there are still several limitations to be taken into account, such as regulations, stakeholder relationships, data ownership, and scalability. To enhance comprehension of the technology and enable the creation of novel applications, it would be advantageous for researchers and developers to establish a comprehensive assessment model.

The adoption of new technologies by stakeholders in the agricultural sector is only possible when they are made easy to use, enhances productivity, and delivers additional value to end users. Therefore, the implementation of new technologies in a traditional agricultural setting is a major challenge that should be approached gradually and efficiently, with the active involvement of stakeholders who are directly affected throughout the supply chain. The complexity of the agriculture ecosystem gives rise to a set of interrelated obstacles that impede the complete integration of digital technologies for DA implementation. Therefore, it is crucial to identify possible challenges to formulate strategic solutions to overcome them. This review aimed at examining these challenges.

The various advantages that can encourage farmers and stakeholders to embrace the adoption of digital technologies in the agricultural sector were identified and compiled in Table 5. These benefits possess the potential to optimize farm productivity, improve product quality, and ultimately contribute to boosting food security.

Table 5 Added value of DA

Benefits	Explanation
Improved agility	Digital technologies enhance the flexibility and responsiveness of farm operations. By leveraging real-time monitoring and predictive systems, farmers or agricultural specialists can promptly respond to any potential changes in environmental and water conditions to protect crops from stress.
Green process	Digital platforms can enhance the efficiency of resource utilization by optimizing the quantity and quality of agricultural output while reducing the consumption of water, energy, fertilizers, and pesticides.
Time and cost savings	Digital technologies enable considerable time and cost savings by automating various operations, such as sowing, harvesting, irrigation, and regulating the application of pesticides or fertilizers.
Asset management	Digital technologies enable instantaneous monitoring of agricultural properties and equipment to prevent theft, expedite replacement of components, and carry out regular maintenance.
Product safety	The application of digital technologies ensures sufficient farm productivity and assures a safe and healthy supply of agro-food products by preventing fraudulent activities related to adulteration, counterfeiting, and artificial enhancements.

The possibility of using advanced technologies to improve plant production under normal and stress conditions can promote the development of digital farms in a scalable manner to sustain livelihood and increase food supply Although digital technology has enormous potential to contribute significantly to crop production and protection, the application of this modern technology also comes with risks, such as the lack of privacy, the over-concentration of service providers, exclusion and even job losses for specific occupations, and cyber security breaches . Even though digital technologies offer numerous advantages, they should not be considered a final solution. The importance of other branches of plant science like plant biotechnology and breeding to produce new varieties or improve the defence mechanisms of available plant varieties against adverse condition should be considered. In addition to these, the role of infrastructure and the importance of investments, such as better roads, uninterrupted electricity, post-harvest storage facilities, and improved logistics for connecting farmers to markets, cannot be overstated. A more favourable investment climate and enhanced governments policies could boost the deployment of digital technologies in agriculture.

Conclusion:

Modern industrial farms and enhanced agricultural production methods are becoming necessary due to the growing concern over the world's food security crisis. The Industry Revolution 4.0 agenda, which pioneered the proliferation of data-driven approaches, has equipped the agricultural sector with a wide range of creative solutions to boost

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agricultural yields, lower prices, reduce waste, and maintain process inputs. This review presents a comprehensive analysis of the current state of prevailing digital technologies in the agriculture sector. Our assessment indicate that big data and analytics, wireless sensor networks, and cyber-physical systems are in still the preliminary phase. Most use cases are in the developmental stage and have not yet reached the market for commercial use. Also, incorporating blockchains can prove advantageous for farmers by enabling the irreversible and immutable storage of data.

The utilization of blockchain technology for securing food traceability and data storage across the supply chain appears to hold great promise. In addition certain challenges are identified, which must be carefully examined and addressed to achieve digitalization of the agriculture industry. This review highlights and elucidates the added value of digital technologies in the agricultural industry. It is envisaged that this review will contribute a valuable resource to the ongoing research on DA. This review has two primary limitations. Firstly, the literature search was restricted to only five online repositories, (Scopus, Springer Link, Science Direct, National Agricultural Library, Google Scholar). Secondly, there is a possibility that using additional keywords and synonyms could have resulted in the identification of more relevant studies for inclusion in this review. Nevertheless, in either scenario, the likelihood of altering the overall conclusion of this study is minimal.

REFERENCES

1. Veronique Bellon-Maurel, Ludovic Brossard, Frédérick Garcia, Nathalie Mitton, Termier Alexandre. Getting the Most Out of Digital Technology to Contribute to the Transition to Sustainable Agriculture and Food Systems
2. R.W. Scholz, et al. Unintended side effects of the digital transition: European scientists' messages from a proposition-based expert round table
3. Veronique Bellon-Maurel, Huyghe Catherin. Innovation for a more sustainable and prosperous agriculture
4. C. Padhy, M. Reddy, R. R.-I. J. of N., and undefined. Role of digital technology in agriculture
5. T. Banhazi, H. Lehr, J. Black, H. C.-I. J., and undefined. Precision livestock farming: an international review of scientific and commercial aspects
6. Y. Liu, X. Ma, L. Shu, G.P. Hancke, A.M. Abu-Mahfouz. From industry 4.0 to agriculture 4.0: current status, enabling technologies, and research challenges
7. F. da Silveira, F.H. Lermen, F.G. Amaral. An overview of agriculture 4.0 development: systematic review of descriptions, technologies, barriers, advantages, and disadvantages.

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