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CURRENT TRENDS IN DIGITAL FARMING TECHNOLOGY

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Abstract: The future of agriculture must be digital, but only if it is developed with farmers, and for farmers. Agricultural technology, encompasses a broad range of disciplines and devices that improve agricultural output. The modern agriculture technologies include robotics, computers, satellites, drones, mobile devices, and software. The use of big data analytics and artificial intelligence (AI) technology in agriculture is also an example of how the farming sector is embracing technological advancement. In today's agribusiness, advanced technology in agriculture helps farmers prosper, by promoting more efficient and sustainable farming methods. This paper presents the most relevant digital technologies in agriculture and the benefits of digitalization in agriculture.
Keywords: farm digitalization, agricultural digital technology, digital and AI tools, sustainability

INTRODUCTION

Farm digitalization marks a transformative era in modern agriculture, incorporating advanced technologies and innovations that entails diverse costs and benefits, perceived differently by various stakeholder groups, including farmers, policymakers, agricultural associations, researchers, consultants, and other experts (Dhanaraju, M., Chenniappan, P., Ramalingam, K., Pazhanivelan, S., Kaliaperumal, R. , 2022).

Changes in farming and field management have been revolutionary during the past few decades.

By integrating advanced technologies such as sensors, drones, robotics, and data–driven decision–making tools, digitalization enables farmers to enhance productivity, efficiency and sustainability of their land and agricultural practices (Abiri, R., Rizan, N., Balasundram, S.K., Shahbazi, A.B., 2023; Mishra, S., Sharma, S.K., 2023).

However, the adoption of digital technologies is not without its complexities, especially when viewed through the diverse perspectives of stakeholders involved in agricultural systems.

Farmers, technology providers, policymakers, cooperatives, and advisors often approach digitalization with varying expectations, priorities and concerns, resulting in both opportunities and divergences (Cesco, S., Sambo, P., Borin, M., Basso B., Orzes, G., Mazzetto, F., 2023).

From smart sensors for soil monitoring to AI agronomists in farmers' pockets, digital innovations are transforming agriculture worldwide. Yet without the right frameworks in place, these technologies risk reinforcing inequalities rather than resolving them – and ultimately isolating farmers instead of connecting them.

Digital and AI tools must be tools to empower farmers, strengthen their competences and self–determination, and enable them to take a leading role in addressing global challenges.

With technologies such as remote sensing and data analytics, digital agriculture enables more efficient and sustainable food production (Morchid, A., Rachid El Alami, R., Raezah, A.A., Sabbar, Y., 2019). This can optimize resource utilization, enhance crop yields, and alleviate environmental impacts, growth in food availability and access (Ali, A., Hussain, T., Tantashutikun, N., Hussain, N., Cocetta, G., 2023). Additionally, digital platforms can promote access to information among farmers, and financial services, connect them to new markets, and empower them to make informed decisions and improve their livelihoods.

Thus, the increase in farmers' adoption of digital agriculture tools and the steadily growing automation of farms will propelling the growth of the digital agriculture market.

This paper examines these dynamics, focusing on the most relevant digital technologies in agriculture and benefits of digitalization in agriculture.

MATERIALS AND METHODS

The employment of modern, state–of–the–art technology in agriculture can be credited with much of the recent success in crop management and increased harvests.

The fundamental components of digital farming are showed in Figure 1.

Figure 1 – The fundamental components of digital farming

Modern farming practices have been changed by the integration of the latest technologies, such as the IoT, robotics, blockchain, embedded electronics, and automation, giving rise to the idea of smart farming. This new paradigm involves the intelligent application of data–driven technology to improve the productivity, efficiency, and sustainability of agricultural methods.

According to recent studies, the key digital technologies in agriculture are:

— Internet of Things (IoT): In agriculture, IoT enables the monitoring of soil moisture, temperature, and other environmental factors. This data helps farmers make informed decisions regarding irrigation, pest management, and crop health. The combination of sensors, IoT, and data analytics technologies allows for real–time monitoring and management of farming activities, which helps to maximize resource utilization and increase crop yields.

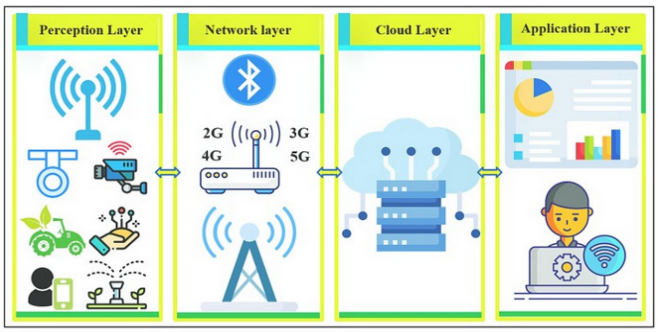

Figure 2 – The IoT architecture for smart agriculture

The most important IoT applications in smart agriculture are used on irrigation monitoring systems, fertilizer administration, crop disease detection, monitoring (yield monitoring, quality monitoring, processing monitoring), forecasting, and harvesting, climate conditions monitoring, and fire detection. IoT technology and its architecture (shown in figure 2) has the potential to change the farming sector through these applications, fostering more effective, and sustainable agricultural methods (Friha, O., Ferrag, M.A., Shu, L., Maglaras, L., Wang, X., 2021).

— Agriculture sensors: These wireless sensors provide farmers with data to optimize crop management based on environmental conditions. They assist in soil analysis, moisture detection, nutrient monitoring, precise location tracking, and airflow assessment. By using sensors, farmers can reduce pesticide and labor costs while efficiently applying fertilizers, maximizing yields, and conserving natural resources (Pyingkodi, M., Thenmozhi, K., Nanthini, K., Karthikeyan, M., Palarimath, S., Erajavignesh, V. et al., 2022)

— By using soil moisture monitors, farmers may plan when to irrigate their crops, only applying water when it is required (Jain, R.K., 2023). In addition to saving water and money, this can avoid overwatering, which can cause soil erosion and nutrient depletion. Similarly to this, farmers may employ targeted treatments just where they are required by utilizing sensors to track soil quality and nutrient levels. This reduces the need for pesticides and fertilizers while supporting sustainable agricultural methods.

— Artificial Intelligence (AI): AI technologies, such as machine learning and predictive analytics, analyze vast amounts of agricultural data to provide valuable insights. AI can assist in crop disease identification, yield prediction, optimization of resource allocation, and automated decision–making processes.

— Robotics and automation: Robotic systems are increasingly used in agriculture for tasks like planting, harvesting, and weeding. These technologies improve precision and efficiency while reducing labor costs and physical strain on farmers. IoT is reinforced by robotics, which automates operations such as planting and harvesting to increase production and reduce manual labor (Xu, J., Gu, B., Tian, G., 2022). Automation driven by real–time data improves yields and optimizes the use of resources while reducing errors in farming practices. This technology seeks to

simplify operations and improve productivity and decision–making.

— Remote sensing and satellite imaging: Remote sensing and satellite imaging techniques provide real–time and accurate information on crop conditions, vegetation health, and soil moisture levels. This data helps farmers monitor crop growth, detect diseases, and optimize irrigation practices.

By acquiring data on a range of environmental factors, including nutrients, soil moisture, temperature, and others, farmers may make decisions about irrigation, fertilization, and pest control (Obaideen, K., Yousef, B.A.A., AlMallahi, M.N., Tan, Y.C., Mahmoud, M., Jaber, H.et al., 2022; Postolache, S., Sebastião, P., Viegas, V., Postolache, O., Cercas, F., 2023).

Thanks to smart agriculture, farmers can continuously monitor crop growth and environmental conditions, anticipate potential problems, and take quick action in reaction to changes. This approach, which promotes efficient and environmentally friendly farming methods, is essential in light of climate change and other environmental problems. The application of sensor technology in agriculture is anticipated to have a substantial influence on future food production (Siddiquee, K.–e.–A., M.S. Islam, M.S., N. Singh, N., V.K. Gunjan, V.K., W.H. Yong, W.H., M.N. Huda, M.N. et al., 2022).

— Precision agriculture: Precision agriculture utilizes GPS, GIS, and data analytics to optimize farm operations. Farmers can create detailed field maps, apply fertilizers and pesticides precisely, and monitor crop variability to maximize productivity and minimize resource waste.

Precision agriculture technologies can improve resource management through the precise application of inputs, such as water, fertilizer, and feed, leading to more efficient agricultural production. Precision agriculture can be implemented through a suite of technologies that can be used in isolation or in conjunction with other technologies.

Table 1. Examples of emerging precision agriculture technologies

Technology	Description
Remote sensing platforms	Drones and ground robots can provide new ways to provide measurements on crop conditions.
In–ground sensors	Provide farmers near–real–time information on soil and plant properties such as temperature, moisture and nutrients.
Targeted spray systems	Use machine learning to precisely spray in a specific spot.
Automated mechanical weeders	Use machine learning to start and stop weeding blades to avoid damaging the growing crops.

Examples of emerging precision agriculture technologies are in the table 1.

— Farm management software: Farm management software enables farmers to streamline operations, manage inventory, track machinery maintenance, and monitor financial aspects of their business. These tools enhance efficiency and enable data–driven decision–making.

— The Farm Management Software Market is experiencing substantial growth as a result of the growing demand for improved productivity and the increasing adoption of precision agriculture. Farmers are progressively employing software solutions to more effectively manage crop produce, resources, and operations. Software developers can leverage initiatives that promote wise farming practices to develop customized solutions that cater to the unique requirements of various regions and agricultural types.

— Blockchain technology: Blockchain offers secure and transparent data management and transaction systems. In agriculture, blockchain can enhance traceability, supply chain management, and food safety by recording and verifying every stage of production, processing, and distribution.

— The agricultural supply chain is transparent and traceable thanks to blockchain technology. Immutable records boost consumer and stakeholder confidence by confirming the provenance of products and facilitating interactions between farmers and buyers.

— Big data analytics: Big data analytics involves analyzing large and complex data sets to derive meaningful insights. In agriculture, it aids in crop modeling, weather forecasting, market trends analysis, and supply chain optimization.

— Drones: Drones have gained widespread usage in agriculture, provide valuable insights that may not be easily observable from the ground, aiding in determining optimal harvest timing, monitoring irrigation needs, implementing pest protection measures, and more.

— Cloud connectivity: Cloud–based connectivity revolutionizes the digital solutions available to farmers by leveraging real–time internet connections. This upgrade is especially significant as many farmers still lack connectivity. Embracing cloud connectivity enables farmers to access a

broader range of digital tools and services, empowering them to make real–time decisions and accomplish more efficiently. It also offers the potential for economies of scale and enhanced productivity in agricultural operations.

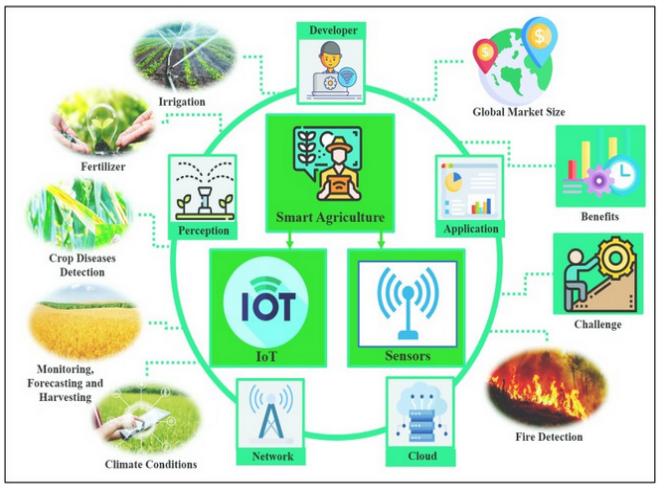

Figure 3 – Graphical IoT applications in smart agriculture

RISK MANAGEMENT IN DIGITAL AGRICULTURE

Mandatory and continuous risk assessments are needed to address pre–emptively potential AI risks, but also broader digitalization challenges such as connectivity gaps and cybersecurity threats.

To address identified risks, AI and digital developers must:

- Establish protocols: develop and implement protocols to mitigate risks and protect farmers and relevant stakeholders.
- Testing and validation: ensure regular testing to ensure AI and other digital systems operate as intended across varying connectivity levels.
- Incident response: develop response plans for any unexpected events or system failures that may affect the farming community.
- Long–term resilience: ensure mitigation strategies include not only technical and ethical responses but also infrastructure investments and capacity–building initiatives that enable long–term digital resilience at farm level.

RESULTS

The implementation of smart agricultural technology is advantageous for all players in the agri–food chain. With its use in optimizing and automating agricultural operations and field activities, growers and landowners can now save significant amounts of time and effort. These are just a few examples of how farming has benefited from advances in agriculture technology:

- using less water, fertilizer, pesticides, and other inputs allows agricultural producers to cut costs and keep more of their profits;
- by preventing or drastically reducing the amount of chemical runoff into waterways, businesses lessen agriculture's impact on the environment and take steps toward greater sustainability;
- increasing crop yields while decreasing labor inputs;
- making it easier for farmers, agronomists, or other agricultural workers to communicate and coordinate activities using mobile devices, apps, or web–based resources;
- lowering barriers to accessing agricultural insurance and financial services as well as market and technological data;
- mitigation of the damage that could be caused by pests, natural calamities, and bad weather in agriculture with the help of affordable, always–on agricultural monitoring systems;
- increase in farm income through improved product quality and increased quality controls;
- timely recognizing nutrient deficiency in plants and notifying agricultural producers of the type and amount of fertilizer and other amendments needed;
- ability to foresee potential problems on the farm through the visualization of production patterns and trends gleaned from an analysis of current and historical agricultural data. By estimating their overall crop yield, agricultural producers can precisely budget for the next growing season and better prepare for emergencies.
- Compared to prior farming methods, digital agriculture technology excels in the following aspects:
- data collection efficiency: how much data can be collected in a given amount of time or space;
- data accuracy: how close a measurement is to the truth;
- timeliness: how quickly the data can be processed into practical information and reported to end users.

When it comes to weather, pests, and diseases, agricultural producers have little to no control. Yet, with the advent of digital technologies in agriculture, they may lessen the negative influence of these elements. Meanwhile, digital agricultural technologies give farmers the opportunity to greatly increase the efficiency of

decision–making and the return on factors that they directly control. Some examples are:

— what types of crops to grow;
— how to rotate crops for the best results;
— when and how much water to use for precision irrigation;
— when, how much, and what kind of nutrients and plant protection products to apply;
— what kind of tillage works best with a given type of soil.

Agricultural experts agree that the most valuable tools and technologies of digital agriculture regarding competitive advantages are cutting–edge farm management software, space–based solutions (especially those that provide high–resolution satellite images), proximal sensors, connectivity instruments, and data–driven algorithms for threat prediction.

Digitalization and AI systems should reinforce Farmers' access to the best available science, knowledge and technology. This includes:

— Digital inclusion: ensuring that all farmers—regardless of location, size, age, gender, language and dialects, and overcoming existing gap in access and use of digital technologies —can benefit from AI and other digital solutions.
— Verifiable sources: AI and other digital solutions should give farmers immediate access to information and data from verifiable sources.
— Strategic autonomy: digital tools and applications should empower farmers, strengthening their capability to exercise good judgement in making strategic decisions on the farm, thus enhancing their self–reliance rather than patronizing them or creating new dependencies.
— Cultural alignment: AI development and deployment must respect farmer's values, traditions, and cultural norms, leveraging rather than obliterating differences and specificities.
— There is a growing recognition of the benefits of integrating farm management software with other agricultural technologies, thereby establishing a more comprehensive ecosystem for producers. Cloud–based farm management solutions, which provide scalability and simplicity of access, have experienced a recent surge in popularity. Also, the popularity of mobile applications is on the rise, which enables producers to remotely manage their operations

Despite the benefits, challenges remain:

— Lack of awareness and skills: Many farmers may not be aware of the potential benefits of digitalization and may lack the necessary skills and resources to use new technologies.
— Digital divides: Many rural areas still lack reliable and affordable internet access, hindering the adoption of digital technologies, which is one key factor inducing "digital divides" between farmers.
— Lack of cost–effectiveness: The cost of implementing certain digital technologies might be higher than the potential benefits, especially for small–scale farmers.
— Need of trust in data sharing: Concerns about data privacy and ownership among farmers can hamper data sharing between different actors in the agricultural sector.
— Shortcoming in interoperability: Lack of interoperability between different systems, as many digital applications or machines from different brands may not be compatible, making it difficult to share data and integrate data.

CONCLUSIONS

Digital agriculture offers numerous benefits, making farming more sustainable and efficient compared to traditional methods. By incorporating technologies such as artificial intelligence, the Internet of Things (IoT), mobile solutions, and other digital tools, the agricultural sector can experience significant potential for enhancing food security and sustainable agricultural methods.

A lot of IoT solutions for agriculture are built to maximize the use of resources like electricity, water, and land. With the help of data gathered from numerous field sensors, IoT–based precision farming helps farmers to accurately distribute the proper quantity of resources.

Digital and AI applications in the agricultural sector should be designed and developed in close collaboration with farmers and their organized structures to ensure tools are easy to use and relevant to the needs of farmers and the logic of farm operations.

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