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Literature Review

Importance of Technology in Agriculture

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contents

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01

Importance of technology in agriculture

IMPORTANCE OF TECHNOLOGY IN AGRICULTURE

In recent decades, the agricultural sector has witnessed an unprecedented transformation through the adoption of digital and innovative technologies. Digitisation is revolutionizing the way farmers run their businesses, enabling more efficient management of natural resources, reduced environmental impact and an overall improvement in sustainability.

According to the EU **Joint Research Centre**, the digital transition is essential to ensure sustainable food systems and strengthen the socio-economic resilience of rural communities. Through technologies such as precision **agriculture**, the**Internet of Things (IoT)** and **blockchain**, modern agriculture is better able to adapt to the challenges posed by climate change and growing global food needs. **Greenhouse technologies**, for example, offer advanced microclimate control, optimising the use of resources such as water and energy. These structures enable increased food production even in resource-limited environments, such as arid or semi-arid areas. According to a recent study, greenhouse technology has made it possible to sustainably address the challenges of irrigation, soil conservation and energy resource control, minimizing environmental impacts and contributing significantly to global food security.

The adoption of these technologies is closely linked to the UN **Sustainable Development Goals (SDGs)**. In particular, digital agriculture plays a crucial role for the SDGs related to climate action (SDG 13), responsible production and consumption (SDG 12), and fighting hunger (SDG 2). Digital technologies, such as **decision support systems (DSS)** and IoT sensors, enable farmers to monitor soil and crop conditions in real time, acting quickly to optimize water use and minimise the use of pesticides and chemical fertilisers. This improves productivity, reduces waste and minimises environmental impact.

The use of blockchain technologies in agriculture represents a further development. Thanks to blockchain, complete traceability along the agricultural supply chain can be ensured, improving consumer confidence and ensuring transparency in production processes. This innovation is particularly useful for managing complex and globalised supply chains, where transparency and trust have become key elements for success.

Furthermore, precision agriculture, which exploits advanced tools such as drones and satellite-guided technologies, enables farmers to optimise land management, improving farming practices and reducing the risk of soil erosion. **Soil monitoring sensors** and IoT-based **automated irrigation systems** can provide accurate, real-time data, enabling farmers to respond quickly to crop needs while ensuring more efficient use of natural resources.

The concept of **sustainable intensification** represents one of the most significant challenges of the agricultural future. With a growing global population, there is a need to increase food production without compromising natural ecosystems. Greenhouses and other advanced technologies make it possible to cultivate more efficiently on existing land, reducing the need to expand agricultural areas. This type of intensification maintains a balance between agricultural productivity and the preservation of biodiversity while minimising pressure on natural ecosystems. **Smart Villages** represent a further step in the digital transformation of agriculture. This concept aims to improve the quality of life in rural areas through the use of advanced technologies to optimise resource management, reduce environmental impact and create new economic opportunities. Smart Villages initiatives, supported by the European Union, focus on digital literacy and access to technological infrastructure in rural areas, fostering active citizen participation and improving local public services.Digitisation is a necessary revolution to address the challenges of agricultural production in a context of limited resources and climate change. The integration of advanced technologies in agriculture not only improves efficiency and productivity, but also contributes to a more sustainable and resilient future for farming communities worldwide.

02

Methodology

METHODOLOGY

The research was conducted through a thorough review of existing literature and publicly available information regarding the adoption of digital technologies in agriculture. This **desk research** approach allowed for the collection and analysis of relevant data from various authoritative sources, both academic and institutional, in order to provide a comprehensive and up-to-date view of the topic.

The research process consisted of several stages. First, an initial reconnaissance of available online sources was carried out, focusing on reports and documents published by governmental bodies, international organisations and research centres. Priority was given to documents that directly addressed the use of digital technologies in the agricultural sector, with a focus on innovative and sustainable practices.

Subsequently, articles and academic studies published in recognised scientific journals and databases were identified and selected. The aim was to identify emerging trends, the benefits of new technologies and the main challenges farmers face in the digitisation process. The choice of sources was guided by criteria of topicality, relevance and reliability, selecting studies published mainly within the last ten years to ensure that the information was up-to-date.

In parallel, the results of European-funded projects were examined, especially those related to research and innovation programmes aimed at promoting agricultural sustainability. These projects have provided valuable information on how digital technologies are being applied in different agricultural contexts, making it possible to identify best practices and potential solutions to overcome technological and cultural barriers.

The analysis of the collected data focused on several main categories: the impact of digital technologies on production efficiency, reducing environmental impact, increasing sustainability and contributing to better natural resource management. In addition, the challenges associated with the adoption of such technologies were explored, including the lack of adequate infrastructure, initial implementation costs and the need to overcome resistance to change within farming communities.

The collected data were critically synthesised to identify the main guidelines that characterise the current digital transition in agriculture, with the aim of providing a clear view of the opportunities and challenges in this area.

03

Overview of Digital Technologies in Agriculture

DECISION SUPPORT SYSTEMS (DSS) IN AGRICULTURE:

Decision Support Systems (DSS) are key tools in modern agriculture, designed to help farmers make informed, data-driven decisions. These systems integrate information from a variety of sources, including IoT sensors, weather data, and soil and crop information, to provide accurate and timely advice. The main objective of a DSS is to improve the efficiency of agricultural resources by optimising operations such as irrigation, fertilisation and pest management, with the dual aim of maximising crop yields and minimising environmental impact.

One of the most common uses of DSS in agriculture is in fertiliser management. For example, a DSS model based on two fuzzy models was designed to optimise NPK (nitrogen, phosphorous and potassium) fertiliser rates for sugarcane crops. This system not only improved crop yields, but also ensured that fertilisation rates met safety standards while minimising the impact on climate and human health.

In addition to fertiliser management, DSS are used to optimise farming operations through the use of advanced optimisation algorithms. For example, the **AgriSupport II** system was developed to improve agricultural production through optimal decisions in terms of operating costs, resource allocation and operation planning. This system uses an optimising algorithm to calculate all possible operating modes and compare them to suggest the least costly and most efficient one for agricultural activities.

Another innovative example is the integration of DSS systems with the use of unmanned aerial vehicles (**UAVs**), which allow images and data to be collected on the health of crops. This data is then analysed to determine appropriate actions, such as the precise spraying of pesticides in areas affected by crop diseases. Using image analysis algorithms, DSS can identify areas that require targeted interventions, increasing efficiency and reducing chemical use.[1] [2]

Despite the considerable benefits, the adoption of DSS in agriculture still faces challenges, including the high initial cost of implementing the technologies and the need for adequate training to use the data produced. In addition, DSS systems require a connection to real-time data to function optimally, which can be a challenge in rural areas without adequate digital infrastructure.[3]

[1] Yousaf A, Kayvanfar V, Mazzoni A and Elomri A (2023) Artificial intelligence-based decision support systems in smart agriculture: Bibliometric analysis for operational insights and future directions. *Front. Sustain. Food Syst.* 6:1053921. doi: 10.3389/fsufs.2022.1053921

[2] MDPI and ACS StyleFuentes-Peñailillo, F.; Gutter, K.; Vega, R.; Silva, G.C. Transformative Technologies in Digital Agriculture: Leveraging Internet of Things, Remote Sensing, and Artificial Intelligence for Smart Crop Management. *J. Sens. Actuator Netw.* 2024, *13*, 39. https://doi.org/10.3390/jsan13040039

[3] https://www3.weforum.org/docs/WEF_Artificial_Intelligence_for_Agriculture_Innovation_2021.pdf

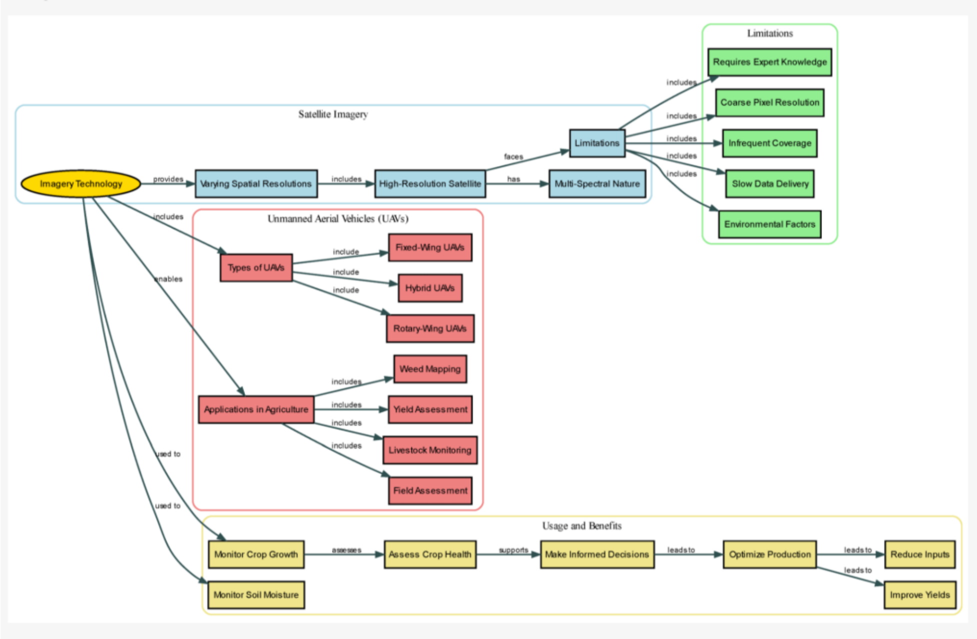


FIG: Overview of challenges, benefits, and applications of imagery technology in agriculture.[4]

BLOCKCHAIN IN AGRICULTURE:

Blockchain represents an emerging technology that is beginning to transform the agricultural sector, especially in Europe, by improving the transparency, traceability and efficiency of agri-food supply chains. One of the main advantages of blockchain is its ability to ensure that every step in agricultural production, from sowing to distribution, is recorded in a secure and immutable way.

This offers consumers the possibility to trace the origin of agricultural products, verifying their quality, authenticity and compliance with food safety standards in real time. According to the European Commission's Blockchain **Observatory and Forum**, the use of blockchain in the European agri-food sector could improve consumer confidence, reduce the risk of fraud and facilitate compliance with environmental and sustainability regulations required by the market. The European Union is actively promoting the adoption of blockchain through initiatives aimed at supporting technological innovation and the creation of more sustainable supply chains[5]

In particular, blockchain is seen as a key tool for reducing environmental impact, thanks to its ability to monitor the entire production cycle and ensure that resources are used efficiently. Furthermore, the **FAO**highlights how blockchain can offer new business opportunities for small and medium-sized enterprises (SMEs), facilitating inclusive trade and providing them with access to global markets with better sustainability and traceability standards[6]. However, the adoption of blockchain in agriculture still presents significant challenges, including the need for advanced digital infrastructure and the lack of widespread knowledge of its applications in rural areas. It is crucial that there are training programmes and incentives to encourage smallholder farmers and SMEs to adopt this technology.

[4] Fuentes-Peñailillo, F.; Gutter, K.; Vega, R.; Silva, G.C. Transformative Technologies in Digital Agriculture: Leveraging Internet of Things, Remote Sensing, and Artificial Intelligence for Smart Crop Management. *J. Sens. Actuator Netw.* **2024**, *13*, 39. https://doi.org/10.3390/jsan13040039

[5] EU BLOCKCHAIN OBSERVATORY & FORUM, Author: **I**ordanis Papoutsoglou Published: January 2021

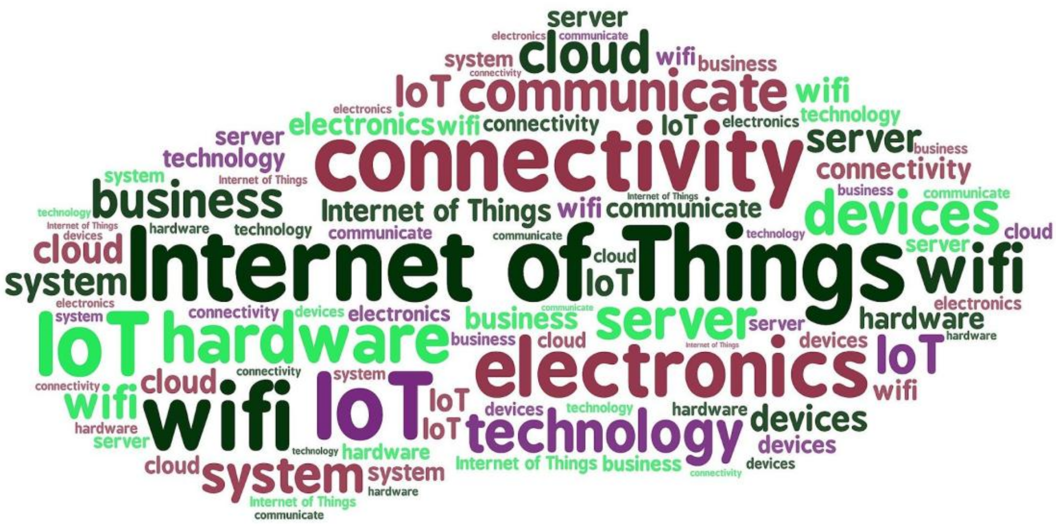
[6] FAO for Asia and Pacific 2019

INTERNET OF THINGS (IOT):

Internet of Things (IoT) technology plays a key role in the EU's agricultural sector, particularly in the area of precision agriculture. **IoF2020** (Internet of Food & Farm 2020) was one of the large-scale pilot projects funded by the EU to develop IoT-based solutions in agribusiness. The project involved farmers, food companies, technology developers and research institutes to build an integrated ecosystem, improving the efficiency and sustainability of food production through the use of IoT sensors and other digital technologies.

IoT allows farmers to collect real-time data on various parameters, such as soil moisture, air temperature, crop health and rainfall density. This data is then processed through analytics platforms to make informed decisions on irrigation, fertiliser application and pest control. Thanks to IoT, it is possible to optimise the use of resources, minimising waste and increasing agricultural productivity[7][8].

In particular, a practical example within the IoF2020 project concerns the optimisation of wine production. Sensors installed in vineyards measure critical parameters such as fermentation and temperature, allowing wine producers to intervene more efficiently than with traditional methods, reducing the margin of error and improving product quality[9]. In addition, the European Commission continues to promote digitisation in rural areas through initiatives such as **SmartAgriHubs** and **EIP-AGRI**, which foster the creation of **Digital Innovation Hubs** to support the adoption of IoT technologies by farmers, particularly in small and medium-sized farms. These hubs connect the agricultural sector with technology experts, providing access to new solutions and encouraging innovation[10]. IoT is therefore a crucial component for **precision agriculture** in Europe, improving the sustainability and competitiveness of farms and responding to the growing demand for more efficient and environmentally friendly farming solutions.



[7]https://projects.research-and-innovation.ec.europa.eu/en/projects/success-stories/all/cultivating-internet-things-farming
[8] EPi-Agri, Shaping the digital (r)evolution in agriculture.
[9] https://cordis.europa.eu/article/id/241024-internet-of-things-plays-a-key-role-in-precision-farming
[10]https://agriculture.ec.europa.eu/system/files/2023-05/factsheet-agriresearch-digital-transformation_en.pdf

DRONES & SATELLITE GUIDANCE IN AGRICULTURE:

Drones and **satellite technologies** are key tools for innovation in modern agriculture, particularly in Europe, where their adoption is actively promoted to improve the sustainability and efficiency of agricultural operations. These tools offer a range of applications from crop monitoring to land mapping, enabling farmers to make informed decisions and optimise the use of natural resources.

One of the main advantages of **drones** over satellites is their greater **flexibility**. While satellites provide information at regular intervals based on their orbit, drones can be deployed on an as-needed basis and can collect high-resolution images at any time, adapting better to farmers' specific needs. This capability allows for detailed data on soil conditions, moisture and crop health, making faster and more targeted intervention to prevent disease and improve yields possible[11].

For example, a European Commission report highlighted how drones and satellites are being used to detect **crop diseases**before they spread, enabling targeted treatments and reducing overuse of pesticides. Because of their precision, drones can also be used to map agricultural areas, assess soil heterogeneity and optimise irrigation, thus reducing water waste and increasing sustainability[12].

The EU-supported **Product Watch** project has highlighted the central role that drones and satellites play in supporting low-intensity agriculture and the cultivation of arable crops. The aim is to improve crop yields and food quality, increasing economic margins for farmers while reducing environmental impact.
In conclusion, the adoption of drones and satellites in European agriculture is growing rapidly, offering advanced tools to address sustainability challenges, improve traceability of agricultural supply chains and increase productivity. However, the initial cost and the need for training in the use of these technologies are still barriers to their widespread adoption[13].

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[11] European Monitor

[12] Knowledge4Policy, E-Agricolture in Action: Drones for Agricolture, 2018

[13] Arza-García, M.; Burgess, A.J. Drones in the Sky: Towards a More Sustainable Agriculture. *Agriculture* **2023**, *13*, 84.

AI AND MACHINE LEARNING IN AGRICULTURE:

Artificial Intelligence (AI) and **Machine Learning (ML)** are central technologies in the context of**Agriculture 4.0**, revolutionising agricultural practices through process optimisation and efficient use of resources. In Europe, the use of these technologies is seen as key to addressing environmental and climate challenges, and to achieving the sustainability goals set out in the **European Green Deal**.

Machine Learning allows farmers to analyse large amounts of data collected from IoT sensors, drones and satellite images to make informed decisions on irrigation, fertilisation, disease management and yield forecasting. For example, ML models can be trained to predict crop yields, detect anomalies in plants and optimise water use, thereby reducing waste and improving sustainability.[14][15]

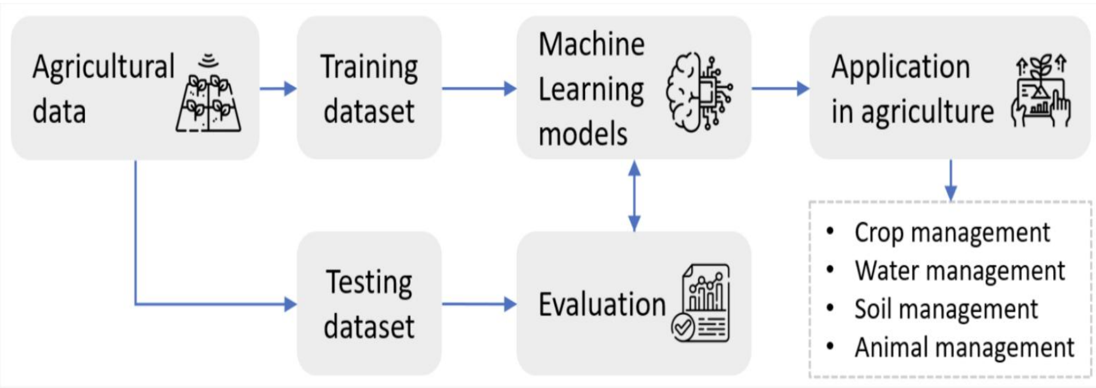

FIG: General flow for the creation of Machine Learning models and their application in agriculture

In a European context, the **European Commission** report on AI highlights the potential of these technologies to reduce the environmental impact of agriculture and contribute to the conservation of biodiversity. AI can help monitor greenhouse gas emissions, optimise logistical operations along the supply chain and improve the monitoring of natural resources. However, to fully exploit this potential, sound governance and policies that ensure data protection and security are needed.

A concrete example of the application of AI in agriculture in Europe is the use of AI algorithms to manage crop health in real time, through systems that collect data from **drones** and **satellites**. These systems are able to identify diseases or nutrient deficiencies in crops, allowing farmers to take timely action[16].

In summary, **AI** and **Machine Learning** are powerful tools for European agriculture, with applications ranging from yield forecasting to natural resource management. Their adoption can improve the sustainability of farming practices, but requires significant investment in infrastructure and farmer training.

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[14] Araújo, S.O.; Peres, R.S.; Ramalho, J.C.; Lidon, F.; Barata, J. Machine Learning Applications in Agriculture: Current Trends, Challenges, and Future Perspectives. *Agronomy* **2023**, *13*, 2976. https://doi.org/10.3390/agronomy13122976.

[15] Garske, B.; Bau, A.; Ekardt, F. Digitalization and AI in European Agriculture: A Strategy for Achieving Climate and Biodiversity Targets? *Sustainability* **2021**, *13*, 4652. https://doi.org/10.3390/su13094652.

[16] El Jarroudi, M., Kouadio, L., Delfosse, P. *et al.* Leveraging edge artificial intelligence for sustainable agriculture. *Nat Sustain* 7, 846–854 (2024). https://doi.org/10.1038/s41893-024-01352-4

04

Impacts on Sustainability

CONTRIBUTION TO THE SUSTAINABLE DEVELOPMENT GOALS (SDGs)

The digital technologies described in the previous chapter (DSS, blockchain, IoT, drones and AI) are crucial tools for achieving the **Sustainable Development Goals (SDGs)**, especially those related to climate **action (SDG 13)**, **responsible production and consumption (SDG 12)**, and **life on Earth** (**SDG 15)**. With these technologies, agriculture can evolve towards more sustainable practices, minimising the use of natural resources and optimising agricultural operations.

Decision Support Systems (DSS) help optimise fertiliser and water use, reducing overuse of resources and contributing to agricultural sustainability, as highlighted in EU-funded projects such as the **IoF2020** programme.**Blockchain-based solutions** improve the traceability and transparency of supply chains, reducing emissions and ensuring compliance with sustainability standards through digital monitoring of supply chains(EU Blockchain Observatory and Forum).

IoT systems monitor critical parameters such as soil moisture and plant health, enabling more efficient use of water and reducing environmental damage from overuse of natural resources.

REDUCING ENVIRONMENTAL IMPACT

Digital technologies play a central role in **reducing the environmental impact** of agriculture. These technologies enable farmers to make more informed decisions, reducing the use of pesticides and chemical fertilisers and optimising water use:

- **Drones** and **satellite technologies** enable detailed and continuous monitoring of crops, accurately detecting any diseases or deficiencies. This enables localised interventions, reducing the indiscriminate use of pesticides and contributing to the preservation of soil and water quality.
- **Machine Learning (ML) models** can analyse large amounts of data collected in the field to predict yields and optimise resource use, reducing the overuse of chemical fertilisers and promoting more sustainable soil management(Nature).
- The use of **blockchain** helps reduce environmental impact by ensuring product traceability and ensuring that production processes meet strict environmental standards. This reduces the need for manual checks and minimises the use of extra resources to ensure compliance(EU Blockchain Observatory and Forum).

RESOURCES EFFICIENCY

Technological innovations in agriculture contribute to a **more efficient use of resources** by reducing waste and optimising farming operations. These technologies help farmers make informed decisions based on real data, improving productivity and reducing costs:

- IoT systems improve water management, enabling more targeted irrigation and reducing waste. Sensors collect continuous data on soil conditions, allowing farmers to avoid over-irrigation.
- DSS enable optimal resource management through real-time data collection and analysis. These systems suggest to farmers how to use resources more efficiently, reducing agricultural inputs and operating costs.
- Technologies such asAI make it possible to predict weather conditions and crop yields with great accuracy, enabling farmers to better plan their farming activities and reduce wastage of resources.
- In conclusion, the adoption of digital technologies not only reduces environmental impact, but also improves the overall efficiency of farming operations, contributing to the sustainability of the sector and ensuring that natural resources are optimally utilised.

05

Barriers and Challenges

BARRIERS AND CHALLENGES:

Despite the many benefits offered by digital technologies in agriculture, their large-scale adoption encounters several barriers. These challenges can be divided into **technological**, **cultural** and **professional barriers**, which must be overcome to ensure a complete and sustainable digital transformation.

Technological Barriers

- One of the main barriers is limited **access to digital infrastructure**, especially in rural areas. The lack of stable, high-speed Internet connectivity in agricultural regions is a significant barrier to the adoption of technologies such as the**Internet of Things (IoT)** and **Decision Support Systems (DSS)**, which require real-time data to function effectively. The**European Union** has already identified this gap, promoting initiatives such as **SmartAgriHubs** and **EIP-AGRI**, which aim to bridge the digital divide in rural areas.
- Another technological barrier concerns the **high upfront costs** of implementing advanced technologies such as drones, sensors and artificial intelligence. Although these technologies can reduce operating costs in the long run, many farmers, particularly small and medium-sized farms, do not have access to sufficient funding to invest in these innovations.

Cultural and Professional Barriers

- At the cultural level, one of the most significant barriers is resistance to change. Many farmers are used to traditional methods and are reluctant to experiment with new technologies. This reticence is often fuelled by a lack of confidence in technology and the perception that adopting new tools can be complicated and require advanced technical skills.
- Low digital literacy is another important barrier. Many farmers, especially those who are older or in less developed regions, lack the technical skills needed to use tools such as AI, machine learning or DSS. The lack of specific training in the use of these technologies is a real obstacle to their widespread adoption.

Proposed solutions

To overcome these barriers, several solutions can be implemented:

- **Targeted training and technical support**: It is crucial to develop training programmes that help farmers improve their digital skills. These courses should be accessible to all and cover both practical and theoretical aspects of adopting digital technologies in agriculture. In addition, technical support and ongoing assistance should be provided to ensure that farmers feel comfortable using these new tools.
- **Financial** incentives: Offering economic incentives, such as subsidies or tax breaks, can help reduce the economic burden of implementing new technologies. This is especially important for small and medium-sized farms that have limited financial resources.
- Networking**and sharing best practices**: It is essential to create networks to exchange knowledge and promote collaboration between farmers, technology companies and institutions. These platforms would allow farmers to share experiences and best practices, accelerating technology adoption and reducing uncertainties related to the use of new solutions.

06

Recommendations

RECOMMENDATIONS

To foster an effective and sustainable digital transition in the European agricultural sector, it is essential to address the technological and cultural barriers highlighted in the previous chapter. Below are some key recommendations to overcome these challenges and promote the adoption of digital technologies in agriculture.

Digital Literacy

- One of the main priorities must be to improve the **digital skills** of farmers, especially in rural areas and small farms. To address the lack of training and technical support, **tailor-made training programmes** need to be developed that introduce farmers to the use of technologies such as **Decision Support Systems (DSS)**, **IoT sensors** and **AI and Machine Learning** systems . EU-funded **SmartAgriHubs** initiatives can be expanded to offer accessible and targeted courses covering the technical and operational aspects of these technologies[17][18].
- In addition, it is crucial to create **e-learning platforms** and provide educational resources in digital format that are also easily accessible in rural areas. Such platforms could include video tutorials, practical manuals and interactive webinars to ensure that farmers have access to flexible and understandable learning tools[19].

Stakeholder collaboration

- Collaboration between different stakeholders is essential to promote the adoption of digital technologies in the agricultural sector. **Farmers, public institutions, technology companies and research institutes** must work together to create an innovation ecosystem that fosters the adoption of new technologies. Initiatives such as **Digital Innovation Hubs** can play a crucial role in this regard, acting as collaborative hubs where different actors can share knowledge, resources and best practices.
- This collaboration should also include the private sector, with the support of large technology companies developing advanced solutions for agriculture. Public institutions, in turn, should facilitate these partnerships with **financial incentives** and tax breaks to encourage investment in digital innovation.

Dissemination of Best Practices

- Another crucial aspect of promoting agricultural digitisation is the dissemination of best practices. Sharing experiences and knowledge among farmers who have successfully adopted digital technologies can accelerate adoption by others. Online platforms, such as farmers' forums and communities, can be created to facilitate the exchange of experiences and practical tips.
- In addition, it is important to organise national and European workshops and conferences where farmers and stakeholders can discuss technological innovations and their practical applications. These events can help overcome cultural barriers and create a more open community for digital innovation.

Support Policies and Economic Incentives

- Finally, public policies should be aimed at stimulating the adoption of digital technologies through subsidies and funding. The European Union, through the Common Agricultural Policy (CAP) and other initiatives, should continue to offer economic support to help farmers overcome the initial costs of implementing new technologies. Specific funding programmes for the purchase of drones, IoT sensors and digital infrastructure can facilitate the transition to more sustainable agriculture.

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[17] Araújo, S.O.; Peres, R.S.; Ramalho, J.C.; Lidon, F.; Barata, J. Machine Learning Applications in Agriculture: Current Trends, Challenges, and Future Perspectives. *Agronomy* **2023**, *13*, 2976. https://doi.org/10.3390/agronomy13122976

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- https://doi.org/10.3390/su13094652

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