Pak. j. life soc. Sci. (2025), 23(1): 151-160 E-ISSN: 2221-7630;P-ISSN: 1727-4915

Pakistan Journal of Life and Social Sciences

www.pjlss.edu.pk

https://doi.org/10.57239/PJLSS-2025-23.1.0013

RESEARCH ARTICLE

The Impact of Digital Innovations on Sustainable Agricultural Practices in Europe

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ARTICLE INFO

Received: Jul 22, 2024

Accepted: Sep 15, 2024

Keywords

Economy

Digital technologies

Smart agriculture

Digital agriculture

Biodiversity

Sustainable agriculture

Common Agricultural Policy (CAP)

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ABSTRACT

In today's digital European agriculture, agricultural technologies and digital innovations are becoming increasingly important. These include research on technologies such as precision agriculture, the Internet of Things (IoT), artificial intelligence (AI), big data and blockchain, and their impact on sustainable agricultural development in Europe. Digital agriculture considers how these technologies contribute to increasing production efficiency, reducing environmental impact, and improving the economic stability of agricultural enterprises. The purpose of the study is to examine the theoretical and practical aspects of digital agriculture in Europe and its impact on sustainable agricultural development. The research methodology includes the Agile methodology, which is about adapting agriculture and bringing it to a reasonable balance, an axiological method based on the values of digital technologies that affect agriculture, which is becoming more attractive. Digital technologies in European agriculture are critical to ensuring a common agricultural policy, as they help to address climate change, reduce resources and increase the efficiency of food production, optimise the use of resources (water, fertilisers, and pesticides) to increase yields, and reduce environmental impact.

INTRODUCTION

The relevance of the study of agricultural technologies and digital innovations in European agriculture lies in the fact that they constitute a significant part of the modern agricultural sector. Digital agriculture is also known as smart agriculture, precision agriculture, and the Fourth Technological Revolution in agriculture. We need new thinking to deal with the challenges of the twenty-first century. Globally, digital agricultural technologies are represented by five main modules:
1) agricultural Internet of Things; 2) big agricultural data; 3) precision agriculture; 4) smart agriculture; and 5) artificial intelligence, are widely used in the agricultural sector and are developing rapidly. From artificial intelligence (AI) and robotics to the Internet of Things (IoT) and 5G, the latest

technologies can provide invaluable support to farmers and agribusinesses. Europe's agriculture sector can make the most of the digital age, increasing farm sustainability and profitability while addressing pressing issues such as food security and climate change. Internet of Things (IoT) technology has transformed the agricultural sector by giving farmers access to real-time data on the environment and digitalisation status.

The productivity and efficiency gains realised by digital technologies, through the development of functional tools and visual symbols, represent a predictable transition to eco-civilisation in agriculture. Eco-civilisation in agriculture contributes to sustainable development through innovation and environmental awareness, as innovative approaches and environmental awareness can contribute to sustainable development. It includes an analysis of organic farming practices, the use of renewable energy sources, biodiversity conservation and the integration of digital technologies to reduce environmental impact. The study also focuses on the social aspects of eco-civilisation, such as raising awareness of farmers and consumers, developing local communities and promoting equitable distribution of resources.

The aim of the study: theoretical and practical aspects of the implementation of digital agriculture in Europe, and its impact on sustainable agricultural development.

Research objectives: 1) to analyse the areas of use of digital technologies in agriculture in the EU countries; 2) to find out the conditions for preserving biodiversity to ensure a stable future: environmental, economic, cultural importance for ensuring a stable future; 3) to reveal the importance of the Common Agricultural Policy (CAP) as a factor of a sustainable and competitive system of sustainable development in the EU; 4) to identify the advantages and disadvantages of using digital twins in agriculture in the EU countries.

LITERATURE REVIEW

Meadows Donella, Randers Jorgen, Meadows Dennis played an important role in analysing the concept of digitalisation in European agriculture and its impact on sustainable agricultural development. The limits to growth. 30 years later (2018). Ernst Ulrich von Weizsäcker, Anders Wijkman. Come On! Capitalism, shortsightedness, population and the destruction of the planet. Report to the Club of Rome (2019), based on a study of the impact of digital technologies on reducing greenhouse gas emissions, conserving biodiversity and sustainable management of natural resources, using GPS, drones, sensors and other technologies to accurately measure and manage agricultural processes, predict yields, detect plant diseases and optimise production processes, make informed decisions on crops, yields and risk management.

Developing strategies to ensure the economic sustainability of agricultural enterprises using digital technologies. We have used the work of Naomi Klein (2016) to reveal the directions of forming a secure digital ecosystem. Everything is changing. Capitalism versus Climate (2016); Oltrade Dagogo (2021), contributing to the study of the impact of digital innovations on the agricultural workforce, in particular on the education and training of farmers, the assessment of the socio-economic impact of new technologies on local communities and rural areas, and the use of blockchain technology to ensure transparency and traceability of the agricultural supply chain.

The authors used their own research on the use of digital technologies in agriculture in the EU countries, which is reflected in Voronkova, V., Nikitenko, V., Oleksenko, R., Andriukaitiene, R., Polysaiev, O. (2023). Environmental crisis overcoming as a factor for achieving economic sustainability in the context of the European green course Nikitenko, Vitalina, Voronkova, Valentyna, Oleksenko, Roman, Matviienko, Halyna, Butkevych. Oksana (2023). Sustainable agricultural development paradigm formation in the context of managerial experience of industrialised countries.

Metelenko, N., Klopov, I., Voronkova, V., Nikitenko, V., Oleksenko, R., Brytvienko, A., Runcheva, N. (2023). Development of Flexible Management Structures in the Context of Digital Transformation of INDUSTRY 5G.

Nikitenko, V., Voronkova, V., Oleksenko, R., Filoretova, L., Lanoviuk, L., Khvistel, V. (2023). Perspectives of civilisational political development of world regions in the context of current challenges and opportunities (2023); and also works of Oleksenko, R., Kolokolchykova, I., & Syzonenko, O. Ukraine in the Context of the World Organic Production of Agricultural Products (2019), based on the introduction of a network of connected devices for monitoring soil conditions, weather conditions, plant and animal health, and the implementation of automated farm management systems.

Authors Joe Studwell, Chandran Nair, Ruchir Sharma and Michael Spence address a wide range of issues related to economic development, globalisation and socio-economic changes in their works. Joe Studwell, in his book How Asia Works: Success and Failure In the World's Most Dynamic Region, analyses the reasons for the success and failure of East Asian countries. The main issues he examines are: the role of land reforms in stimulating economic growth. industrialisation as the basis of economic development. Chandran Nair, in his book The Sustainable State: The Future of Government, Economy, and Society, draws attention to the problems of sustainable development. How governments can implement policies that promote long-term sustainability. The impact of economic growth on the environment and ways to minimise the negative consequences. Ruchir Sharma (2020) in his book The 10 Rules of Successful Nations, Sharma analyses the factors that influence the success of countries the impact of government policies on economic success¸ the importance of effective institutions for sustainable growth. Michael Spence (2017), Nobel Prize winner in Economics, discusses globalisation and economic development, the factors that stimulate or constrain economic growth in different countries. These authors offer an in-depth analysis of various aspects of economic development and technological changes that affect the welfare of countries.

The literature analysis has made it possible to show that the use of digital technologies in agriculture has resulted in a new area of research that is the study of many sciences. This is a sub-discipline of agroecology - digital agriculture in Europe and its impact on sustainable agricultural development, which combines numerous digital technologies and their use in agriculture. Thanks to digital technologies and communications, smart agriculture uses sensors and connects them to the Internet to collect soil and weather data for more accurate monitoring and management of agricultural production processes. These technologies and innovations are aimed at improving the productivity, efficiency and sustainability of agriculture and reducing its environmental impact.

MATERIALS AND METHODS

The ecological method of researching the introduction of digital technologies in European agriculture and their impact on sustainable agricultural development is an interdisciplinary method developed in line with the development of environmental issues and the improvement of modern research methods. The use of mathematical methods is widely used in research at the population and ecosystem levels. The methods used to study the concept of digital technologies implementation in European agriculture and their impact on sustainable agricultural development include the following: 1) the method of system analysis and synthesis, which allows all the disparate facts of agriculture to be brought into a system of smart agriculture based on digital technologies; 2) Agile methodology, which is reduced to adapting agriculture and bringing it to a reasonable balance; 3) the axiological method, based on the values of digital technologies that affect agriculture, which becomes more attractive, and investments in digital technologies contribute to economic development and job creation in rural areas; Multidimensional methods are used to promote global cooperation in addressing global environmental issues such as climate change, biodiversity conservation and sustainable development, using principal component analysis and cluster analysis. The methodology of the study of digital technologies in European agriculture and their impact on sustainable agricultural development includes the analysis of the relationship between agricultural phenomena and processes, based on the use of an interdisciplinary ecological method for the implementation of technologies such as process automation, the use of drones for field monitoring, the use of modern irrigation and fertilisation systems, and the impact of digital innovations on agricultural land management. The study of the adoption of digital technologies in European agriculture and their impact on sustainable agricultural development is an interdisciplinary area that focuses on the analysis and integration of the latest technologies to improve the efficiency and environmental sustainability of the agricultural sector.

RESULTS

1. Areas of use of digital technologies in EU agriculture

Digital innovations have great potential to transform European agriculture and land management. They help to increase production efficiency, ensure sustainable development, improve product quality and food safety, and support production diversity. Digital innovations contribute to improved land management by providing better analysis and planning of land use, improving the system of land rights registration and reducing conflicts over these rights. Overall, the introduction of digital technologies in agriculture and land management contributes to a more efficient, sustainable and transparent system that meets the needs of the modern world. Digital technologies play a key role in the development of agriculture in the European Union, contributing to the efficiency, productivity and sustainability of the agricultural sector.

Digital technologies in EU agriculture contribute to the transition to a more efficient, sustainable and innovative agricultural sector, while ensuring economic development and environmental protection. The implementation of digital technologies in the EU agriculture is very broad and includes the following important aspects - economic, environmental, social, and production, as it is a threat to the whole of humanity. For every calorie of food we consume today, at least five calories of oil are consumed. However, for every calorie of technical energy consumed by farms, about five calories of food are converted into energy from the sun. What is needed here is something like a digital revolution - replacing fossil fuels with smart biofuels, reducing the amount of fertilisers and pesticides and carbon sequestration in the soil, using drones to monitor the condition of fields, detect diseases and pests, and spray fertilisers and pesticides in hard-to-reach places. (Ernst Ulrich von Weizsäcker, Anders Wijkman, 2019, p. 234; Altassan et al., 2023.)

Digital technologies are making a significant contribution to the development of more sustainable and productive agriculture, enabling the transition to an eco-civilisation that harmoniously combines productivity with environmental care.

Digital innovation in European agriculture involves the use of digital technologies to help farmers make more informed decisions and improve all aspects of their operations, including monitoring of agriculture and livestock. By combining real-time IoT data with accurate geospatial data, farmers can practice precision agriculture, resulting in higher yields, reduced waste and more sustainable practices. Digital IoT technologies allow farmers to remotely monitor crops and livestock, reducing labour costs and ensuring the health and safety of their animals. The functional role of digital agriculture is: first, to reduce chemical inputs and labour requirements, increase agricultural productivity and efficiency, and create new market opportunities to increase economic benefits; second, to improve communication and inclusiveness, and provide social and welfare benefits; and third, environmental benefits aimed at optimising resource use and adapting to climate change.

Table 1: Use of digital technologies in agriculture

№	Digital technology tools	Areas of application of digital technologies
1.	Precision agriculture systems	The use of sensors, GPS technology and drones to accurately monitor soil, plant and climate conditions. This allows farmers to apply resources (water, fertilisers, pesticides) only where they are needed, reducing costs and negative environmental impact.
2.	Internet of Things (IoT)	Thanks to IoT sensors and satellite imagery, farmers can know exactly where and when to water or fertilise their fields, which saves water and fertiliser. IoT-enabled drip irrigation technologies can significantly reduce water consumption, increasing water efficiency.
3.	Mobile technologies and network devices	Digital technologies will greatly expand the scope of agriculture. For example, mobile technologies and networked devices will connect farmers to the supply chain, giving them access to better seeds and fertilisers, thereby increasing yields and quality.
4.	Big Data analysis	Collecting and analysing large volumes of data to make informed decisions on optimising agricultural operations, forecasting yields and managing risks.
5.	Geographic information systems (GIS)	Using map data to visualise agricultural resources and processes, such as crop distribution, soil fertility analysis and land management
6.	High-resolution drones	Using drones to take aerial photos and create detailed visualisations of fields, which helps identify problem areas and monitor the condition of crops. to detect diseases or pests at early stages allows for a quick response and prevents the spread of problems. The use of drones to monitor rice fields, which reduces the use of water and chemicals, increasing yields.
7.	Internet and farm management software	Platforms such as Climate FieldView and FarmLogs help farmers analyse data and make decisions that optimise their operations. Develop online markets and platforms that enable direct communication between farmers and consumers, as well as farmers and suppliers. The Internet allows for direct sales and thus reduces the opportunities for traditional trade. Farm management software allows for the integration of all aspects of operations, from finance to yield monitoring, which simplifies management and planning.
8.	Robotics engineering	The use of robots to perform tasks such as sowing, harvesting and tillage, which reduces labour costs and increases efficiency. Robotic systems and automated tractors reduce the need for manual labour and increase the accuracy of agricultural tasks. The use of robots and automated equipment to perform routine tasks in agriculture, such as irrigation, harvesting, fertilisation and environmental issues, as a factor in shaping the paradigm of sustainable and balanced agricultural development
9.	Sensors and automated systems	Precise control of growing conditions is ensured, which improves the quality of the final product. Automation of harvesting and other routine operations reduces the need for physical labour. Precision agriculture, which is based on the use of sensors, GPS, and mapping to optimise crop production. This allows for precise management of resources such as water, fertilisers and pesticides. The use of connected devices to automate agricultural processes such as watering, livestock health monitoring and inventory management
10.	Big data and analytics tools	It helps to make informed decisions that improve the overall efficiency of the farm. The use of artificial intelligence and machine learning algorithms to analyse large amounts of data in agriculture, allowing for yield forecasting, disease and pest detection, and crop optimisation.
11.	Blockchain technologies	They allow tracking the path of a product from farm to table, which increases consumer confidence and ensures food safety. Transparency of the supply chain contributes to high quality and safety standards. Using blockchain technology to trace the origin of food, ensure transparency and support sustainability programmes.

2. Conditions for biodiversity conservation for a sustainable future: environmental, economic, cultural significance

Digital technologies have enormous potential to increase productivity and efficiency in agriculture, contributing to the transition to an eco-civilisation. Digital technologies facilitate the introduction of sustainable agricultural practices that minimise the negative impact on the environment. This includes precision farming, reduced use of chemicals and water, and support for biodiversity. Optimising the use of resources and increasing the efficiency of agricultural operations helps to reduce greenhouse gas emissions, which contributes to the fight against climate change. The use of digital technologies can increase yields and ensure food security without expanding agricultural land, which helps to preserve natural ecosystems. For agriculture, this means high ecological diversity with low chemical use and high-quality products, as opposed to large monocultures that depend on large amounts of agrochemicals. Biodiversity conservation is a set of measures aimed at maintaining and restoring the diversity of living organisms on Earth, including species diversity, genetic diversity and ecosystem diversity.

Table 2: Biodiversity conservation: ecological, economic and cultural importance

1	Environmental significance:	Biodiversity ensures the stability of ecosystems and their ability to recover from stressful events. All species are interconnected, and the disappearance of one can have unpredictable consequences for others.
2	Economic importance:	Many species of plants and animals are a source of food, medicine, raw materials for industry and other resources.
3	Cultural significance:	Biodiversity is of great importance to the culture and religion of many peoples. Many species are symbols and objects of worship.
4	Threats to biodiversity climate change	Global warming affects the natural habitats of species by changing temperature and weather conditions, which can lead to species extinction.
5	The threat of habitat destruction	Expansion of agricultural land, deforestation, and urbanisation lead to the loss of habitats for many species.
6	The threat of pollution	Chemical pollution of water, air and soil negatively affects the health of ecosystems.
7	Invasive types	The introduction of new types of species into ecosystems can lead to the displacement of native species.
8	Excessive use of resources	Hunting, fishing, and plant gathering often exceed the regenerative capacity of populations.
9	Methods of biodiversity conservation: creation of nature reserves and national parks	Protected areas help preserve natural habitats and protect species from human impact.
10	Environmental education and awareness raising	Informing the public about the importance of biodiversity and ways to preserve it.
11	Laws and international agreements	Legislative regulation, both at the national and international level, is aimed at protecting species and their habitats.
12	Sustainable development	Adoption of agricultural, forestry and fishing practices that minimise negative impacts on ecosystems
13	Restoring degraded ecosystems	Forest, marsh and river restoration projects aimed at restoring natural habitats.
14	Gene banks	Preservation of genetic material of rare and endangered species in seed banks and other genetic resources

The Serengeti Conservation Area in Tanzania protects a large number of animal and plant species. The Panda Conservation Programme in China to restore the population of the great panda through conservation measures and captive breeding programmes. Projects to restore coral reefs through coral replanting and protection from pollution and overfishing. Biodiversity conservation is an important task that requires the joint efforts of governments, NGOs, scientists and each of us. Only by joining forces can we ensure a sustainable future for all species on our planet. Thanks to precise dosing of water, fertilisers and pesticides, farmers reduce their costs for these resources. Modern technology makes it possible to predict weather conditions and adapt agricultural practices to minimise the risks associated with climate change.

Another incentive to take action to mitigate climate change is the link to agriculture. The use of sustainable farming methods helps to maintain productivity in the face of climate change. A new taxation philosophy should be introduced that rewards job creation and penalises the consumption of natural resources, while continuing to respect everyone's need to meet the challenges of the twenty-first century.

Johan Rockström and John Schelliguder have proposed a roadmap in the form of a 'carbon law' - which seems to have been inspired by the Moore Act. This law calls for halving carbon emissions every decade until 2050. If this path is followed, greenhouse gas emissions could reach zero as early as 2050, which would put us on track to meet the 2 degree Celsius target. Subsidies for fossil fuels should be cancelled no later than 2020. Coal should be phased out of the energy mix by 2030 at the latest. Internal combustion engines should be phased out completely by 2030. Industrial agriculture should develop sustainable food strategies and launch massive reforestation programmes. All of these processes should be complemented by cleaning the atmosphere of CO, through bioenergy using carbon capture and storage technology and/or direct carbon capture from the air in the work of Come On! Capitalism, Shortsightedness, Population and the Destruction of the Planet. Report to the Club of Rome' (Ernst Ulrich von Weizsäcker, Anders Wijkman, 2019, pp. 167-188; Assaf et al., 2024).

Examples of digital technologies implementation in EU countries; 1) The Netherlands: Use of high-tech greenhouses with automated climate control and irrigation systems. Farm management software that helps farmers optimise production processes. 2) Germany: The introduction of drones to monitor fields and optimise fertiliser use. Development of robotic harvesting systems. 3) France: The use of IoT sensors to monitor the condition of vineyards and optimise wine production processes. Farm management software that integrates all aspects of farming. 4) Spain: Satellite monitoring for the management of large agricultural areas. AI is used to analyse yields and protect plants from pests. However, technological progress alone cannot fully solve the future challenges of global food security.

Digital agriculture is expected to mean a major transformation of agricultural production systems, rural economies, communities, and land management. Digitalisation can help farmers make more informed decisions, optimise operations and increase productivity, leading to higher profits and overcoming the environmental crisis as a factor in achieving economic sustainability in the context of the European Green Deal (Voronkova et al., 2023).

3. Advantages and disadvantages of using digital twins in EU agriculture

A digital twin in agriculture is a real-time digital representation of physical objects, processes and systems used to monitor, analyse and optimise agricultural operations. These twins are created by collecting and integrating data from various sources, such as sensors, satellites, drones, weather stations and other systems that provide information about soil, plant, climate, equipment and other aspects of farming. The benefits of using digital twins in agriculture are numerous, including increased efficiency and productivity, reduced waste and environmental impact, and improved decision-making capabilities for farmers. In addition, digital twins can provide a platform for testing new agricultural methods and technologies, reducing the risk of costly and time-consuming trial and error processes.

Digital twins in agriculture have significant potential to improve efficiency and productivity. Thus, despite the significant benefits, the introduction of digital twins in agriculture requires farmers to shape the state of sustainability and the future of governance, economy and society (Chandran Nair, 2020). Examples of the use of digital twins in agriculture: 1) Tracking soil moisture, plant health, light levels, and other parameters to optimise watering and fertilisation. 2) Analysing plant growth data and forecasting yields to plan harvesting and sales. 3) Monitoring the health and behaviour of animals, which allows timely detection of diseases and optimisation of housing conditions 4) Forecasting weather conditions and adapting agrotechnical measures to minimise the risks associated with climate change. Digital twins enable farmers to make more informed decisions, increase resource efficiency, reduce costs and improve yields, making agriculture more sustainable and productive through digital innovation. Digital innovation is having a significant impact on agriculture in Europe and on land management. Land management is also undergoing significant changes due to digital innovations: 1) The use of geospatial technologies allows for better analysis

and planning of land use, ensuring more efficient utilisation and protection. 2) Digital systems allow for improved land rights registration, which contributes to more transparent and efficient land management. 3) Digital tools can help resolve conflicts between landowners, tenants and communities by providing access to objective and reliable information. In general, digital innovations in agriculture and land management open up new opportunities for increasing efficiency, sustainability and transparency in agricultural production, shaping the paradigm of sustainable agricultural development in the context of the management experience of advanced countries in anticipation of a new ‘economic miracle’ (Sharma Ruchir, 2020; Qadri et al., 2024).

CONCLUSION

The introduction of digital technologies in agriculture in EU countries has a significant practical impact, contributing to increased productivity and efficiency, reduced costs, improved product quality, reduced environmental impact and adaptation to climate change. These technologies also contribute to the socio-economic development of rural areas, making the agricultural sector more sustainable and competitive. The use of digital technologies can help farmers reduce their environmental impact by optimising resource use, reducing waste and using precision farming techniques. The competitiveness of the EU's digital procurement industry can help the European agricultural sector remain competitive on the global market by providing innovative solutions and creating new business opportunities. By automating tasks and streamlining operations, digital technologies can help reduce the physical and mental workload of farmers, leading to better working conditions. Many farmers may be unaware of the potential benefits of digitalisation and lack the skills and resources to adopt new technologies. The implementation of digital agriculture depends on building infrastructure, including electricity, mobile network coverage, and internet connectivity.

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