Digital transformation in agricultural economics: a global review towards sustainability and resilience

CORRESPONDENCE:
Lutfullah Ebrahimi
E-mail: lutfullahebrahimi10@gmail.com

FOR CITATION:
Ebrahimi L.
Digital transformation in agricultural economics: a global review towards sustainability and resilience. *Global Agricultural Research.* 2026;1:1.

Lutfullah Ebrahimi

Stavropol State Agrarian University, Stavropol, Russia

ABSTRACT

The global agricultural sector is undergoing a profound transformation driven by digital technologies. This article comprehensively examines the status, impacts, and future directions of digital transformation in agricultural economics. The analyze of global trends and regional implementations revealed that digital technology adoption significantly enhances agricultural productivity by 14–16 % in implementing regions and substantially improves supply chain resilience. The integration of Internet of Things (IoT), artificial intelligence (AI), big data analytics, and blockchain technologies is revolutionizing traditional farming practices, market access, and food distribution systems. Despite promising advancements, significant challenges persist, including digital infrastructure gaps, literacy barriers among aging farmer populations, and regional disparities in technology adoption. This research synthesizes evidence from international case studies, empirical data, and market projections to provide stakeholders with actionable insights for navigating the digital transition in agricultural ecosystems. The findings underscore the critical need for coordinated policies, targeted investments, and knowledge-sharing initiatives to maximize the economic, social, and environmental benefits of agricultural digitalization while ensuring equitable access across diverse farming communities.

KEYWORDS: digital transformation, agricultural economics, precision agriculture, smart farming, agricultural sustainability, supply chain resilience, economic impacts, digitalization

INTRODUCTION

The convergence of digital technologies with agricultural systems represents a paradigm shift in how food is produced, distributed, and consumed worldwide. Digital transformation in agriculture encompasses the integration of advanced technologies including IoT sensors, AI algorithms, blockchain platforms, and data analytics into farming operations, supply chain management, and market access mechanisms [1]. This technological revolution responds to mounting pressures on global food systems from population growth, climate change, resource scarcity, and evolving consumer demands [5].

By 2050, the world population is projected to reach nearly 10 billion, requiring substantial increases in agricultural output while minimizing environmental impacts [8]. The economic implications of this transformation are profound. Research indicates that digital agriculture could boost the agricultural GDP of low- and middle-income countries by more than $450 billion annually a 28 % increase from current levels [8]. The global smart agriculture market is projected to grow from $15.9 billion in 2025 to $43.3 billion by 2034, reflecting a compound annual growth rate of 11.8 % [7]. This growth trajectory underscores the significant economic potential embedded in digital agricultural solutions, from precision farming technologies to digital market platforms.

This article provides a comprehensive analysis of digital transformation in agricultural economics through multiple dimensions. We examine the theoretical foundations underpinning this transition, assess current global adoption patterns and regional implementations, quantify economic impacts and performance metrics, identify persistent challenges and barriers, and propose evidence-based policy recommendations. By synthesizing research from diverse geographical contexts including China, the European Union, Indonesia, and global market trends this review offers valuable insights for researchers, policymakers, agricultural practitioners, and industry stakeholders navigating the complex interplay between technology and agricultural economics.

THEORETICAL FOUNDATIONS AND KEY CONCEPTS

Defining the digital agriculture ecosystem the digital agriculture ecosystem comprises interconnected technological platforms, data streams, and agricultural applications that collectively transform traditional farming into a knowledge-intensive, precision-oriented sector

Digital Agriculture refers to the integration of digital technologies into all aspects of agricultural production, processing, distribution, and consumption. At its core, this ecosystem leverages data as a strategic asset to optimize decision-making, enhance resource efficiency, and create new value propositions across the agricultural value chain [1]. Key components include sensing technologies for real-time monitoring, communication networks for data transmission, analytical platforms for insight generation, and automation systems for precision operations.

The theoretical underpinnings of digital transformation in agriculture draw from several conceptual frameworks. The Resource-Based View (RBV) explains how digital technologies create competitive advantages by enabling farmers to optimize scarce resources through data-driven insights [3]. According to this perspective, digital tools become valuable, rare, and difficult-to-imitate resources that generate sustainable economic returns. Complementarily, Innovation Diffusion Theory helps explain the varying adoption rates of digital technologies across different farmer demographics, regions, and production systems [9]. Research indicates that technology adoption follows distinct patterns influenced by perceived benefits, complexity, compatibility with existing practices, and observability of results.

Key technological components and their economic functions

The digital transformation of agriculture is powered by a suite of interconnected technologies, each serving distinct economic roles. Table 1 summarizes these core technologies, their primary applications, and their fundamental contributions to agricultural economics, illustrating how they translate technical capability into economic value.

Table 1
Core digital agriculture technologies and their primary economic functions

Primary economic functions	Key applications	Technology category
Input optimization, yield prediction, risk reduction	Soil monitoring, livestock tracking, climate monitoring	IoT & Sensors
Decision support, efficiency gains, quality improvement	Predictive analytics, disease detection, yield forecasting	AI & Machine Learning
Strategic planning, market intelligence, waste reduction	Market trend analysis, supply chain optimization	Big Data Analytics
Transaction security, value transparency, certification premium	Food traceability, smart contracts, certification	Blockchain
Market access reduction, information asymmetry, financial inclusion	Market linkages, knowledge sharing, financial services	Digital Platforms

The Internet of Things (IoT) represents a foundational layer of digital agriculture, enabling continuous monitoring of field conditions, crop health, and resource utilization through networked sensors and devices. These systems generate real-time data that facilitates precise resource application, reducing input costs while minimizing environmental impacts [1]. For instance, smart irrigation systems can reduce water consumption by 20–30 % while maintaining crop yields, directly impacting production economics through lower operational costs and improved resource sustainability.

Artificial Intelligence (AI) and machine learning algorithms transform raw agricultural data into actionable insights, enabling predictive modeling and prescriptive recommendations. The agricultural AI market is projected to grow from $1.7 billion in 2023 to $4.7 billion by 2028, reflecting rapid technology adoption and value creation [8]. AI applications in agriculture span from computer vision for weed detection to natural language processing for market analysis, collectively enhancing productivity and economic efficiency across the sector.

GLOBAL STATUS AND REGIONAL IMPLEMENTATIONS

Varied adoption patterns across economic regions

Digital transformation in agriculture manifests differently across global regions, reflecting varying levels of technological infrastructure, policy support, and agricultural systems. Recent data reveals both significant advancements and persistent disparities in technology adoption and implementation effectiveness. The European Union demonstrates high adoption rates, with 93 % of farmers reporting use of at least one IT or software tool, 79 % implementing crop-specific technologies, and 83 % utilizing livestock-specific digital tools [6]. This widespread adoption reflects comprehensive policy support through mechanisms like the Common Agricultural Policy (CAP), which explicitly promotes digital innovation for environmental sustainability [3].

In emerging economies, adoption patterns are more heterogeneous. China shows remarkable progress in digitalizing agricultural product circulation, with significant regional variations in implementation effectiveness. Research indicates that provinces such as Shaanxi (24.95 %), Sichuan (20.79 %), and Hubei (19.75 %) exhibit higher contributions to digital transformation outcomes, attributed to varying technology adoption rates, farm sizes, and production scales [9]. These disparities highlight the importance of region-specific digital strategies that account for local infrastructure, agricultural systems, and socioeconomic conditions.

Meanwhile, in developing agricultural economies like Indonesia, digital transformation focuses on foundational applications with immediate impacts. Studies from Polewali Mandar Regency demonstrate that adoption of basic digital tools including marketplace applications, weather prediction systems, and e-fishery platforms increased rice productivity by 14–16 % from a baseline of 4.98 tons/hectare [1]. Such implementations, while technologically modest compared to advanced precision agriculture systems, deliver substantial economic benefits by addressing critical constraints in market access and information availability.

Spatial dynamics and knowledge spillovers

The digital transformation of agriculture exhibits distinct spatial patterns characterized by knowledge spillovers and technology diffusion across geographic boundaries. Research employing spatial error models reveals that digitalization generates significant positive externalities, with technologically advanced regions stimulating agricultural modernization in neighboring areas through demonstration effects, knowledge transfer, and integrated supply chains [3]. These spillover effects amplify the economic returns on digital investments, creating regional innovation clusters that transcend administrative boundaries. The significant variations in adoption levels and economic outcomes across major global regions are summarized in Table 2.

Table 2
Regional variations in digital agriculture adoption and impacts

Primary economic impacts	Key technologies	Adoption level	Region/Country
Economic benefits (76 % farmers), environmental gains (72 %), social benefits (67 %)	IoT, precision agriculture, farm management software	High (93 % farmers use digital tools)	European Union
68 % variance in agricultural productivity explained, 73 % improvement in market access	Digital circulation platforms, smart logistics, mobile applications	Medium-High (regional variations)	China
14–16 % productivity increases, income rises of $2–3 million per month for adopters	Mobile marketplaces, weather apps, digital payment systems	Medium (developing infrastructure)	Indonesia
120 % profit increases for regenerative agriculture adopters, significant input cost savings	AI, automation, GPS technologies, robotic systems	High (precision agriculture focus)	United States

The spatial dimension of digital agriculture has important implications for development policies and investment priorities. Regions with advanced digital infrastructure and innovation ecosystems tend to generate disproportionately high benefits from digital agriculture investments, while less-developed areas risk being left behind. This dynamic necessitates targeted interventions to ensure equitable access to digital technologies and prevent the emergence of “agricultural digital divides” that could exacerbate existing economic disparities between and within countries.

ECONOMIC IMPACTS AND PERFORMANCE METRICS

Productivity, efficiency and value chain enhancements

Digital technologies generate substantial economic benefits across agricultural value chains, from production to consumption. Empirical evidence demonstrates significant impacts on productivity, resource efficiency, and market functionality. Research from China employing structural equation modeling (SEM) found that digital technology adoption rates and agricultural infrastructure collectively explain 68 % of the variance in agricultural productivity, which subsequently strengthens market access (73 % variance explained) and supply chain resilience (62 % variance) [9]. These findings highlight the central role of digital technologies in enhancing the overall performance and robustness of agricultural economic systems.

The digitalization of agricultural product circulation encompassing storage, transportation, marketing, and trading deserves particular attention for its economic impacts. Studies developing a Digital Agriculture Product Circulation Index (DAPCI) find strong correlations between digitalization levels and rural agricultural modernization, particularly in technologically advanced regions [3]. The efficiency gains from digital circulation systems translate into reduced transaction costs, minimized food waste, and improved price realization for producers. In fisheries sectors, digital technologies like e-platforms and digital cold chains have reduced post-harvest losses from 27 to 18 %, representing significant economic preservation [1].

Farmer incomes and profitability implications

Perhaps the most compelling economic evidence for digital transformation comes from income effects at the producer level. Field research from Indonesia demonstrates that farmers and fishers adopting digital technologies experienced income increases of IDR 2–3 million per month (approximately $130–200) compared to conventional counterparts [1]. This substantial income enhancement, representing 20–30 % increases for many smallholders, underscores the potential of digital technologies to directly improve rural livelihoods and reduce agricultural poverty.

At a more advanced implementation level, studies of regenerative agriculture combined with digital technologies suggest even more dramatic profitability impacts. Research cited by the World Economic Forum indicates that farmers adopting regenerative and precision agricultural methods may gain profit increases as high as 120 % over time [8]. These extraordinary gains result from synergistic effects reduced input costs through precision application, premium prices for sustainably produced goods, and improved ecosystem services that enhance long-term productivity. The economic case becomes particularly compelling when considering that expanding these sustainable practices to cover 40 % of the world's farmland could play a crucial role in limiting climate change while strengthening food system resilience.

Financial markets and investment flows

The economic significance of digital agricultural transformation extends to financial markets, where agricultural technology companies have demonstrated remarkable performance. In 2025, major agricultural input and technology companies have outperformed market expectations, with firms like Mosaic experiencing 43 % growth in stock value and Nutrien achieving 13 % quarterly revenue growth [4].

This robust market performance reflects investor recognition of the strategic position these companies occupy at the intersection of food security, technology innovation, and sustainability transition.

The financial market dynamics surrounding digital agriculture reveal shifting investment priorities and valuation metrics. Companies focusing on agricultural technologies such as John Deere with its autonomous tractors and precision sprayers maintain positive market outlooks despite fluctuations in conventional equipment sales [4]. Simultaneously, major corporate restructuring through mergers and acquisitions (such as Bunge with Viterra) creates integrated agricultural giants positioned to leverage digital technologies across global supply chains. These market developments signal a structural transformation in how value is created and captured in the agricultural sector, with digital capabilities becoming central to competitive advantage.

CHALLENGES, BARRIERS AND FUTURE PATHWAYS

Structural and infrastructural constraints

Despite promising advancements, the digital transformation of agricultural economies faces significant implementation barriers that vary across geographic and socioeconomic contexts. Infrastructure limitations represent perhaps the most fundamental constraint, particularly in rural areas of developing countries. Limited internet connectivity, unreliable electricity supplies, and inadequate digital service platforms impede technology adoption even when farmers recognize potential benefits [1]. These infrastructure gaps create digital divides that exclude vulnerable farming communities from technological opportunities, potentially exacerbating existing economic inequalities.

The economic accessibility of digital solutions presents another critical barrier, especially for smallholder farmers with limited financial resources. High upfront costs for precision agriculture equipment, subscription fees for digital services, and technical training requirements create adoption thresholds that marginalize resource-constrained producers [3]. Without innovative financing mechanisms and business models tailored to smallholder contexts, digital agriculture risks becoming a privilege of large-scale commercial operations, excluding the majority of the world's farmers from its benefits.

Human capital and institutional limitations

Beyond technological and economic constraints, human capital and institutional factors significantly influence digital transformation trajectories. Digital literacy gaps, particularly among older farmers, limit the effective utilization of available technologies even when physical access exists [1]. Research indicates that technology adoption rates vary significantly across age groups, with younger farmers demonstrating higher affinity for digital tools [9]. This generational dimension of the digital divide has important implications for agricultural education and extension systems, which must evolve to address emerging skill requirements.

Institutional and policy frameworks often lag behind technological possibilities, creating regulatory uncertainties that inhibit investment and innovation. Issues of data governance, privacy, ownership, and interoperability require coordinated solutions across multiple stakeholders [6]. The European Commission's emphasis on improving data digitalization and interoperability as "vital for reducing administrative burdens" highlights the importance of institutional innovation alongside technological advancement [6]. Similarly, policy misalignments and subsidy structures that favor conventional practices over sustainable digital innovations create disincentives for transformation.

CONCLUSION

The digital transformation of agricultural economics represents a paradigm shift with far-reaching implications for productivity, sustainability, and rural development. This comprehensive review demonstrates that digital technologies significantly enhance agricultural productivity, strengthen supply chain resilience, improve market access, and increase farmer incomes. Evidence from diverse international contexts confirms the transformative potential of appropriately designed and implemented digital solutions across varied agricultural systems and economic conditions.

However, realization of this potential faces significant challenges, including infrastructure limitations, digital literacy gaps, economic accessibility constraints, and policy misalignments. The spatially heterogeneous nature of digital transformation further risks exacerbating existing economic disparities between and within regions. Addressing these challenges requires coordinated action across multiple stakeholders' policymakers, technology developers, agricultural producers, researchers, and civil society organizations.

Several key policy priorities emerge from this analysis. First, targeted investments in rural digital infrastructure are prerequisite for inclusive transformation. Second, capacity building programs must enhance digital literacy across diverse farmer demographics. Third, innovative financing mechanisms are needed to improve smallholder access to digital technologies. Fourth, supportive regulatory frameworks should encourage experimentation while safeguarding public interests. Fifth, knowledge sharing platforms can facilitate cross-learning between regions at different stages of digital transformation.

As agricultural economies worldwide navigate the complex interplay between technological possibilities and socioeconomic realities, this review provides stakeholders with evidence-based insights to inform strategic decisions. By harnessing digital technologies while proactively addressing implementation challenges, the agricultural sector can transition toward more productive, sustainable, and resilient economic systems capable of meeting twenty-first-century food security and environmental challenges.

REFERENCES

1. Rybchenko E.V., Klychova G.S., Zakirov A.R., Klychova A.S. Development of digital technologies in the agro-industrial complex. *Vestnik of the Kazan State Agrarian University*. 2021;16(3):90-95. https://doi.org/10.12737/2073-0462-2021-90-95
2. Wolfert S., Ge L., Verdouw C., Bogaardt M.J. Big data in smart farming – a review. *Agricultural Systems*. 2017;153:69-80. https://doi.org/10.1016/j.agsy.2017.01.023
3. Klerkx L., Jakku E., Labarthe P. A review of social science on digital agriculture, smart farming and agriculture 4.0: The contribution of systems thinking and the role of the digital-Agroecological double transition. *Agricultural Systems*. 2019;176:102742. https://doi.org/10.1016/j.agsy.2019.102742
4. Zhang X., Fan D. Can agricultural digital transformation help farmers increase income? An empirical study based on thousands of farmers in Hubei Province. *Environment, Development and Sustainability*. 2024;26:10993-11012. https://doi.org/10.1007/s10668-023-03200-5
5. Shew A.M., Gustafson C.R., Nayga R.M., Snell H.A., Lague H. Digital transformation of the agricultural sector: pathways, drivers and policy implications. *Applied Economic Perspectives and Policy*. 2021;43(4):1221-1242. https://doi.org/10.1002/aepp.13120
6. Khan N., Ray R.L., Kassem H.S., Hussain S., Zhang S., Khayyam M., Ihtisham M., Asongu S.A. Potential for artificial intelligence (AI) and machine learning (ML) in smart agriculture and agricultural supply chain. *Frontiers in Artificial Intelligence*. 2023;6:1115450. https://doi.org/10.3389/frai.2023.1115450
7. Trendov N.M., Varas S., Zeng M. *Digital Technologies in Agriculture and Rural Areas: Status Report*. Food and Agriculture Organization of the United Nations (FAO). 2019.
8. Li J., Ma W., Zhu H. A Review on the policy, technology and evaluation of digital agriculture in China. *China Agricultural Economic Review*. 2023;15(3):467-488. https://doi.org/10.1108/CAER-01-2023-0006
9. Yang G., Li Y., Wang H., Li H. Digital Economy and Agricultural Modernization: Empowerment Mechanisms and Practical Pathways. *Agriculture*. 2023;13(5):1075. https://doi.org/10.3390/agriculture13051075
10. Pan Z., Yang P., Yu F., Gao P. Digital economy and high-quality agricultural development: embodiment mechanisms and empirical evidence. *International Review of Economics and Finance.* 2025;95:103343. https://doi.org/10.1016/j.iref.2024.103343

About the author

Lutfullah Ebrahimi –
student, Regional Sectoral Economics (specialization in Agricultural and Agribusiness Economics), Stavropol State Agrarian University, Stavropol, Russia

lutfullahebrahimi10@gmail.com