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FEATURES OF THE APPLICATION OF INNOVATIVE TOOLS IN THE MANAGEMENT OF ENTERPRISES IN THE AGRICULTURAL SECTOR OF THE ECONOMY

ABSTRACT

The agricultural sector requires innovative management approaches to ensure competitiveness and sustainable development amid rising global food demand, resource constraints, and climate change. This paper analyzes the specific features of agricultural innovation management tools, focusing on three categories: digital technologies (such as precision farming systems and other AgriTech applications), financial instruments (including index-based crop insurance and fintech solutions), and organizational innovations (like clustering and modern cooperatives). The overarching goal is to evaluate how these innovations are being applied and their effects on the efficiency and resilience of agricultural production. The study adopts a mixed-method approach, combining a comprehensive literature review with an analysis of secondary statistical data. Data from international organizations (e.g., FAO, World Bank, USDA) were examined to assess current innovation adoption trends. The results indicate that innovations significantly improve agricultural productivity and resource efficiency. For example, precision farming tools can boost crop yields by around 4–6% and reduce input use (water, fuel, agrochemicals), lowering costs and environmental impacts while enabling producers to "do more with less." Likewise, modern financial instruments and organizational strategies (e.g., index insurance and farmer cooperatives) enhance producers' resilience to climate and market risks. However, the adoption of innovations is uneven: large high-tech enterprises embrace new tools much faster, whereas small farms often lag behind due to limited capital, skills gaps, and inadequate infrastructure—creating a growing innovation divide in the sector. This study provides a novel integrated perspective by systematically comparing technological, financial, and managerial innovations in agriculture, including global trends and specific cases from Ukraine. It synthesizes previously fragmented knowledge, reveals interactions between technological and organizational factors that were overlooked in earlier studies, and addresses how its findings differ from those of prior research. Finally, the paper proposes several recommendations to accelerate digital transformation and innovative development in the agricultural sector.

Keywords: innovative management tools, agricultural sector, precision farming, digital technologies in agriculture, innovation implementation, sustainable agriculture, agribusiness management

JEL Classification: Q16, O33, Q12

INTRODUCTION

Although the agricultural sector plays an important role in ensuring food security and economic development, it is facing serious challenges. According to FAO forecasts, global agricultural production will need to increase by 70 per cent by 2050 in order to feed the world's population (Associated Press, 2011). However, the expansion of arable land is limited, and much of the existing arable land has already been degraded. Furthermore, climate change, the depletion of natural resources, and geopolitical risks (such as the destruction of agricultural infrastructure by war) require new approaches to agricultural management. This emphasizes the urgent need for intensive and sustainable development – achieving greater productivity through innovation. Today, agriculture is rapidly moving towards the fourth agricultural revolution (Agriculture 4.0), which combines digital technologies, the Internet of Things (IoT), big data, artificial intelligence (AI), and robotics. Innovative agricultural management tools include wide-ranging developments, ranging from digital technology (such as GPS-driven machines, field monitoring sensors, drones, and agricultural software platforms), financial instruments (such as new credit models, agricultural insurance, trading platforms), and organizational innovations (such as clustering, cooperatives, and electronic markets). Scholars have examined various aspects of this topic and highlighted the important potential of digital agriculture to increase yields and optimize resource use, although their impact varies depending on regional conditions, the size of farms, and the willingness of enterprises to adapt.

These innovative management tools, ranging from precision agriculture systems to fintech solutions, provide new opportunities to improve agricultural efficiency, resilience, and competitiveness. They provide a new quality of decision-making by improving the transparency, accuracy, speed, and effectiveness of management processes. Innovation is particularly important in the context of Ukraine's agricultural sector, which is strategically important to the country's economy, accounting for almost 20 per cent of foreign currency revenues and a significant share of GDP (about 11% in agriculture and 9% in food processing). Ukraine is one of the world's major agricultural exporters. However, the agricultural productivity of Ukraine remains lower than that of technologically advanced countries. This emphasizes the need to reconsider agricultural management practices using modern innovative approaches. The relevance of this topic is therefore to synthesize current experiences in the implementation of innovations in agricultural management and identify factors that can facilitate or hinder such a process. The study of innovative management tools in the agricultural sector is of great theoretical and practical importance. Therefore, this paper aims to thoroughly analyse the innovative practices in the management of agricultural enterprises, their impact on performance, and future prospects.

LITERATURE REVIEW

The issue under investigation lies at the intersection of agricultural management, innovation economics, and information technology. Existing scholarly literature can be broadly divided into several thematic directions: analysis of the adoption of digital technologies in agriculture and their related socio-economic impacts; studies of innovative financial mechanisms and their influence on the agricultural sector; and research on organizational innovations and the transformation of agribusiness management models.

The first direction is represented by a growing body of research on "digital agriculture" and "precision farming." For instance, Araújo et al. (2021) emphasize that the transition to Agriculture 4.0 involves the integration of IoT, sensor networks, robotics, artificial intelligence, and cloud technologies, which collectively enable sustainable productivity growth and food security. Their study, based on the analysis of 8,485 scientific publications over the last decade, identifies key trends: the development of sensors and automated decision-making systems, the use of big data to optimize production, and the need for integrated IT architectures to support "smart" farming systems. Alongside the benefits, the literature also highlights the challenges of digitalization. For example, Klerkx et al. (2019) underline the socio-economic implications of smart farming, such as the risk of increased inequality between large and small producers, concerns over data privacy and ownership, the need for new skills among farmers, and the potential dependence on large IT corporations. Similarly, Yeo & Keske (2024) argue that trust and the perception of technology are critical for the successful adoption of digital farming—issues such as algorithmic opacity or fears over data control may hinder innovation uptake, even when its economic viability is well-established.

Empirical studies on the impact of precision farming confirm its economic and environmental benefits. According to a report by the Association of Equipment Manufacturers (2021), the use of a suite of precision agriculture technologies (e.g., GPS autopilot, variable-rate application, section control) already enables a yield increase of around 4%, while reducing fuel consumption by 6%, water use by 4%, and pesticide use by 9%. The same study suggests that universal adoption of these technologies could further increase yields by 6% and reduce water usage by up to 21%. Despite these advantages, empirical studies indicate that the economic impact for agricultural enterprises may be modest due to the high cost of technology. For example, Schimmelpfennig (2016) found that the use of variable-rate application systems in the U.S. increased grain farm profitability by only about 1–3%, aligning with findings from other studies showing a gradual return on investment from precision farming. At the same time, researchers such as Shepherd et al. (2018) emphasize that economic feasibility is only one factor—in order to bridge the "adoption gap," it is crucial to account for the human factor and provide entrepreneurs with the necessary knowledge and support to fully integrate technologies into their operations.

The second strand of literature focuses on innovative financial instruments in the agricultural sector. These include new forms of credit and insurance tailored to the specific needs of agriculture. The African Development Bank (2015) highlights the potential of weather derivatives and index-based crop insurance, which allow farmers to hedge against climatic risks

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without the need for traditional damage assessments. Credit guarantee schemes and public-private funds are also widely discussed, as they help unlock agricultural financing by sharing risks between the state and investors. In developing countries, mobile financial services are a particularly important tool. Thanks to mobile connectivity, millions of smallholder farmers in Africa and Asia have gained access to banking services (payments, microloans) and market information for the first time. For instance, the introduction of simple SMS-based agricultural advisory services has significantly increased yields: research by Fabregas et al. (2019) published in Science found that digital advice on crop management (via SMS and mobile apps) can boost yields by 4–11% by improving farmer knowledge.

This direction is closely linked to the concept of farmer empowerment through information. The idea of digital extension is viewed as an effective and scalable way to educate producers in remote areas (Aker, 2011; Fabregas et al., 2019). Important components also include e-commerce platforms and blockchain solutions for agricultural products, which enhance supply chain transparency and trust between producers and consumers (e.g., through product traceability). Although academic research on blockchain in the agricultural sector is still limited, it is expected that such tools will help reduce transaction costs and improve farmers' access to markets (World Economic Forum, 2018).

The third research strand covers organizational and managerial innovations. Historically, the agricultural sector has been slow to adopt new management approaches, but this process is now accelerating. Ukrainian scholars Ihnatenko et al. (2024) note that in the modern digital economy, traditional agricultural practices are transforming: new organizational forms of interaction between science, business, and government are emerging, such as biotechnology clusters, agro technoparks, and startup incubators. Their work proposes a classification of innovation implementation tools—financial, managerial, and technological—operating within the organizational-economic, investment, motivational, and institutional frameworks that support agricultural innovation. This approach generalizes various aspects of the innovation process—from funding sources to staff motivation strategies—and emphasizes that only an integrated application of these tools can generate maximum effect.

A distinct body of literature focuses on the dissemination of knowledge and information among farmers. In many countries, agricultural extension services are undergoing modernization with an emphasis on innovation: the involvement of private advisory services, the creation of online knowledge platforms, and the training of "lead farmers" to demonstrate new technologies in practice (Wolfert et al., 2017; Brooks, 2021). In her study, Brooks (2021) explores the concept of the "digital farmer" and the use of behavioural "nudging" policies to promote innovation adoption, examining how governmental and commercial actors shape farmers' behaviour through digital channels. Scholars agree that a successful digital transformation of the agricultural sector requires not only technical solutions but also institutional changes—such as the development of infrastructure (e.g., rural internet access, smart farms), the adaptation of public policy (e.g., data standards, incentive programs), and the training of a new generation of professionals (e.g., agri-data scientists, agri-IT specialists).

Thus, the literature review indicates that innovative management tools in agriculture are widely studied, yet the existing knowledge remains fragmented. Many studies focus either on technological aspects (e.g., precision farming, digital agriculture), financial innovations, or specific regional case studies. Fewer works are dedicated to an integrated analysis that simultaneously covers different types of innovation and compares their impacts. Moreover, the interaction between technological and socio-organizational factors in innovation adoption remains insufficiently explored. This highlights the need for a comprehensive study that integrates these aspects. The present research aims to address this gap by uniting digital, financial, and managerial innovations in the agricultural sector within a single analytical framework and assessing their application based on current data.

AIMS AND OBJECTIVES

The aim of this study is to identify and characterize the specific features of applying innovative management tools in the agricultural sector at the current stage, as well as to assess their impact on the efficiency and resilience of agricultural production. The research seeks to comprehensively evaluate the influence of innovations on the agricultural sector and to formulate recommendations for the effective use of advanced management tools in agriculture. It also aims to address existing knowledge gaps by conducting an integrated analysis of different types of innovative management tools in the agricultural sector and evaluating their practical implementation—both globally and within Ukraine.

METHODS

This research is based on a combination of qualitative and quantitative methods. In the first stage, a comprehensive literature review was conducted, encompassing scholarly articles, monographs, and industry reports from international organizations (FAO, World Bank, OECD), as well as analytical materials. Source identification relied on scientometric databases (Scopus, Web of Science) and open data from specialized institutions. The literature review provided the theoretical framework and identified the key analytical dimensions—technological, financial, and organizational aspects of innovation.

In the second stage, methods of secondary data analysis were employed. Statistical data on the adoption of innovations in the agricultural sector were collected and processed from various sources, including official statistics (e.g., Eurostat, USDA, Ukraine's State Statistics Service), industry surveys, and reports (e.g., studies on the implementation of precision farming in the U.S., ICT usage among farmers, and market indicators for agrotechnologies).

Descriptive statistical methods were used to synthesize numerical data, including the calculation of proportions, averages, and trends, as well as the construction of visual tables and charts. For example, USDA survey data on the digital readiness of farms, EU statistics on the age and education of farmers, and findings from African countries regarding the use of mobile services among smallholders (Tsan et al., 2019) were analyzed. Comparative analysis was applied to assess differences across countries and types of farms. Specifically, adoption rates of precision agriculture in developed countries (e.g., the U.S., Denmark, Canada) were compared with those in developing nations. Differences between large agribusinesses and small farms were also analyzed based on stratified data and case studies.

Elements of systems analysis were additionally employed—the agricultural sector was viewed as a complex system with interrelated technological, economic, and social components. This allowed for an assessment of how specific innovations (e.g., GPS autopilots or agricultural insurance) influence the system as a whole (e.g., productivity, risk exposure, market structure). All findings are supported by references, and statistical data were verified for accuracy and relevance (with most datasets drawn from the last 5–7 years). Data processing was performed using office and specialized software tools (e.g., MS Excel for charts and tables). General scientific methods were applied throughout the analysis—induction and deduction (for synthesizing case-specific findings into general conclusions), analogy (to apply global experience to the Ukrainian context), and elements of the expert approach (interpreting trends based on researcher consensus). A limitation of the methods used is the reliance on data availability and completeness. Statistics on specific innovations (e.g., blockchain use or precision methods among smallholders) are limited, requiring reliance on isolated estimates or expert forecasts. Nevertheless, the combination of multiple methods and information sources ensures the credibility of the findings presented by the author.

RESULTS

Digitalization has become the core of modern innovation processes in the agricultural sector. Digital management tools include precision agriculture (PA) systems, various sensors and platforms for data collection and analysis, automated machinery and robotics, as well as software solutions for supporting decision-making (Farm Management Information Systems). The implementation of these technologies transforms traditional agrotechnical operations into data-driven processes and enhances the accuracy and timeliness of managerial actions. Table 1 summarizes the main categories of digital tools and their key advantages.

As shown in Table 1, digital technologies provide agriculture with unprecedented capabilities for precision control and forecasting. The study found that the most widespread component of precision agriculture is the use of GPS navigation systems and machinery autopilots. According to the latest USDA survey (2023), 52% of medium-sized and 70% of large U.S. farms are equipped with such systems. Autopilots optimize machinery paths, reduce fuel consumption and operator fatigue, and save time. Another fundamental PA element is yield monitoring: 68% of large American farms use yield sensors and field mapping during harvesting. This enables the identification of productivity variations across fields and supports informed decisions on variable-rate applications.

However, more advanced technologies—such as variable-rate technology (VRT) and agricultural drones—are being adopted more slowly. For example, as of 2021, only about 16% of Canadian farms applied variable-rate fertilization, and fewer than 5% used drones for spraying. This supports the argument of Araújo et al. (2021), who note that not all innovations spread equally: there are "first-wave" technologies that have become routine (GPS, on-farm computers, and smartphones—over 56% of Canadian farmers use the latter), and "second-wave" technologies (robotics, artificial intelligence) that are just beginning to commercialize.

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Table 1. Categories of Innovative Management Tools in the Agricultural Sector (Digital, Financial, and Organizational) and Their Examples.

Category of Tools	Examples	Key Benefits and Capabilities
Digital Technologies (AgriTech)	Precision agriculture systems (GPS-guided machinery, autopilots, variable-rate fertilizer application); soil moisture sensors, weather stations; drones and satellite field monitoring; farm management software (FMS); robotic agro-operators (e.g., robotic milking systems)	Resource optimization (fertilizers, seeds, water) through precise application; yield increase (by 4–6% with full PA implementation); reduced fuel, labour, and time costs via automation; early detection of field issues (pests, diseases) using sensors and drones; reduced environmental impact (less chemical overuse).
Financial Innovations	Index-based crop insurance (payouts linked to weather indices or regional yields); agricultural receipts and warehouse certificates; digital lending platforms (peer-to-peer loans, crowdfunding); mobile wallets and payments (e.g., M-Pesa in Kenya); public/donor-supported agricultural insurance funds	Reduced financial risks for farmers (e.g., drought insurance covers losses); easier access to credit and working capital for smallholders (online lending, mobile microfinance); faster transactions and trade (e-payment systems); increased private investment via innovative instruments (agro bonds, green bonds); operational transparency and trust (e.g., blockchain for product quality assurance).
Organizational Innovations	Agro-clusters (farmers, processors, and researchers integrated into regional innovation systems); modern agricultural cooperatives (using IT platforms for collective sales/purchases); educational hubs and agrotech incubators; public-private extension partnerships (government-supported knowledge platforms); contract farming schemes integrated into value chains (outgrower schemes)	Economies of scale and synergy through shared infrastructure and knowledge (e.g., clusters provide access to research and services); improved bargaining power of smallholders via cooperation (better prices and input access); faster innovation uptake through peer learning; youth and entrepreneur engagement (via incubators, competitions); managerial flexibility and adaptation (new business models focused on value-added products such as organic or niche goods).

Numerous studies support the impact of digital tools on the efficiency of agricultural production. Precision agriculture reduces input costs: according to the Association of Equipment Manufacturers (AEM), American farmers who regularly use such technologies have cut fertilizer use by approximately 7% without compromising yields. Simultaneously, environmental conditions improve, with less soil and water contamination by excessive agrochemicals. In essence, precision farming enables farmers to "produce more with fewer resources." Moreover, digital technologies enhance farmers' adaptability to climate change: for example, weather and soil moisture monitoring systems allow optimal irrigation planning, which is especially important in arid regions (full implementation of precision irrigation can reduce water use by up to 21%). A separate class of innovation—artificial intelligence and machine learning—is being applied to yield forecasting, plant disease detection (via computer vision), and management decision support. While these approaches are still gaining traction, some agribusinesses already employ AI models for logistics and marketing optimization.

However, the results of the analysis indicate significant barriers to digitalization in the management of agricultural enterprises. Key challenges include high technology costs and the need for substantial upfront investment. Estimates show that a fully equipped large-scale farm with precision agriculture systems (including machinery, sensors, and software) may require hundreds of thousands of dollars—a feasible investment primarily for agribusinesses or wealthy farmers, while smaller farms often lack such resources. Limited knowledge and skills also hinder adoption: even when equipment is available, farmers may not know how to interpret data correctly or adjust practices accordingly. As a result, some functionalities remain unused. EU surveys show that only about 11% of farmers are under the age of 40, while the rest belong to older generations less inclined to adopt new technologies. In addition, infrastructural issues (e.g., rural internet coverage and electricity reliability) remain problematic in many countries, including Ukraine, limiting the use of cloud services and online platforms. These impediments are slowly but surely being lifted; more agro-digital education programs have been initiated, governments are working to extend internet networks in rural areas, and the costs of technologies are going down as adoption spreads.

The next category of management tools to be considered is financial innovation, which nowadays forms a core part of agricultural management. These tools increase the resilience of production under uncertainty and improve resource mobilization. One of the most promising approaches is index-based agricultural insurance. Unlike conventional insurance, which requires field damage assessment, index-based insurance ties payouts to objective indicators—such as seasonal rainfall levels or average regional yields. If the index (e.g., drought severity) exceeds a threshold, the farmer automatically receives compensation. This streamlines procedures and reduces costs: as noted by the African Development Bank (AfDB), index policies can cover thousands of smallholders while minimizing insurers' transaction costs. Successful examples already exist: in Kenya and Ethiopia, drought insurance programs have been introduced with payouts based on satellite vegetation data. Another instrument is agricultural receipts, which have gained traction in countries such as Ukraine and Brazil. An agricultural receipt is a debt instrument backed by the future harvest; it allows a farmer to obtain a planting loan with an obligation to repay in cash or kind post-harvest. This innovation improves lenders' trust in the agricultural sector by providing collateral in the form of expected yields. As of 2021, more than 1,000 agricultural receipts had been issued in Ukraine, totalling over UAH 8 billion, according to the Ministry of Agrarian Policy.

The development of financial technologies (FinTech) has introduced digital financing platforms into agriculture. In Asian countries, online services are rapidly connecting farmers directly with investors and lenders. For example, in India, platforms such as Kiva or Rang De enable urban residents to invest small amounts in farming projects and earn interest, while farmers receive loans at lower rates than those offered by local lenders. Crowdfunding and peer-to-peer lending diversify capital sources for smallholders. In developed countries, agricultural investment funds and "green bonds" have emerged, channelling resources toward innovative projects (e.g., organic farming, and climate-smart agriculture). The World Bank, for instance, has issued green bonds to fund climate-resilient agri-projects in developing nations, demonstrating new pathways for mobilizing private capital in agriculture.

For farmers in poorer regions, mobile money and services have brought about a genuine financial revolution. The M-Pesa mobile application, launched in Kenya in 2007, allowed rural populations to make payments and transfers via mobile phones without bank accounts. Today, more than 32 million Kenyans use M-Pesa, including hundreds of thousands of farmers who receive payments for produce or loans through this service. GSMA (the Global System for Mobile Communications Association) reports that by 2020, around 60% of the adult population in Sub-Saharan Africa had mobile wallets, with agriculture as a key beneficiary of this technology (e.g., crop payments, and seed procurement). Digital payments reduce transaction time and theft risks while easing market access. Moreover, the emergence of digital financial footprints (payment histories) enables the creation of farmer credit scoring models, facilitating access to loans previously unavailable due to a lack of credit history. Thus, FinTech fosters financial inclusion in agriculture.

Agricultural markets and supply channels are also undergoing major changes under the influence of innovation. Electronic trading platforms for agricultural products are becoming increasingly widespread. In India, the government-run e-NAM platform has integrated hundreds of local agri-markets, enabling farmers to sell produce nationwide at market prices. In China, major e-commerce companies such as Alibaba and JD.com are entering the farming sector, launching digital farm shops and logistics networks that connect rural producers directly to consumers. These models reduce the role of intermediaries and can increase farmers' incomes by 10–20% through lower markup costs (World Bank, 2019). Another aspect is contract farming: agribusinesses or processing companies sign pre-harvest contracts with smallholders, providing them with resources (seeds, fertilizers) and guidance, and later purchasing the harvest at agreed prices. While not new, this model has evolved with innovative features—including IT platforms for contract monitoring, drones for field inspections, and blockchain-based smart contracts for automated settlements. Such schemes (e.g., out-grower programs in Africa) have shown success in stabilizing farmers' incomes and improving product quality by ensuring adherence to standards set by contracting firms.

In summary, innovative financial instruments significantly expand the capacity of agricultural producers to manage risks and finances. The analysis confirms that in transition economies (including Ukraine), the impact of implementing such tools can be as substantial as that of technological innovations. For example, the introduction of public support for crop insurance or accessible credit programs stimulates farmers to invest in new machinery, fertilizers, and seed varieties—indirectly contributing to increased productivity. At the same time, financial innovations require strong institutional foundations: clear regulations, transparency, and trust. Without these, failures may occur—as seen in some microfinance programs, where a lack of financial literacy has led to excessive indebtedness among farmers. Therefore, the introduction of innovations must be accompanied by educational efforts and regulatory oversight.

In recent years, there have been significant changes in how agriculture is organized: a shift from isolated farming to network-based models, greater involvement of scientific and IT organizations in agribusiness, and a rethinking of the role of cooperation. Innovations in agricultural enterprise management encompass not only technology or finance, but also new forms of business organization, market participant interaction, and decision-making processes.

One of the key organizational innovations is the development of agricultural clusters. A cluster is a geographically concentrated group of interconnected organizations (producers, processors, research institutions, service companies) that both cooperate and compete. In agriculture, the cluster concept involves creating regional agro-industrial complexes with a full production and sales cycle, enabling joint solutions to innovation challenges. As noted by Kostiuk et al. (2024), the development of biotechnology clusters is a critical prerequisite for innovation in Ukraine's agricultural sector: combining research institutions, implementation structures, producers, and marketers creates the synergy needed for deploying expensive high-tech developments that individual companies cannot afford. European experience (e.g., agricultural clusters in the Netherlands or agri-tech parks in France) demonstrates that clusters accelerate the commercialization of scientific achievements, improve farmers' access to innovative services, and enhance the added value of agricultural products. In Ukraine, conditions for developing such clusters have emerged in several regions (e.g., a bioenergy crop cluster in Poltava, and a

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fruit-and-vegetable cluster with processing in Kherson). Government support and coordination among stakeholders can provide a strong impetus for these initiatives.

Another important direction is the reform of extension systems and knowledge dissemination. In the 20th century, agricultural knowledge was transmitted mainly by state agronomists; today, this has evolved into multichannel models involving private consultancy firms, online knowledge portals, and mobile advisory applications. One example is the e-Extension platform in the U.S., which integrates university research and practical advice for farmers in a digital format. Farmers can ask questions to experts online or search for relevant information in the knowledge base. In developing countries, the training of "lead farmers" is especially relevant—these individuals receive instruction in modern techniques and pass on knowledge to their peers. Such approaches are supported by the FAO and the World Bank through rural development projects (e.g., Farmer Field Schools). Digital tools also enhance communication: messaging apps and social media facilitate communities of farmers with shared interests, allowing them to exchange experiences on innovation implementation. For instance, in China, over 50% of entrepreneurial farmers subscribe to specialized WeChat channels where they access information on new crop varieties, machinery, and market prices. Our study found that the educational level of farm managers significantly influences the pace of innovation adoption: enterprises led by individuals with higher education or specialized training are much more likely to invest in innovations—a trend observed in both Ukraine and other Eastern European countries.

It is also important to highlight innovations in the management practices of agricultural companies themselves. Large agribusiness holdings increasingly adopt concepts from corporate management: implementing ISO quality management systems, product traceability standards, and lean production principles adapted for agriculture. For instance, lean elements such as waste minimization and logistics optimization are applied at grain elevators and processing plants within agroholdings—representing a managerial innovation that boosts efficiency not by introducing new technologies, but through better organization of processes. Many companies are also implementing ERP (Enterprise Resource Planning) systems for integrated tracking and planning of all resources—from fields to finances. This enables data-driven decision-making, where choices are based on up-to-date information. The decision-making culture is shifting: instead of relying on intuition, companies now apply data analysis and scenario modelling (e.g., forecasting profitability under different grain prices and yield levels). These approaches, while relatively new to the agricultural sector, are transforming agribusinesses into high-tech, management-oriented enterprises.

Among small and medium-sized farmers, organizational innovation often takes the form of new types of cooperation. While traditional agricultural cooperatives of the 20th century focused on joint sales or procurement, modern cooperatives are investing in innovation collectively—for example, a group of farmers jointly purchasing a drone or subscribing to satellite monitoring services for shared use. It is also common to jointly hire an IT specialist or agronomic consultant, reducing individual costs while ensuring access to professional support. In countries like France and Germany, farmer associations have even established shared data centres to collect and analyze agricultural data and apply it across member farms. This collective data handling is especially important, as a single small farm's dataset may be insufficient for meaningful analysis, whereas aggregated data from dozens of farms enables statistically robust conclusions—such as comparing the performance of different seed hybrids.

The study also highlights a trend toward diversification and sustainable development as a new management paradigm. Instead of specializing in a single crop or activity, innovative farms aim to diversify production (e.g., integrating crop production, livestock farming, and bioenergy from waste). This allows for more efficient resource use and reduces exposure to risk. Such transformations often require organizational innovations as well—creating new departments, cross-training staff in related fields, and forming partnerships with processing companies.

Thus, organizational innovations define the context in which technological and financial innovations can deliver the greatest benefits. Where there is a supportive institutional environment—such as clusters, cooperatives, and robust extension services—innovations are adopted more rapidly and effectively. For example, in Denmark, a high level of farmer cooperation contributed to approximately 40% of farms using precision agriculture tools by 2023, covering 78% of the country's arable land. By contrast, in countries with fragmented agricultural sectors and weak stakeholder coordination (including Ukraine), innovation adoption is more sporadic—concentrated mainly among large enterprises—and does not always extend to smallholders. Therefore, the development of social capital (trust, cooperation skills) and institutions (legal norms, educational frameworks) is an integral part of the innovation process in agriculture.

An analysis of the application of innovative management tools would be incomplete without addressing the extent to which these innovations are actively and evenly implemented across different countries and categories of producers. This study identified substantial disparities in innovation diffusion—both geographically and structurally.

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At the global level, a significant gap exists between developed and developing countries in the adoption of modern agricultural technologies. According to a study by McFadden et al. (2024), which analyzed survey data from 48 countries, in none of the developing nations does the share of land under variable-rate application or other advanced technologies exceed 10–15%. In contrast, in technologically advanced agricultural countries—such as the United States, Canada, Australia, and EU member states—the adoption of certain precision agriculture components already covers between 20% and 60% of farms. For instance, in Denmark, 67% of arable land is cultivated using high-precision RTK GPS navigation systems, although this corresponds to only 27% of all farms. This example illustrates the concentration of technologies among more powerful producers: large farms control more land area, so even a small number of such enterprises contributes to high land coverage rates.

Farm size is arguably the most important determinant of innovation adoption. Our analysis of USDA data confirms that large and medium-sized farms are far more likely to implement precision agriculture compared to small farms. Figure 1 illustrates the percentage of farms by type using modern technologies in the United States as of 2023.

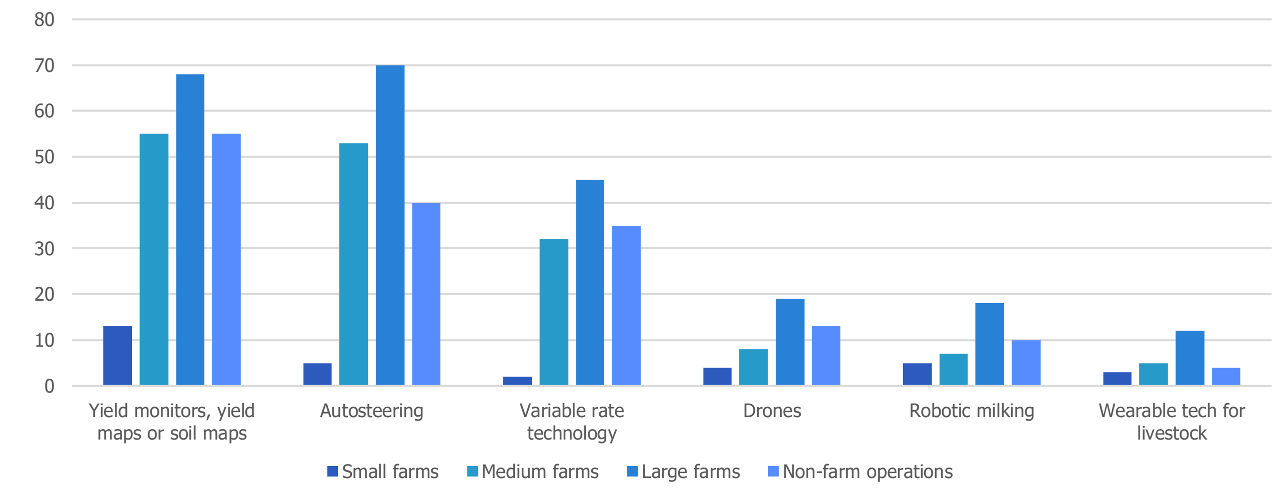

Figure 1. Share of US farms adopting precision agriculture technologies, by farm type, 2023. *(Source: McFadden, J., & Lim, K., 2024)*

Small farms are defined as those with annual sales < USD 350,000; medium farms as USD 350,000–USD 1 million; and large farms as > USD 1 million. The figure clearly shows that large farms (in red) significantly outperform small farms (in yellow) in the adoption of all technologies—from yield monitoring to drones and robotic systems. For instance, 70% of large farms use autopilot and GPS navigation, compared to only 5% of small farms. A similar gap exists for yield mapping (68% vs. 13%) and drone usage (19% vs. <1%). This is explained by financial capacity and economies of scale: technological investments have quicker payback on larger areas, while smallholders often lack both the resources and incentive to adopt expensive innovations.

As Figure 1 indicates, there is structural inequality in access to innovation: large commercial agro firms are the first to adopt and benefit from new technologies, while small family farms lag behind. This may accelerate the consolidation trend in agriculture, as technological advantages make large players more competitive, while small producers find it increasingly difficult to maintain efficiency. Basso and Antle (2020) warned that the digital revolution could exacerbate the "winners and losers" problem in agriculture unless support mechanisms are in place for smallholders. One potential solution, previously discussed, is improving access to innovations through cooperatives or subsidies.

Regional disparities in innovation adoption are also considerable. In developed countries, the fastest uptake occurs for technologies that provide immediate cost savings or reduce labour. For example, the use of automated milking systems in dairy farming has grown substantially over the past five years in the U.S. and Canada: while their overall share remains modest (5–10%), large farms are transitioning rapidly to robotic milking to reduce labour costs. In the EU, ecological innovations receive particular attention. Technologies for targeted pesticide application are promoted under the "Farm to Fork" policy to reduce chemical load. In France and Germany, co-financing programs help smallholders acquire precision farming equipment—significantly accelerating adoption. Still, adoption rates within the EU vary greatly: DEFRA reported that in England in 2019, around 29% of farms used GPS for field operations, while in less technologically advanced EU members, adoption was far lower, with some farmers completely unfamiliar with such technologies.

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In developing countries, innovation adoption often involves "leapfrogging" certain stages and adapting technologies to local realities. For instance, many African farmers skip wired internet and move directly to mobile services. Similarly, instead of costly weather stations, farmers receive meteorological data via low-cost sensors or even SMS updates. These solutions are often localized: Brazil has developed low-cost precision farming tools adapted to tropical crops, while in India, portable soil testers costing only a few dollars help smallholders assess fertilizer needs without paying for laboratory services. These "fractal" innovations, designed for specific contexts, gradually improve efficiency even without access to the latest global technologies. Nevertheless, the innovation gap remains wide: according to the World Bank (2019), agricultural labour productivity in Sub-Saharan Africa is only about 20% of the U.S. level—largely due to the slow adoption of new knowledge and technologies.

In Eastern Europe, particularly Ukraine, the picture is polarized: large agribusinesses match Western standards in technology (with widespread use of autopilots, drones, and proprietary agri-IT systems), while many small farms still operate with outdated practices. As a result, national averages often mask extremes: though agriculture contributes about 17% of Ukraine's GDP, most innovation and export value are concentrated in a few dozen major companies.

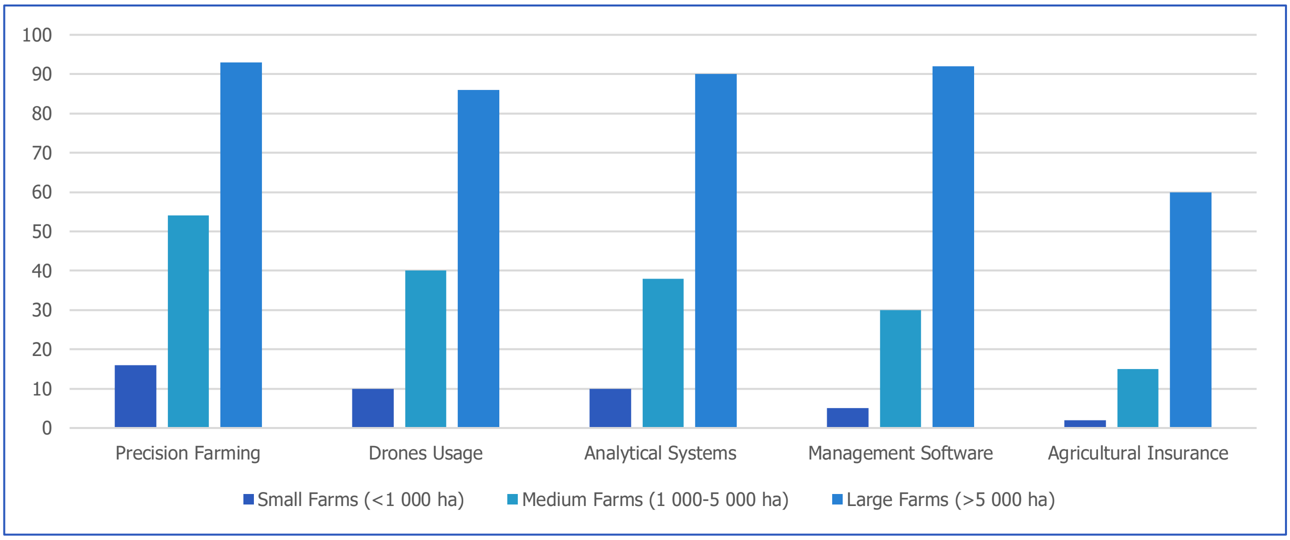

Figure 2. Adoption of innovative agricultural management tools by farm size in Ukraine. Data adapted from Precision Farming Technologies in Ukraine (2021).

Factors influencing innovation adoption can be internal (farm-specific) or external (policy and macroeconomic conditions). Internal factors include farm size, access to finance, the manager's education, and age (many studies confirm that younger farmers are more open to innovation). External factors include infrastructure availability, price environments (high product prices stimulate investment), and government incentives. For instance, the EU's 2014–2020 rural development programs co-financed purchases of innovative equipment—greatly improving technology uptake. By contrast, in economically unstable countries, farmers are often reluctant to invest in innovations due to uncertainty.

It is also essential to consider cultural factors in innovation adoption. A strong innovation culture within a society can significantly facilitate the uptake of new technologies. For instance, farmers in the United States have historically been receptive to machinery and technological innovations—dating back to the era of mechanization. In contrast, small-scale farmers in Japan tend to be more conservative, relying on traditional methods despite the availability of modern technologies.

Finally, the impact of the COVID-19 pandemic and other geopolitical events must be acknowledged in the context of innovation adoption. The pandemic acted as a catalyst for digitalization—remote technologies such as sensors and drones gained renewed momentum as in-person labour availability on farms was restricted. Farmers with the capacity to manage operations remotely had a clear advantage during lockdowns. At the same time, disruptions in logistics during 2020–2021 accelerated the development of local supply chains and direct online sales, with farmers increasingly using social media to market their products.

In terms of the war in Ukraine, preliminary observations indicate a dual effect: on the one hand, the agricultural sector has suffered enormous losses; on the other hand, it has triggered a more rapid adoption of innovations as part of the recovery process. For example, drones have proven valuable not only for agro-monitoring but also for humanitarian demining and regaining access to occupied farmland. This is a distinct area that warrants further study, but it already illustrates how extraordinary circumstances can stimulate unconventional and adaptive innovation strategies.

Thus, on a global scale, the application of innovative management tools in agriculture is shaped by a complex interplay of economic, social, and political factors. Leading agricultural nations maintain their edge through continuous technological upgrading, while others strive to catch up—often by leapfrogging several stages of development. The uneven pace of adoption generates new challenges, particularly the risk of widening productivity gaps between different groups of countries and producers.

DISCUSSION

The findings of this study offer a comprehensive understanding of how innovative management tools influence the agricultural sector and highlight how our research differs from prior work. Overall, the observed trends support the conclusions of numerous authors regarding the positive effects of innovation: increased productivity, more efficient resource use, and improved resilience to risks. At the same time, our analysis revealed several new aspects and interrelationships that have not been previously addressed in an integrated manner.

The scientific novelty and distinction of this study lie in its holistic approach. Most previous research has focused on individual components of innovation—detailing the trends associated with Agriculture 4.0, for example—while largely neglecting financial and organizational innovations. Conversely, prior studies have explored the profitability of precision agriculture but paid little attention to issues such as social acceptability or managerial transformation. This study offers a synthetic analysis that simultaneously covers technological, financial, and organizational instruments, thereby providing a complete picture of their interactions. This integrated approach distinguishes our work from the more fragmented academic discourse that currently prevails. In particular, the comparative analysis of different types of innovations conducted in this study shows that their effectiveness is maximized when applied in combination—an insight demonstrated through concrete examples. This comprehensive perspective has been largely absent in earlier studies, where technological dimensions are often examined in isolation from organizational ones. Regarding the technological dimension, our findings align with broader global trends reported in the literature, but they are updated for 2023–2024. The study confirms classical theoretical expectations—such as the S-shaped innovation diffusion curve—and contextualizes them using current empirical data.

A further contribution lies in the identification and systematic assessment of multiple barriers to innovation adoption in agriculture, many of which had previously been mentioned but not thoroughly analyzed. Therefore, the core novelty of this work lies in its integrated assessment of innovation, which enabled the identification of several patterns and practical dependencies that are not evident when innovations are studied in isolation. One of the key findings is that financial innovations act as catalysts for technological ones: regions with well-developed agri-financial institutions (insurance, credit access) tend to adopt agricultural technologies more rapidly because farmers are more capable and less risk-averse when investing. This conclusion, derived from data comparisons, contributes to the broader discussion on the complexity of agricultural transformation. Our findings, discussed in light of existing research, confirm the relevance and timeliness of the topic. The world stands on the threshold of a new wave of agricultural innovations—robotics, artificial intelligence, biotechnology—and understanding how to prepare the agricultural sector for their adoption is critical. This study essentially suggests that in order for the next wave (tentatively termed Agriculture 5.0) to realize its full potential, the barriers we have identified must be addressed now—by improving access to finance and knowledge and encouraging cooperation. Accordingly, this research expands theoretical understanding while also offering practical value: its results can inform the development of agricultural policy and sectoral strategies.

CONCLUSIONS

Innovative management tools play a pivotal role in the modern agricultural sector, acting as catalysts for improving efficiency, productivity, and the sustainability of agricultural production. The conducted research allows for several generalizations and conclusions regarding the specifics of their application. Digital technologies (precision agriculture, sensors, big data, drones, robotics) have proven their effectiveness. Farms that have adopted these technologies report measurable benefits in resource savings and increased yields. On average, consistent use of the full suite of PA technologies boosts yields by approximately 4–6% and reduces input use by 5–10%. However, the effect is strongly scale-dependent: the economic return is highest for large enterprises, while smaller farms often struggle to recoup their investments. To maximize the effectiveness of digital innovations, personnel training and adaptation to local farm conditions are essential.

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Importantly, precision agriculture enhances not only profitability but also environmental sustainability—reducing chemical loads on soils and promoting efficient water use, thus aligning with the goals of sustainable development.

Financial innovations (new forms of credit, insurance, fintech services) significantly expand opportunities for agricultural producers. Index-based crop insurance protects against weather-related risks with minimal transaction costs, while agricultural receipts and targeted credit programs improve farmers' access to capital during planting seasons. Digital payment systems and platforms simplify marketing and transactions, integrating farmers into modern markets. Our study emphasizes that financial mechanisms serve a dual function: they directly reduce risks and costs (via payouts or affordable credit) and indirectly stimulate technological innovation, as financial security encourages farmers to invest in new equipment. Therefore, the development of agro-financial infrastructure is a prerequisite for breakthrough innovation in the sector.

Organizational and managerial innovations create an enabling environment for the effective deployment of technological and financial tools. Cooperation and clusters help small and medium-sized producers overcome innovation barriers by pooling resources and sharing knowledge. Networked structures and partnerships with research institutions accelerate knowledge transfer and local adaptation of innovations. The implementation of modern management systems (ERP, quality standards) enhances internal efficiency and readiness for integration into global value chains. Overall, successful cases—such as Dutch agricultural clusters or Danish cooperatives—demonstrate that "soft innovations" in management and organizational models can significantly amplify the impact of "hard" technological innovations. Thus, agricultural sector modernization must include institutional development alongside technological advancement.

Uneven innovation adoption presents a major challenge. The gap between large and small producers in accessing advanced management tools remains substantial. Without targeted interventions, this gap may widen, exacerbating inequality in agriculture and weakening the competitiveness of smallholders. Similarly, at the global level, lagging countries face risks to food security and economic stability. This highlights the need for inclusive innovation policies: subsidizing technology purchases for smallholders, expanding training programs, promoting best practices, and supporting service companies that deliver innovative solutions to small producers (e.g., drone services on demand). Such measures can help reduce disparities and ensure that the benefits of agricultural innovation reach a broad range of farmers—not just large agri-holdings.

In Ukraine and other transition economies, innovation adoption is fragmented: large progressive enterprises actively adopt cutting-edge tools (some already use AI and have digitized land banks), while many small farmers and household producers rely on outdated practices. This calls for an adapted agricultural policy—focusing not only on traditional instruments (subsidies, price controls) but also on innovation promotion. Positive examples include Ukraine's agricultural receipts program and the development of advisory services, but further initiatives are needed: establishing demonstration "farm schools," investing in rural digital infrastructure, and integrating national agricultural research institutions into international innovation networks. For developing countries, it is critical to adopt successful models tailored to local realities—using cost-effective alternatives (e.g., sensors instead of lab services) and leapfrogging development stages via mobile services that require less capital investment.

Based on our analysis, we recommend a comprehensive approach to innovation adoption: technical, financial, and educational–organizational measures must be implemented in parallel. Governments should design support programs for smart farming—e.g., subsidizing the cost of precision technologies, offering index insurance premium support, and creating enabling conditions for agri-startups. Farmer cooperation for shared innovation use should be encouraged through tax incentives or grant schemes for cooperatives adopting new technologies. Educational institutions must play a more active role by modernizing agricultural curricula to emphasize IT and business skills, and by expanding non-formal education (training programs, online courses) for farmers and managers. International organizations should direct technical assistance toward knowledge and technology transfer in lagging regions to avoid a global digital divide.

In conclusion, the agricultural sector is undergoing rapid transformation. Innovative management tools are already reshaping the face of agriculture—making it more knowledge-intensive, high-performing, and integrated into the digital economy. This study has confirmed the vast potential of these changes. At the same time, the realization of this potential depends on addressing key bottlenecks—financial, educational, and infrastructural. Coordinated efforts by government, businesses, and the scientific community to support innovation can ensure accelerated growth of the agricultural sector and its contribution to sustainable development. Implementing innovative management tools in agriculture is an investment in the future of food security, economic growth, and rural prosperity—an investment that will yield substantial returns.

ADDITIONAL INFORMATION

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CONFLICT OF INTEREST

The Author declares that there is no conflict of interest.

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Кондрат О.

ОСОБЛИВОСТІ ЗАСТОСУВАННЯ ІННОВАЦІЙНИХ ІНСТРУМЕНТІВ В УПРАВЛІННІ ПІДПРИЄМСТВАМИ АГРАРНОГО СЕКТОРА ЕКОНОМІКИ

Аграрний сектор потребує впровадження інноваційних підходів до управління для забезпечення конкурентоспроможності та сталого розвитку в умовах зростання світового попиту на продовольство, обмеженості ресурсів і змін клімату. У цій статті проаналізовано специфіку застосування інноваційних управлінських інструментів у сільському господарстві з акцентом на три основні категорії: цифрові технології (зокрема системи точного землеробства та інші рішення AgriTech), фінансові інструменти (зокрема індексне страхування врожаю та фінтех-рішення), а також організаційні інновації (такі як кластеризація та сучасні кооперативи). Основна мета полягає у визначенні особливостей упровадження цих інновацій та оцінці їхнього впливу на ефективність і стійкість аграрного виробництва.

Дослідження ґрунтується на змішаному методологічному підході, що поєднує ґрунтовний огляд наукової літератури з аналізом вторинних статистичних даних. Зокрема проаналізовано інформацію міжнародних організацій (зокрема FAO, Світового банку, USDA) з метою оцінки сучасних тенденцій у царині впровадження інновацій. Результати засвідчують, що інновації суттєво підвищують продуктивність аграрного сектора та ефективність використання ресурсів. Наприклад, використання технологій точного землеробства може збільшити врожайність на 4–6% і зменшити обсяги використання води, пального й агрохімікатів, водночас знижуючи витрати й зменшуючи екологічне навантаження. Так само сучасні фінансові інструменти й організаційні стратегії (зокрема індексне страхування та фермерська кооперація) підвищують стійкість виробників до кліматичних і ринкових ризиків.

Водночас упровадження інновацій залишається нерівномірним: великі високотехнологічні господарства значно швидше впроваджують нові інструменти, а малі фермерські господарства часто відстають через обмеженість капіталу, нестачу відповідних знань і навичок, а також слабку інфраструктуру — що спричиняє посилення «інноваційного розриву» в галузі.

Це дослідження пропонує новий інтегрований погляд на інновації, здійснюючи системне порівняння технологічних, фінансових і управлінських нововведень у сільському господарстві — і в глобальному контексті, і на прикладі України. Воно узагальнює раніше фрагментарні знання, виявляє взаємозв’язки між технологічними й організаційними факторами, які не були належно враховані в попередніх дослідженнях, і окреслює, чим отримані результати відрізняються від раніше опублікованих.

Насамкінець стаття пропонує низку рекомендацій для прискорення цифрової трансформації та інноваційного розвитку аграрного сектора.

Ключові слова: інноваційні інструменти управління; аграрний сектор; точне землеробство; цифрові технології в сільському господарстві; впровадження інновацій; стале сільське господарство; агробізнес-менеджмент

JEL Класифікація: Q16, O33, Q12