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Smart farming models in urbanised regions: Prospects for economic efficiency and sustainability

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▶ **Abstract.** The aim of this study was to assess the economic efficiency and sustainability of implementing smart technologies in agriculture within urbanised regions, specifically using the case of the agro-industrial holding "Myronivsky Hliboproduct" (MHP). The methodology incorporated both quantitative and qualitative analytical methods. An empirical analysis of the yield of key crops was conducted. To evaluate the economic efficiency of the implemented technologies, a graph of the company's income dynamics was constructed, enabling an assessment of the impact of smart technologies on the enterprise's financial performance. The key findings indicate that the adoption of smart technologies at MHP contributed to a significant increase in crop yields and a reduction in resource costs. For instance, maize yields rose from 8.6 t/ha in 2016/2017 to 10 t/ha in 2021/2022, remaining stable at 9.9 t/ha in 2023/2024. A similar trend was observed in other crops: rapeseed yields increased from 3.7 t/ha to 4.2 t/ha, while soybean yields grew from 2.4 t/ha to 2.8 t/ha. These results are attributed to the application of advanced techniques, including Real-Time Kinematic (RTK) navigation, automated management systems, and variable-rate fertilisation. An analysis of economic indicators revealed steady growth in the company's revenue even under challenging economic conditions. The graph demonstrated that MHP's income increased significantly during the period of active smart technology adoption. In 2024, the company's revenue reached USD 770 million, confirming

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the economic efficiency of the implemented solutions. Furthermore, the use of digital platforms for field monitoring and process management optimised machinery maintenance costs and yield forecasting. The conclusions confirm that smart farming is an effective tool for modernising agriculture in urbanised regions. The practical significance of the study lies in demonstrating the efficiency of smart farming adoption for enhancing agricultural productivity. The results indicate the potential for substantial yield increases and resource cost reductions through the use of innovative technologies such as precision farming, digital platforms, and automation

▸ **Keywords:** innovative technologies; precision farming; digital platforms; process automation; yield dynamics

▸ Introduction

Urbanised regions face numerous challenges, including limited resources, high population density, and the need to ensure food security amid environmental instability. In this context, smart farming represents an innovative approach to agricultural production, integrating digital technologies, sustainable development strategies, and process automation. Such models enhance the productivity of agricultural systems, reduce ecological pressure, and optimise the use of constrained resources. Ukraine holds significant potential for the adoption of smart farming models, particularly in urbanised regions where industrialisation and urbanisation often limit access to land and natural resources. At the same time, innovative approaches to agricultural production are necessary due to global trends such as climate change, urbanisation, the need to reduce greenhouse gas emissions, and the adaptation to modern environmental responsibility requirements.

The agricultural sector in Ukraine faces challenges in adopting precision farming due to industry conservatism and farmers' limited awareness. O. Hrynevych *et al.* (2022) examined the impact of precision farming on the economics and efficiency of agricultural enterprises in Ukraine. Their study demonstrated that precision farming technologies can reduce costs, increase yields, and enhance resilience to environmental changes. However, the low adoption rate of these technologies is linked to limited resources and insufficient farmer awareness. Innovative methods play a crucial role in the development of smart technologies in Ukraine's agricultural sector, improving efficiency and competitiveness. A. Hutorov *et al.* (2021) explored the development of smart specialisation in Ukraine's agrarian sector, emphasising the importance of supporting rural entrepreneurship and establishing new technological platforms. They also highlighted the need for investment and infrastructure improvements to implement these strategies. The use of digital technologies in agriculture, including precision farming, process automation, and drone and satellite monitoring, was examined by O. Khaietska & I. Babiy (2024). They noted that the main barriers to adopting these innovations are high technology costs and inadequate infrastructure.

Agriculture faces challenges in implementing innovative technologies for sustainable development (Bekpayeva *et al.*, 2025). M. Gemtou *et al.* (2024) explored the use of smart technologies such as precision farming, water resource management, and energy efficiency. Their findings demonstrate the significant potential of these technologies to enhance productivity, optimise resource use, and reduce environmental impact. However, the authors highlight adoption barriers, including limited farmer awareness, insufficient funding, and lack of policy support. The digitalisation of agriculture in Ukraine is crucial for improving managerial efficiency. A. Tarasiuk & V. Hamalii (2021) emphasised the role of intelligent systems and machine learning technologies in enhancing agribusiness management but noted the absence of a comprehensive digital strategy.

E. Koutridi & O. Christopoulou (2023) investigated digital technologies in agribusinesses, analysing the implementation of Industry 4.0 technologies such as drones, the Internet of Things (IoT), and sensors. They found that these technologies hold great potential for increasing productivity, economic efficiency, and local adaptability. The growing urban population and associated food security challenges necessitate efficient resource use in urban agroecosystems. A.-S. Christmann *et al.* (2025) examined digital opportunities in smart urban agriculture, proposing a multi-level taxonomy encompassing digital technologies, data, and urban farming approaches. They also identified 20 organisational readiness factors for successful implementation. Their study demonstrated that integrating smart technologies can enhance economic, environmental, and social sustainability in urban agriculture. Climate instability and rapid urbanisation pose significant challenges to sustainable agricultural development in Africa. A.-L. Balogun *et al.* (2022) explored the potential of digitalisation for climate adaptation and sustainable agriculture, identifying opportunities for digital technologies to improve productivity, optimise resource use, and enhance farm management practices. However, the study also revealed infrastructure deficiencies, limited access to digital tools, and low digital literacy among farmers.

Overall, insufficient research has been conducted on the economic efficiency of precision farming, the influence of social factors on decision-making, and the adaptation of digital technologies to diverse agricultural policies and urban ecosystems. Further studies are required to assess their impact on regional economic stability and productivity enhancement under Ukrainian conditions. The objective of this study was to develop practical recommendations for the implementation of smart farming models in urbanised regions, aimed at enhancing economic efficiency and ensuring the sustainable development of agricultural production. The research tasks included analysing contemporary approaches to smart farming adoption in urbanised regions, considering resource availability and technological capabilities; and assessing the impact of smart technologies on economic performance and environmental sustainability in agricultural production within urbanised regions.

▸ Materials and methods

The study's timeframe spans from 2016 to 2024, enabling an analysis of dynamic changes and an evaluation of technology implementation effectiveness in the long term. Scientific sources dedicated to agricultural innovations, particularly precision farming, IoT, process automation, and digital platforms (Kumar *et al.*, 2024; Rane *et al.*, 2024; Sekhar *et al.*, 2024), were analysed. These sources facilitated a systematic approach to understanding the role of smart farming in improving productivity, reducing environmental impact, and ensuring sectoral resilience. The research focused on the agro-industrial holding "Myronivsky Hliboproduct" (MHP) due to its leadership in adopting modern precision farming technologies, process automation, and digitalisation. Empirical data included yield metrics for key crops (maize, wheat, sunflower, rapeseed, soybean), allowing an assessment of productivity dynamics relative to applied technologies. Data were sourced from publicly available reports detailing innovations, financial results, and production costs (Giua *et al.*, 2022). For economic evaluation, MHP's income statements (2016-2024) were used to construct a graph illustrating revenue trends alongside smart technology adoption (Naruzhna, 2023). External studies on Ukraine's agricultural sector, including smart technology adoption and market conditions, provided context for MHP's national and international positioning (Share UA Potential, 2018).

The methodology employed a mixed-methods approach, combining quantitative and qualitative analyses to evaluate smart technologies' impact on agricultural productivity and economic efficiency. This approach enabled a detailed examination of key innovation aspects, including yield fluctuations, financial outcomes, and enterprise stability. Primary methods included empirical analysis, featuring statistical evaluation of crop yield dynamics (2016-2024), to determine how precision farming, automation, and digital platforms influenced productivity. Longitudinal yield data were correlated with technology adoption timelines. Economic efficiency was assessed via financial analysis, with income trends visualised graphically. This highlighted revenue growth patterns, particularly during intensive innovation phases (e.g., Real-Time Kinematic (RTK) navigation, precision fertilisation, automated management systems). A systems approach ensured holistic understanding, integrating precision farming (resource optimisation), automation, and digital platforms (real-time monitoring/management). This method elucidated interconnections between innovation components, including resource efficiency and productivity gains.

▸ Results

Theoretical and practical foundations of smart farming. Precision farming, or smart agriculture, is a modern agricultural approach leveraging innovative technologies to enhance productivity, profitability, and environmental sustainability. It integrates digital technologies, automation, sensor systems, big data analytics, artificial intelligence (AI), and IoT, optimising all production stages – from soil preparation to harvest – through precise process management. Smart farming employs a field-specific approach, accounting for natural variations via remote sensing (satellite/aerial imagery, GIS) to monitor soil nutrients, moisture, temperature, and health. This reduces input costs, minimises fertiliser/water/pesticide use, and mitigates environmental harm. Sensor technologies are pivotal, enabling real-time plant/soil monitoring for rapid response. Robotics and automation are equally critical: modern tractors, drones, harvesters, and sprayers rely on pre-programmed algorithms for task precision (Kumar *et al.*, 2024). For instance, MHP extensively deploys drones for large-scale fertilisation and crop monitoring, significantly reducing labour/time costs. Its precision sprayers, coupled with drone surveillance, enable accurate problem detection and swift corrective measures. This approach enhances efficiency while reducing chemical usage, promoting ecological farming practices (MHP uses the…, 2018).

Machine learning and AI are also key components of smart farming. They are used to analyse large volumes of data, predict crop yields, and detect pests and plant diseases. For instance, AI-based platforms such as Climate FieldView can identify anomalies in plant development, such as nutrient deficiencies or early signs of disease. This enables farmers to implement precise measures in a timely manner, such as targeted fertiliser application or pesticide use only in specific areas of the field where needed. This reduces losses from uncontrolled pest or disease outbreaks while minimising treatment costs, thereby enhancing production efficiency. All components of smart farming can interact via the IoT, creating an integrated system. IoT devices such as drones, cameras, sensors, and automated systems facilitate data exchange, enabling automated decision-making. For example, an automated irrigation system initiates watering as soon as sensors detect insufficient soil moisture levels. The use of software and analytical platforms is a critical aspect of smart farming. These tools allow farmers to generate forecasts and analytics while managing all production processes from a single device. For instance, cloud-based platforms such as John Deere Operations Center or Climate FieldView enable the processing and storage of large datasets on crop yields, soil conditions, and meteorological data. This simplifies decision-making regarding resource optimisation, irrigation system adjustments, or fertiliser application, ultimately improving agricultural efficiency (Rane *et al.*, 2024).

At the same time, smart farming considers economic and social dimensions. The creation of new jobs in technology, improved education levels, and upskilling farmers all contribute to local community development (Borko & Jammal, 2024). Innovations also enhance food security by reducing reliance on imports. Although smart farming holds significant potential for sustainable agricultural development, its implementation faces several challenges. These include low technical literacy among farmers, high equipment costs, and limited infrastructure access in certain regions. Advances in technology, along with support from governments and international organisations such as the Food and Agriculture Organization of the United Nations, the World Bank, and the International Fund for Agricultural Development, create new opportunities for wider adoption of smart farming despite these barriers. Thus, smart farming is a multi-component system that leverages modern technologies to enhance productivity, efficiency, and sustainability in agricultural production. When implemented, it generates new opportunities for the agricultural sector while promoting efficient resource use and supporting ecological balance.

Modern agricultural production is based on innovative cultivation methods such as precision farming, vertical farming, and AI applications. These technologies not only address the challenges of rising food demand but also promote efficient resource use, environmental sustainability, and increased profitability. Their integration into agricultural practice creates new production models that respond to contemporary challenges such as rapid urbanisation, limited land resources, and climate change. Precision farming is one of the most effective approaches, employing modern technologies to analyse and manage agricultural processes. The goal of precision farming is to use geographic information systems (GIS), satellite monitoring, and sensor technologies to study the natural conditions of each field plot in detail. This method optimises water, fertiliser, and other resource use while reducing costs and minimising environmental impact. For example, soil moisture sensors help determine the exact water requirements of crops, preventing over-irrigation, which often leads to water waste and soil erosion. The use of drones for field monitoring is another key aspect of precision farming. Drones can quickly identify problem areas, such as nutrient-deficient zones or pest infestations. They are particularly valuable for precision farming as they provide farmers with real-time data for decision-making. Moreover, drones are used to apply plant protection agents and fertilisers, significantly reducing labour time and costs (Sekhar *et al.*, 2024).

Vertical farming is another innovative approach that enables crop cultivation in urban environments. Vertical farms require less land, energy, and water, making them economically viable for urban entrepreneurs by optimising limited space and reducing resource expenditures, particularly water and energy, thereby lowering production costs. The core of this technology involves growing plants on multiple levels within climate-controlled facilities. Hydroponics, aeroponics, and other advanced techniques in vertical farming eliminate the need for pesticides and drastically reduce water and fertiliser consumption. For example, hydroponics reduces water usage by 90% compared to traditional farming – a critical advantage in water-scarce regions (Yarmolenko, 2023).

The ability to maintain stable production regardless of climatic conditions is a major advantage of vertical farming. Controlled environments maintain ideal temperature, humidity, and lighting to maximise plant growth. For instance, hydroponics, aeroponics, and spectrally tuned LED lighting enable precise control over growing conditions, ensuring optimal yields irrespective of external climate variability. This is particularly important as climate change disrupts traditional crop productivity. Vertical farming, which allows vegetables and greens to be grown directly in urban areas, has become a vital component of food security in highly urbanised countries such as Singapore.

The CropX system, which analyses real-time sensor data and provides irrigation and soil management recommendations, is a prime example of AI applications in agriculture. It offers customised irrigation advice, saving up to 50% of water while ensuring optimal moisture levels for crops and improving resource efficiency, thereby enhancing agricultural profitability. Farmers using this technology have achieved a 10% increase in yields and a 25% reduction in water consumption. AI is also used to analyse drone or satellite imagery, enabling rapid detection of issues such as pest infestations or nutrient deficiencies (Aggeek, 2021).

It is important to note that these innovative methods are often integrated with broader systems, such as farm management software, drone-based monitoring platforms, or data analytics tools, unlocking new opportunities for production optimisation. For example, integrating data from multiple sources (sensors, drones, GPS technologies) automates irrigation, fertilisation, and crop rotation planning, boosting productivity and reducing costs. Additionally, vertical farms can be equipped with AI-driven sensors and automated irrigation systems, creating fully autonomous farms with higher efficiency and minimal human intervention. In agriculture, successful implementation of innovative approaches depends not only on technology but also on workforce training, access to financing, and government support. Sustainable development of the agricultural sector requires farmer education in modern technologies, creating enabling conditions for adoption, and incentivising investments (Shahini *et al.*, 2023). Thus, the key innovative directions in agricultural production are precision farming, vertical farming, and AI integration. These approaches optimise resource use, increase yields, and mitigate environmental harm.

Population growth and limited land resources necessitate new methods of agricultural production, making smart farming increasingly popular in urban areas. This concept involves integrating new technologies into urban environments to ensure food security, optimise resource use, and reduce environmental impact. Smart farming creates new opportunities for the sustainable development of the agricultural sector in conditions where traditional farming methods face numerous challenges, such as land degradation, climate change, and rapid urbanisation (Makhazhanova *et al.*, 2024). By employing technologies such as precision irrigation, plant health monitoring systems, and data analytics for yield prediction, smart farming reduces water waste, prevents excessive use of chemical fertilisers and pesticides, and maximises the efficiency of limited land resources (Tanchyk *et al.*, 2024). This contributes to preserving soil fertility, mitigating negative impacts on ecosystems, adapting agriculture to climate change, and ensuring sustainable production in urbanised settings.

Urban areas typically have limited access to agricultural land, necessitating solutions that maximise the use of available space. For example, indoor farming projects are actively developing in Kyiv, such as Smart Oasis Farm, which collaborates with the National University of Life and Environmental Sciences of Ukraine to research vertical farming (Smart Oasis Farm…, 2020). In Mykolaiv, farmer Maksym Netudykhata created a unique "smart greenhouse" that autonomously controls irrigation, lighting, and heating, demonstrating the practical implementation of smart technologies in agriculture (Agronews, 2025). In such contexts, smart farming involves vertical farming, enabling crop cultivation on multi-tiered structures. This significantly increases productivity per square metre while reducing the use of resources such as water and fertilisers.

Automation and digital technologies are key components of smart farming in urban environments. Solutions like CropX and Climate FieldView, developed using sensors and AI, enable real-time monitoring of all critical cultivation parameters. This includes tracking humidity, lighting, temperature, and CO_2 concentration, ensuring optimal plant growth conditions. For instance, AI-integrated automated irrigation systems conserve water by tailoring irrigation to plant needs. Such systems can save up to 50% of water through precise control and optimised scheduling. The use of these technologies can increase yields by 20-30% (8 best applications…, 2024), as plants receive the required amount of water at the optimal time, promoting stable growth and development (Van Gerrewey *et al.*, 2021).

Social aspects of smart farming are also important. These technologies create new employment opportunities, particularly in the development, maintenance, and implementation of digital solutions. Additionally, smart farming fosters educational initiatives, such as the Go2Agro project, which offers a "Farming from Scratch" course for veterans. Such programmes upskill workers, equipping them with the knowledge to launch agricultural businesses, which is crucial for enhancing the competitiveness of urban agro-systems (Basanets, 2024). This approach can make urban communities more self-sufficient in food supply, reducing dependence on foreign providers. Smart farming offers significant environmental benefits. It is more sustainable than traditional farming methods, such as intensive tillage, excessive use of chemical fertilisers and pesticides, and inefficient irrigation systems, as it reduces greenhouse gas emissions, conserves water, and minimises pesticide use (Oliynyk *et al.*, 2021). For example, urban vertical farms improve air quality and create green spaces, enhancing the urban microclimate (Share UA Potential, 2024). At its core, smart farming aligns with contemporary demands by providing an innovative agricultural approach tailored to urban regions. Its implementation promotes sustainable development, efficient resource use, increased productivity, and improved urban living conditions.

Economic efficiency of smart technologies. The agro-industrial holding MHP is one of Ukraine's leading agricultural enterprises, excelling in both innovative technology adoption and sustainable industry development (Ukrinform, 2018). The company not only employs modern production methods but also serves as a benchmark for the sector's progress in the country. MHP began implementing precision farming elements as early as 2012-2013, when this technology was just gaining traction in Ukraine. Since then, the company has consistently integrated cutting-edge solutions into agricultural production, prioritising efficiency and operational quality. Automated and parallel steering systems significantly reduced resource consumption, including fuel, fertilisers, seeds, and plant protection products, lowering production costs. Thanks to RTK navigation technology and high-precision positioning (with deviations of no more than 2.5 cm), substantial resource savings were achieved across large areas, optimising enterprise-wide processes.

The company rigorously tests new technologies under real-world conditions, including automated and parallel steering systems, precision farming (e.g., soil and weather monitoring sensors), advanced irrigation technologies, and analytical platforms for agricultural management. Testing involves field trials, comparative analysis across different plots, and monitoring changes in yield and resource expenditure. All technical solutions undergo stringent evaluation before large-scale implementation, ensuring efficacy and compatibility with Ukrainian agricultural practices. Additionally, MHP has developed digital field maps, a critical step for precise monitoring and analysis. Yield maps generated by automated systems enable accurate productivity assessments for each field, facilitating adjustments to production processes. Combined with regular soil agrochemical studies, this allows for optimised field management strategies. Since 2016, the company has developed its Digital AgroTech platform, serving as a mobile office for agronomists. It enables work planning, resource inventory management, field monitoring, and yield history analysis. In 2022, MHP also began implementing the Digital Agro 360 farm management system, integrating digital solutions for agricultural production management (Naruzhna, 2023).

Since 2017, MHP has significantly expanded the use of precision farming technologies, including the installation of automated steering systems and RTK navigation on tractors, the implementation of soil moisture and temperature sensors, and the increased deployment of drones for field imaging and crop condition analysis. This has enabled the company to cover over half a million hectares of land, substantially improving soil tillage accuracy and the optimisation of resources such as water and fertilisers. The company actively implemented a differential liquid fertiliser application system and equipped cultivators with control systems for applying aqueous ammonia as the primary nitrogen fertiliser. This has reduced fertiliser costs and increased application efficiency. Furthermore, MHP introduced variable-rate seeding technology and employed specialised fertiliser spreaders operating based on task maps for more precise and rational application of mineral and organic fertilisers. In 2018-2019, MHP expanded the use of weather monitoring and analysis systems, such as the AgLeader and WeatherSpy platforms, which became integral to field operations planning. In the context of climate change, these solutions enable agronomists to make more accurate decisions regarding sowing and crop management. Additionally, the company began actively testing drones for field monitoring, desiccation, and precision application of plant protection products. From 2022 onwards, MHP started utilising state-of-the-art equipment incorporating automation technologies for all key processes – from soil cultivation to harvesting. For instance, the company employs John Deere AMS functionality to automate technological processes. Technologies such as Augmenta for variable-rate fertiliser application ensure maximum precision and resource efficiency. During 2023-2024, MHP invested in modern machinery equipped with precision farming features. For example, precision seeders with Precision Planting elements not only ensure uniform sowing but also simultaneously apply liquid fertilisers based on task maps. This approach avoids overseeding and significantly enhances efficiency (MHP uses the…, 2018). To assess the impact of precision farming technologies in the MHP agro-industrial holding, an analysis of the yield of key agricultural crops was conducted for the period from 2016 to 2024, when the active implementation of smart technologies began (Table 1). This analysis tracks productivity trends for crops such as maize, wheat, sunflower, rapeseed, and soybeans, demonstrating how innovative approaches contribute to yield improvement.

Table 1. Yield dynamics of key crops at MHP (2016-2024)

Season	Maize (t/ha)	Wheat (t/ha)	Sunflower (t/ha)	Rapeseed (t/ha)	Soybeans (t/ha)
2016/2017	8.6	6.5	3.2	3.4	2.4
2017/2018	7.3	6	3	3.3	2.1
2018/2019	6.8	5.9	3.1	3.4	1.6
2019/2020	9.4	6.4	3.6	3	2.7
2020/2021	5.6	5.1	2.8	2.6	2.3
2021/2022	10	5.9	3.2	3.3	2.5
2022/2023	7.2	5.5	2.5	3.8	2.4
2023/2024	9.9	6.6	3.1	3.7	3.2

Source: developed by the authors based on MHP (n.d.), Share UA Potential (2018), MHP uses the latest technology to spray its fields and controls the process with drones (2018)

The data from Table 1 indicate a significant impact of precision farming technologies on the productivity of agricultural crops at MHP between 2016 and 2024. The most evident positive changes are observed in maize yields, which peaked at 10 t/ha in the 2021/2022 season and remained consistently high in 2023/2024 (9.9 t/ha). This is attributed to the use of differential seeding, variable fertiliser application, and other advanced practices. Rapeseed also demonstrates steady productivity growth, reaching 3.7 t/ha in 2023/2024, confirming the effectiveness of precision seeding and timely fertilisation. Similar positive trends are observed in soybeans, which showed a gradual yield increase to 3.2 t/ha. This was made possible through innovations such as split fertiliser application, precision seeders with Precision Planting elements, and continuous soil monitoring. However, attention should be paid to the negative trends in the 2020/2021 season, when yields of all crops declined significantly due to extreme climatic conditions, including prolonged droughts, unexpected spring frosts, and abrupt temperature fluctuations during vegetation periods, which caused plant stress and reduced yield formation capacity. This underscores the need for additional investments in technologies that can adapt agricultural production to climate change.

A comparison between 2016 and 2024 demonstrates that the adoption of smart technologies has enabled MHP not only to maintain but also to significantly enhance the productivity of most crops, even under challenging conditions. This also proves that an integrated approach – combining modern machinery, digitalisation, and staff training – is key to improving agricultural efficiency. Thus, MHP serves as a successful example of innovation implementation in the agro-sector, ensuring economic resilience and competitiveness even in an unstable environment. The economic efficiency of innovative technologies in agriculture is determined not only by yield growth but also by financial indicators reflecting profitability, return on investment, and enterprise stability. For MHP, a leader in smart technology adoption, it is crucial to assess how these innovations have influenced its financial performance. To evaluate MHP's financial stability between 2016 and 2024, a graph of the company's revenue dynamics was constructed (Fig. 1).

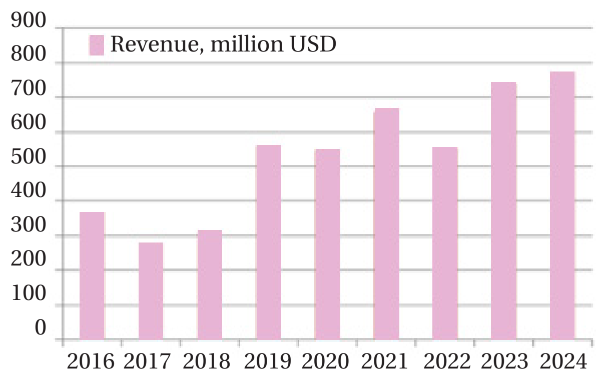

Figure 1. MHP's total revenue from 2016 to 2024
Source: MHP (n.d.)

The analysis of MHP's revenue dynamics indicates a positive impact of smart technologies on the company's financial efficiency. In 2016-2017, a slight revenue decline was observed, likely due to initial investments in new technologies. However, by 2018, revenues began to rise, and in 2019, a significant breakthrough was achieved – USD 560 million – reflecting the success of the implemented innovations. The highest results were recorded in 2023-2024, with revenues reaching USD 739 million and USD 770 million, respectively. These figures demonstrate that investments in precision farming, digital platforms, and modern equipment have paid off, enhancing competitiveness and financial stability. Thus, MHP exemplifies the successful integration of innovations to improve the economic efficiency of agribusiness. The MHP agro-industrial holding has demonstrated significant achievements in adopting smart technologies, which have improved crop productivity and the company's economic efficiency. The use of precision farming technologies – such as RTK navigation, automated control systems, and soil monitoring sensors – has led to substantial reductions in resource costs (fuel, fertilisers, seeds, and plant protection products). Innovative methods, including differential fertilisation and precision seeding, have significantly increased resource efficiency, contributing to higher yields and lower production costs.

The analysis of yield dynamics from 2016 to 2024 confirms the positive impact of smart technologies on the productivity of key crops. Despite adverse factors, such as extreme weather in 2020/2021, MHP maintained and even improved yields through technological innovations and adaptation to changing conditions. The most notable increases were observed in maize, rapeseed, and soybeans, directly resulting from advanced agricultural technologies. Financial results also demonstrate that investments in precision farming and digital platforms have been profitable, ensuring revenue growth and financial stability. Rising revenues attest to the effectiveness of innovation adoption. For further development, MHP should continue investing in new technologies to adapt to climate change, such as automated irrigation systems, weather analysis tools, and expanded drone use for field monitoring. Additional digital platforms should be implemented for more efficient agri-management and integration with international systems to enhance competitiveness in foreign markets. To maximise the effectiveness of cutting-edge technologies, ongoing staff training and upskilling are essential to fully leverage the potential of smart farming.

▸ Discussion

The development of smart farming and its implementation in urbanised regions is a relevant topic in contemporary research. An analysis of scholarly work allows for a comparison of different authors' approaches to addressing efficiency, sustainability, and socio-economic impacts of innovative agricultural technologies. I. Richter *et al.* (2023) examined socio-economic barriers in African countries, such as Nigeria and South Africa, particularly the inaccessibility of technologies and adaptation challenges. Their study focuses on social aspects and technology localisation. In contrast, this research emphasises economic efficiency and environmental sustainability in urbanised regions of Ukraine, including technology integration in urban settings. P.-A. Langendahl (2021) analysed smart farming development in Sweden, highlighting socio-political aspects and ecological balance, stressing the importance of models such as "production as a service". The difference lies in that P.-A. Langendahl's work focuses on social and technopolitical dimensions, while this study prioritises economic and production aspects, such as resource efficiency and productivity gains.

G.N. Yuan *et al.* (2022) focused on a global overview of urban agriculture, particularly vertical farming, hydroponics, and aeroponics, addressing food security and ecological challenges. This study concentrates on technology adaptation in Ukraine, specifically economic efficiency and local conditions. Both studies highlight innovations, but G.N. Yuan *et al.* emphasise global aspects and policy barriers, while this research examines local implementations and financial support. S. Oh & C. Lu (2023) underscored technical aspects of vertical farming, such as hydroponics and IoT, and their benefits for food security. Their focus is on developed countries, whereas this study explores technology adaptation in Ukraine, including farmer training and local conditions.

A. Moghayedi *et al.* (2022) focus on the socio-economic aspects of smart farming, particularly the adoption of technologies in African countries. Their study places greater emphasis on the economic efficiency of smart farming in urban settings. R. Sasmitha *et al.* (2020) examine urban farming as a tool for sustainable development, specifically vertical farms and resource reuse. They devote more attention to social and environmental aspects, whereas this study focuses on the economic efficiency of technologies in the agricultural sector and the local conditions of Ukraine.

The study by L. Gurung *et al.* (2024) explores vertical farming as a promising method for sustainable urban agriculture, highlighting hydroponics, aeroponics, and aquaponics to reduce water consumption, pesticide use, and transportation costs. This aligns with the present study, which also emphasises innovation and environmental sustainability. Both approaches aim to address urbanisation challenges, such as resource scarcity, through the implementation of controlled environments. However, L. Gurung *et al.* place greater emphasis on global environmental impact and renewable energy use, whereas this study concentrates on local economic efficiency and the adaptation of smart technologies.

The study by F. Frimpong *et al.* (2023) explores vertical farming as a promising method for sustainable urban agriculture, highlighting hydroponics, aeroponics, and aquaponics to reduce water consumption, pesticide use, and transportation costs. This aligns with the present study, which also emphasises innovation and environmental sustainability. Both approaches aim to address urbanisation challenges, such as resource scarcity, through the implementation of controlled environments. However, F. Frimpong *et al.* are oriented towards water-saving practices for smallholder farms, including adaptation to regional conditions in West Africa, such as dry seasons and uneven rainfall distribution. This study, in contrast, is more focused on the economic efficiency of smart farming in urbanised regions, emphasising precision agriculture, automation, and digital technologies.

The study by M. Javaid *et al.* (2022) examines the implementation of Agriculture 4.0 technologies, such as IoT, AI, and blockchain, to optimise agricultural processes and reduce environmental impact. This aligns with the present study in the use of smart technologies for sustainable development. However, M. Javaid *et al.* emphasise a global perspective on digital farming, whereas this study focuses more on adapting technologies to local conditions in urbanised regions and economic efficiency. The study by S. Aciksoz *et al.* (2021) centres on smart urban farming to ensure food security and sustainable urban development, highlighting social benefits such as job creation. This aligns with the present study in the shared goal of sustainable development, but this study focuses more on the economic efficiency of smart technologies and local adaptation. Both studies underscore the importance of environmental aspects, but S. Aciksoz *et al.* emphasise the integration of farming into urban infrastructure, whereas this study concentrates on the impact of innovations on agricultural productivity.

The study by G. Rajendiran & J. Rethnaraj (2023) focuses on integrating IoT and machine learning into vertical farming to enhance efficiency, reduce water consumption, and optimise resource use. This aligns with the present study in emphasising the adoption of innovations to address agricultural challenges and ensure food security. However, G. Rajendiran & J. Rethnaraj stress a global approach to vertical farming, whereas this study focuses more on local conditions in urbanised regions and the economic efficiency of technologies. The study by N. Khan *et al.* (2021) examines the integration of IoT, drones, and other technologies to optimise agricultural processes. This coincides with the present study in striving to enhance agricultural efficiency through smart technologies. Both approaches emphasise precision farming and data-driven decision-making. However, N. Khan *et al.* focus more on global perspectives and the development of new sensors, whereas this study highlights the adaptation of smart farming to urbanised regions and the use of existing technologies.

The study by M. Dhanaraju *et al.* (2022) explores the use of IoT in agriculture to optimise processes such as soil monitoring, water resource management, and yield prediction. Similar to the present study, it underscores the importance of modern technologies in improving efficiency and sustainability in agricultural production. Both studies emphasise the role of sensors and precision farming technologies in reducing resource costs and environmental impact. M. Dhanaraju *et al.* provide a detailed description of GPS, sensors, and software applications for real-time decision support. This study, however, is more focused on adapting smart farming to urbanised regions, whereas M. Dhanaraju *et al.* devote greater attention to the global application of IoT in addressing climate challenges and large-scale monitoring using drones. The study by N.M. Trendov *et al.* (2019) focuses on digital technologies, such as IoT, blockchain, and AI, for transforming agri-food systems. This aligns with the present study in using innovations to manage agricultural processes, but N.M. Trendov *et al.* cover a global scale, whereas this study concentrates on the local adaptation of smart farming in urbanised regions.

The present study demonstrates the integration of modern smart farming technologies in urbanised regions, emphasising their economic efficiency and adaptation to local conditions. A comparison with other studies reveals a shared objective – achieving sustainability and enhancing agricultural productivity through innovation. At the same time, differences lie in the context of technology application, socio-economic priorities, and the scale of analysis. This underscores the importance of a comprehensive approach to studying smart farming, considering both local and global aspects.

▸ Conclusions

This study confirms that the implementation of smart farming in urbanised regions is one of the key directions for the development of the modern agricultural sector. The integration of innovative technologies, such as precision agriculture, digital platforms, automation, and IoT, contributes significantly to increased productivity, resource-use efficiency, and agricultural sustainability. A notable example is the results achieved by the agroholding MHP, where the application of modern approaches has enabled consistently high yield indicators. Specifically, maize productivity increased from 8.6 t/ha in 2016/2017 to 10 t/ha in 2021/2022, remaining at 9.9 t/ha in 2023/2024. Such results were made possible through the use of RTK navigation, differential fertiliser application, and other innovations. A similar trend is observed for other crops. Rapeseed yields rose from 3.7 t/ha in 2016/2017 to 4.2 t/ha in 2023/2024, while soybean yields increased from 2.4 to 2.8 t/ha. This demonstrates the effectiveness of precision agriculture, which ensures rational use of fertilisers and water while adapting to climatic and soil conditions. Furthermore, the use of digital platforms for managing production processes helps reduce costs associated with equipment maintenance, field monitoring, and yield forecasting, thereby improving overall economic efficiency.

According to economic analysis, smart farming can significantly enhance profitability and reduce costs. High productivity levels under resource constraints demonstrate that modern technologies can ensure economic stability even in challenging conditions. Additionally, precision agriculture technologies reduce environmental impact by minimising pesticide, fertiliser, and water use. This not only improves economic indicators but also fosters long-term development by mitigating risks associated with external factors such as climate change and resource scarcity. Thus, the study proves that smart farming is a powerful tool for modernising the agricultural sector. It enables high economic efficiency, resource optimisation, and the creation of prerequisites for sustainable development in urbanised regions. Further progress in this direction requires a comprehensive approach, including technological innovation, workforce training, and financial support. Only through the combination of these factors can economic stability, agricultural resilience, and preparedness for future challenges be achieved.

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Моделі смарт-фермерства в урбанізованих регіонах: перспективи економічної ефективності та стійкості

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▸ **Анотація.** Мета дослідження полягала у визначенні економічної ефективності та стійкості впровадження смарт-технологій у сільське господарство урбанізованих регіонів, зокрема на прикладі агроіндустріального холдингу «Миронівський хлібопродукт» (МХП). Методологія включала кількісні та якісні методи аналізу. Було проведено емпіричний аналіз врожайності основних культур. Для оцінки економічної ефективності впроваджених технологій побудовано графік динаміки доходів компанії, який дозволив оцінити вплив смарт-технологій на фінансові результати підприємства. Основні результати свідчать, що впровадження смарт-технологій у МХП сприяло суттєвому підвищенню врожайності та зниженню витрат на ресурси. Наприклад, урожайність кукурудзи зросла з 8,6 т/га у 2016/2017 році до 10 т/га у 2021/2022 році, а в 2023/2024 залишалася стабільною на рівні 9,9 т/га. Подібна динаміка спостерігалася у вирощуванні інших культур: урожайність ріпаку зросла з 3,7 т/га до 4,2 т/га, а сої – з 2,4 т/га до 2,8 т/га. Такі результати пояснюються використанням сучасних підходів, зокрема Real Time Kinematic навігації, автоматизованих систем управління та диференційованого внесення добрив. Аналіз економічних показників показав стабільне зростання доходів компанії навіть у складних економічних умовах. Графік продемонстрував, що доходи МХП значно зросли у період активного впровадження смарт-технологій. У 2024 році доходи компанії сягнули 770 доларів США, що підтверджує економічну ефективність застосованих рішень. Крім того, використання цифрових платформ для моніторингу полів і управління процесами дозволило оптимізувати витрати на обслуговування техніки та прогнозування врожайності. Висновки підтверджують, що смарт-фермерство є ефективним інструментом для модернізації сільського господарства в умовах урбанізованих регіонів. Практичне значення дослідження полягає у демонстрації ефективності впровадження смарт-фермерства для підвищення продуктивності сільськогосподарських підприємств. Результати свідчать про можливість значного зростання врожайності та зменшення витрат на ресурси через використання інноваційних технологій, таких як точне землеробство, цифрові платформи та автоматизація

▸ **Ключові слова:** інноваційні технології; точне землеробство; цифрові платформи; автоматизація процесів; динаміка врожайності