AGRICULTURE 5.0 POTENTIAL AND THE APPLICATION OF ADVANCED TECHNOLOGIES IN SERBIA

Cariša Bešić[1], Dragan Ćoćkalo [2], Mihalj Bakator [3], Marijana Vidas-Bubanja[4], Sanja Stanisavljev [5]

**Corresponding author E-mail: mihalj.bakator@uns.ac.rs*

A R T I C L E I N F O

Original Article

Received: *12 March 2025*

Accepted: *20 May 2025*

doi:10.59267/ekoPolj2502599B

UDC 338.431:004(497.11)

Keywords:

Agriculture 5.0, development, Serbia, AI, advanced technologies

JEL: *O13, Q10, Q16, Q19*

A B S T R A C T

This study explores key factors influencing Agriculture 5.0 adoption in Serbia, focusing on investment trends, government R&D funding, IoT adoption, and rural internet penetration. Data and literature analysis reveals that domestic investment and R&D spending drive digital transformation, and foreign investment remains volatile. IoT and internet expansion support smart farming but require further investment. Policy recommendations include strengthening digital infrastructure and increasing support for agricultural innovation. Future research should examine long-term investment impacts and sustainability benefits to improve Serbia's transition to digital agriculture.

Introduction

Agriculture has experienced significant transformations over the centuries, evolving from manual labor-intensive practices to the integration of advanced technologies. Agriculture 5.0 signifies a paradigm shift towards the adoption of advanced tools such

1 Cariša Bešić, Ph.D., Full Professor, University of Kragujevac, Faculty of technical science Čačak, 32000 Čačak, Svetog Save 65, Serbia. Phone: +381 60 369 96 96, E-mail: carisa.besic@sbb.rs, ORCID ID (https://orcid.org/0000-0001-5370-5328)

2 Dragan Ćoćkalo, Ph.D., Full Professor, University of Novi Sad, Technical faculty “Mihajlo Pupin” in Zrenjanin, 23000 Zrenjanin, Đure Đakovića bb, Serbia. Phone: +381 62 801 97 41, E-mail: dragan.cockalo@uns.ac.rs, ORCID ID (http://orcid.org/0000-0003-2085-5420)

3 Mihalj Bakator, Ph.D., Teaching Assistant, University of Novi Sad, Technical faculty “Mihajlo Pupin” in Zrenjanin, 23000 Zrenjanin, Đure Đakovića bb, Serbia. Phone: +381 61/180-61-69, E-mail: mihalj.bakator@uns.ac.rs, ORCID ID (http://orcid.org/000-0001-8540-2460)

4 Marijana Vidas-Bubanja, Ph.D., Full Professor, Alfa BK University, Faculty of finance, banking and auditing, 11000 Belgrade, Bulevar maršala Tolbuhina 8, Serbia., E-mail: marijana.vidas.bubanja@gmail.com, ORCID ID (https://orcid.org/0000-0003-4257-1066)

5 Sanja Stanisavljev, Ph.D., Assistant Professor, University of Novi Sad, Technical faculty “Mihajlo Pupin” in Zrenjanin, 23000 Zrenjanin, Đure Đakovića bb, Serbia, E-mail: sanja.stanisavljev@uns.ac.rs, ORCID ID (https://orcid.org/0000-0003-3565-2597)

as artificial intelligence (AI), the Internet of Things (IoT), and robotics (Morchid et al., 2024; Munir & Elahi, 2023). This evolution aims to improve productivity, sustainability, and resilience in the agricultural sector. The progression to Agriculture 5.0 builds on previous agricultural revolutions. The initial phase involved the mechanization of agriculture, introducing machinery that reduced the reliance on human and animal labor. Previous phases saw the introduction of chemical fertilizers and pesticides, followed by the Green Revolution, which brought high-yield crop varieties and advanced irrigation techniques (Widianto & Juarto, 2023). Agriculture 4.0 introduced digital technologies, including precision farming and data analytics, enabling farmers to make informed decisions based on real-time data. Agriculture 5.0 extends this digital transformation by integrating AI, IoT, and robotics to create intelligent farming systems that can autonomously monitor, analyze, and manage agricultural processes (Bissadu et al., 2024; Fountas et al., 2024).

Artificial intelligence plays an important role in modern farming by enabling the analysis of vast datasets to inform decision-making. Machine learning algorithms can predict weather patterns, identify pest infestations, and recommend optimal planting times, thereby reducing uncertainties associated with farming (Juwono et al., 2023; Mesías-Ruiz et al., 2023). AI-driven models can analyze soil health and suggest precise fertilizer applications, enhancing crop yields but minimizing environmental impact. Additionally, AI supports the development of autonomous machinery capable of performing tasks such as planting, weeding, and harvesting with high precision, reducing labor costs and increasing efficiency (Holzinger et al., 2024). The Internet of Things further improves agricultural productivity by connecting various devices and sensors throughout the farm. IoT devices monitor soil moisture levels, temperature, humidity, and crop health in real-time, transmitting data to centralized systems for analysis. This connectivity allows for the implementation of precision agriculture techniques, where inputs like water and fertilizers are applied variably across a field based on specific needs, optimizing resource use and minimizing waste (Martos et al., 2021; Victor et al., 2024). For example, soil moisture sensors can trigger automated irrigation systems only when necessary, conserving water and promoting sustainable practices.

Robotics complements AI and IoT by automating labor-intensive tasks, addressing challenges such as labor shortages and the need for increased efficiency. Agricultural robots, or agribots, are designed to perform a variety of functions, including planting seeds, applying pesticides, and harvesting crops (Demircioglu et al., 2023). These robots operate with high accuracy, reducing damage to plants and ensuring uniformity in operations. The use of robotics not only improves productivity but also allows farmers to focus on more strategic aspects of farm management. The integration of these advanced technologies contributes significantly to the sustainability and circularity of agricultural practices. Through utilizing AI, IoT, and robotics, farmers can optimize input usage, reducing the over-application of fertilizers and pesticides, which in turn minimizes runoff and environmental pollution (de la Parte et al., 2024). Precision agriculture techniques ensure that resources are used efficiently, promoting soil health and biodiversity. The data collected through these technologies enable continuous monitoring and improvement of farming practices, supporting a culture of sustainability and resilience against climate change (Imade et al., 2024). The noted technologies are important for improving competitiveness (Bakator et al., 2019). This can further manifest in the development of agro-tourism (Cvijanović, 2020; Đoković et al., 2017). The implementation and application of these technologies often require standards and certification programs that support the changes in the industry (Ćoćkalo et al., 2019). Futhermore, this can lead to increased export of agricultural foods and products which contributes to economic growth (Đurić et al., 2017).

The paper consists of the following sections: Introduction section, and then the theoretical background is provided. Next, the methodology is presented. Afterwards, the results are noted. Then the Discussion section addresses recommendations to improve Agriculture 5.0 potential in Serbia. Finally, Conclusions are drawn and ideas and guidelines for future research are noted.

Theoretical background on Agriculture 5.0 and advanced technologies

In 2016, agriculture has undergone significant transformations, evolving from traditional practices to the integration of advanced technologies, culminating in what is now referred to as Agriculture 5.0 (Aggarwal et al., 2024; Mishra et al., 2024). This latest phase emphasizes the use of artificial intelligence (AI), the Internet of Things (IoT), and robotics to improve efficiency, sustainability, and productivity in farming. Agriculture 5.0 reflects a series of technological advancements. Initially, agriculture relied heavily on manual labor and rudimentary tools. The advent of the Industrial Revolution introduced mechanization, with machinery such as tractors reducing the dependence on human and animal labor. This mechanization marked the first significant shift, enabling farmers to cultivate larger areas with increased efficiency (Haloui et al., 2024).

Agriculture 5.0 integrates digital technologies to create intelligent farming systems. AI plays a central role in this transformation, enabling the analysis of vast datasets to inform decision-making processes. Machine learning algorithms can predict weather patterns, assess soil health, and identify pest infestations, allowing for timely interventions (Polymeni et al., 2023; Tiwari et al., 2021). AI-driven models can analyze satellite imagery to monitor crop health, providing farmers with actionable insights to improve yields and reduce resource wastage (Siddharth et al., 2021). The IoT further amplifies the capabilities of modern agriculture by connecting various devices and sensors across the farm. These IoT-enabled devices collect real-time data on soil moisture, temperature, humidity, and crop growth (Singh & Sobti, 2022). This continuous stream of information allows for precise monitoring and management of agricultural processes. Soil moisture sensors can trigger automated irrigation systems, ensuring that crops receive optimal water levels, thereby conserving water resources and promoting sustainable practices (Das et al., 2024; Sharma et al., 2024).

Robotics complements AI and IoT by automating labor-intensive tasks, addressing challenges such as labor shortages and the need for increased efficiency (Ragazou et al., 2022; Razak et al., 2024). Modern agricultural robots, or agribots, are designed to perform a variety of functions, including planting, weeding, and harvesting. Equipped with advanced sensors and AI capabilities, these robots can navigate fields autonomously, identifying and tending to individual plants as needed (Ayranci & Erkmen, 2024). Autonomous weeding robots can distinguish between crops and weeds, removing unwanted plants without the need for chemical herbicides, thus promoting environmental sustainability. IoT amplifies the capabilities of modern agriculture by connecting various devices and sensors across the farm (Kalpana et al., 2024; Pandrea et al., 2023). These IoT-enabled devices collect real-time data on soil moisture, temperature, humidity, and crop growth. This continuous stream of information allows for precise monitoring and management of agricultural processes. For instance, soil moisture sensors can trigger automated irrigation systems, ensuring that crops receive optimal water levels, thereby conserving water resources and promoting sustainable practices.

Robotics complements AI and IoT by automating labor-intensive tasks, addressing challenges such as labor shortages and the need for increased efficiency (Catala-Roman et al., 2024). Modern agricultural robots, or agribots, are designed to perform a variety of functions, including planting seeds, applying pesticides, and harvesting crops (Sivagami et al., 2024). Equipped with advanced sensors and AI capabilities, these robots can navigate fields autonomously, identifying and tending to individual plants as needed. For example, autonomous weeding robots can distinguish between crops and weeds, removing unwanted plants without the need for chemical herbicides, thus promoting environmental sustainability.

The integration of these technologies not only improves productivity but also contributes to environmental conservation. Precision farming techniques enabled by AI and IoT reduce the over-application of fertilizers and pesticides, minimizing runoff into water bodies and preserving soil health (Mohan et al., 2023). The data collected through these technologies facilitate traceability in the food supply chain, ensuring food safety and quality. Consumers can access information about the origin and cultivation practices of their food, supporting transparency and trust in the agricultural system.

The integration of these technologies not only improves productivity but also contributes to environmental conservation. Precision farming techniques enabled by AI and IoT reduce the over-application of fertilizers and pesticides, minimizing runoff into water bodies and preserving soil health. The data collected through these technologies facilitate traceability in the food supply chain, ensuring food safety and quality. Consumers can access information about the origin and cultivation practices of their food, supporting transparency and trust in the agricultural system. The adoption of digital agriculture practices has been shown to improve on-farm efficiency, with precision technologies enabling variable-rate application of inputs, thereby reducing costs and environmental impact.

However, the adoption of Agriculture 5.0 technologies is not without challenges. Smallholder farmers may face barriers due to the high initial investment costs and the need for technical expertise to operate advanced machinery and interpret data. Additionally, concerns about data privacy and the digital divide between technologically advanced and developing regions pose significant hurdles. Addressing these challenges requires collaborative efforts from governments, technology providers, and the agricultural community to develop affordable solutions and provide training to farmers.

Materials and methods

The research framework for this study follows four main phases. The first phase involved collecting relevant literature and data sources necessary to establish a theoretical background. Literature sources were obtained through international databases, institutional repositories, and publicly available reports (FAO, 2024; RZSS, 2024). The theoretical foundation was built on existing studies in the fields of Agriculture 5.0, digital transformation in agribusiness, sustainable farming practices, and technological innovations in precision agriculture.

The second phase focused on analyzing key economic, technological, and policy-driven indicators that influence the adoption of digital farming solutions. The study examined the impact of foreign direct investment (FDI), domestic capital investment, government R&D spending in agriculture, internet penetration in rural areas, and the adoption of IoT technologies in smart farming.

The third phase comprised the statistical analysis of investment trends and economic indicators affecting Agriculture 5.0. A linear regression model was developed to quantify the impact of various investment factors on the Agriculture 5.0 potential index (Agri5_Index). The model incorporated FDI, gross fixed capital formation (GFCF), government R&D expenditure, IoT adoption rate, and rural internet penetration as independent variables.

The fourth phase involved deriving policy recommendations and guidelines for enhancing Agriculture 5.0 adoption in Serbia. Based on the regression findings and literature review, recommendations were formulated to support smart farming innovations, strengthen digital infrastructure, and improve agricultural sustainability through precision technologies.

The study utilized data from multiple sources, including the Food and Agriculture Organization (FAO), the Statistical Office of the Republic of Serbia (SORS), and external reports on agribusiness investment trends. The dataset covered the period from 2019 to 2022, providing insights into the evolution of agricultural investments and technology adoption in Serbia. Key economic and technological indicators analyzed included:

- Foreign direct investment in agriculture (FDI_Agri)
- Gross fixed capital formation in agriculture (GFCF_Agri)

- Government R&D expenditure on agriculture (R&D_Agri_Exp)
- Rural internet penetration rate (Rural_Internet_Penetration)

These indicators were selected based on their relevance in assessing the digital transformation of Serbia's agricultural sector. Data were extracted and processed using spreadsheet software to facilitate statistical analysis. The model was calibrated using empirical data from 2020 to 2022. The regression findings provided insights into how different investment strategies contribute to Agriculture 5.0 readiness in Serbia. Based on the research objectives and methodology, the following hypotheses were formulated:

- H1: Higher levels of foreign and domestic investment positively impact the digital transformation of agriculture.
- H2: Increased government R&D spending in agriculture accelerates the adoption of smart farming technologies.
- H3: Higher IoT adoption rates significantly contribute to the development of precision agriculture.

Results

The results of the assessment of Serbia's Agriculture 5.0 development potential was based on various economic, investment, and technological indicators. The assessment focused on six key factors affecting Agriculture 5.0 potential:

- Foreign direct investment in agriculture (FDI_Agri) – measures the external capital flow into the agricultural sector.
- Gross fixed capital formation in agriculture (GFCF_Agri) – represents domestic investment in agricultural assets, modernization, and mechanization.
- Government R&D spending in agriculture (R&D_Agri_Exp) – an important determinant of innovation, smart farming technologies, and digital transformation.
- Internet penetration in rural areas (Rural_Internet_Penetration) – serves as a prerequisite for IoT adoption and digital farming.

The dataset was compiled from multiple sources, including FAO databases, national statistical reports, and external research findings. The extracted dataset includes investment trends (both foreign and domestic), agriculture's share in the economy, and government spending. The dataset covers the period 2019-2022 (this is the latest data), with emphasis on available investment-related indicators. Key findings are (FAO, 2024; RZSS, 2024):

- FDI in Agriculture (FDI_Agri) fluctuated significantly: peaking at 216 million EUR in 2020, dropping to 167 million EUR in 2021, and further declining to 21 million EUR in 2022.

- Domestic investment (GFCF_Agri) steadily increased, reaching 1,301 million EUR in 2022, suggesting a stronger reliance on local capital for modernization.
- Internet penetration (Rural_Internet_Penetration) in rural areas reached 83% in 2023, showing a solid foundation for smart farming expansion.
- Government R&D (R&D_Agri_Exp) spending on agriculture remains unclear, though total R&D expenditure reached 77 billion RSD (0.95% of GDP).

The main limitation in data preparation was the lack of direct agricultural technology indicators, requiring indirect measures.

The analysis reveals two contrasting trends:

1. Foreign investment (FDI_Agri) is volatile and declining, indicating a reduced external interest in Serbia's agriculture.
2. Domestic investment (GFCF_Agri) is steadily growing, showing a government-driven push for modernization.

The correlation analysis found a strong negative relationship (-0.757) between FDI and GFCF, suggesting that when foreign investment declines, domestic investment increases to compensate. This indicates a substitution effect rather than a complementary relationship. Additionally, rural internet penetration has grown to 83%, which supports future digital agriculture expansion. However, the IoT adoption rate is still unclear, limiting direct insights into smart farming progress.

A linear regression model was constructed to quantify the impact of investment factors on Agriculture 5.0 potential. Since a direct Agriculture 5.0 index does not exist, a synthetic dependent variable (Agri5_Index) was generated based on a weighted combination of FDI, GFCF, and other known factors.

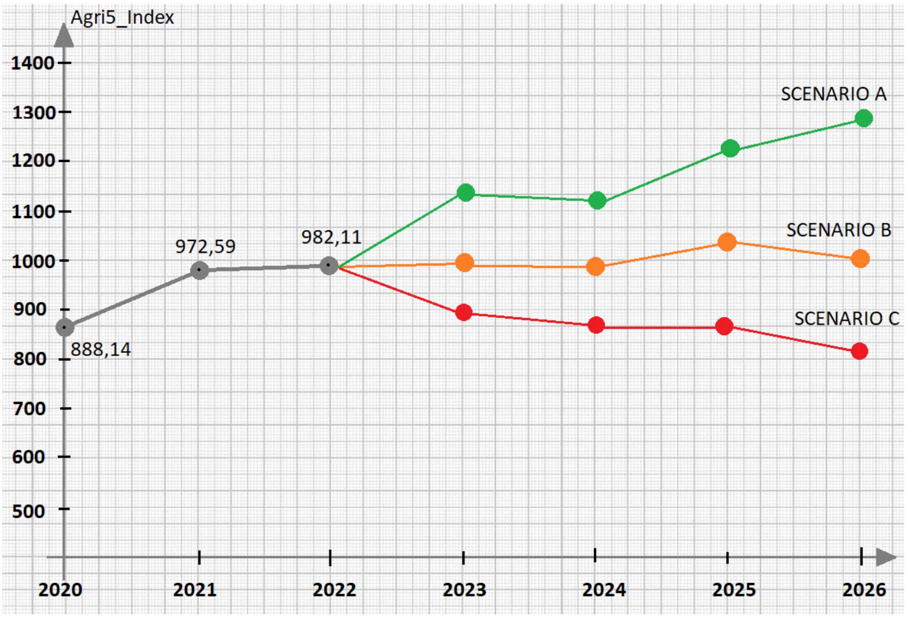
- $\beta0$ = 326.06 (intercept of the regression model)
- $\beta1$= 0.0942 (intercept FDI)
- $\beta2$= 0.3794 (intercept for GFCF)
- $\beta3$ =2.5 estimated (R&D in agriculture has a high impact on digital farming innovation)
- $\beta4$=3.0 estimated (IoT adoption rate has an even greater effect on smart agriculture development).
- $\beta5$=1.5 estimated (Rural internet penetration has a moderate impact on the Agriculture 5.0 index).

The linear equation is: $Agri5\_Index\_t = \beta_0 + \beta_1 * FDI\_Agri\_t + \beta_2 * GFCF\_Agri\_t + \beta_3 * R\&D\_Agri\_Exp\_t + \beta_4 * IoT\_Adoption\_Rate\_t + \beta_5 * Rural\_Internet\_Penetration\_t + \varepsilon\_t$

Based on the regression model, the Agri5_Index2020 is 888.14. The Agri5_Index2021 is 972.59, and the Agri5_Index2022 is 982.11. The regression model suggests that Agricultural 5.0 potential is growing steadily from 888.14 in 2020 to 982.10 in 2022. Additionally, domestic investment (GFCF_Agri) has the strongest impact on Agriculture 5.0 readiness. IoT adoption and rural internet expansion are key accelerators, adding significant predictive power to the index. Declining FDI (from 216M EUR in 2020 to 21M EUR in 2022) weakens growth, but domestic investment compensates. On Figure 1., the potential scenarios of further development of Agriculture 5.0 potential are presented.

Figure1. Agriculture 5.0 potential future outcomes (scenarios)

Scenario A: In this scenario, Serbia undergoes a rapid transformation towards



Source: Authors

Agriculture 5.0, driven by a combination of strong government policies, increased investment, digital infrastructure expansion, and high technology adoption rates. The key influencing factors include a significant increase in government funding for agricultural research and development plays an important role. Serbia allocates more than 1.5% of GDP to R&D, with a specific focus on agricultural digitalization, AI-driven farming solutions, and IoT-based smart monitoring systems. These investments stimulate innovation, enabling the deployment of automated irrigation, drone-based monitoring, and AI-powered predictive analytics for crop management. Government grants and subsidies encourage farmers to adopt precision farming technologies, reducing costs and improving productivity. Investor confidence in Serbia's agriculture sector recovers and strengthens, with annual FDI inflows exceeding 250 million EUR. International agritech companies establish partnerships with local farms, facilitating the transfer of modern machinery, AI-powered robotic harvesters, and big-data-driven farm management software. Increased FDI also supports the creation of agritech incubators, where startups develop machine-learning algorithms for yield prediction and blockchain-based food traceability solutions. IoT adoption in agriculture accelerates beyond 20% of farms, enabled by affordable smart sensors, government-backed innovation programs, and a digital literacy push in rural areas. Farmers integrate IoT-based soil moisture sensors, automated weather stations, and GPS-guided autonomous machinery, which optimize input usage, reduce waste, and improve overall farm efficiency. Large agribusinesses develop cloud-based farm management platforms, allowing real-time tracking of soil health, pest risks, and crop growth, further enhancing precision agriculture practices. Broadband penetration in rural areas increases to over 95%, supported by government-private sector partnerships and EU-backed rural connectivity projects. High-speed 5G networks are deployed in agricultural regions, ensuring seamless real-time data transmission from IoT devices. With reliable connectivity, farmers have direct access to global commodity markets, digital advisory services, and AI-powered farm management platforms. The increased availability of capital and technological advancement lead to a widespread mechanization wave, including the adoption of autonomous tractors, robotic fruit pickers, and AI-driven greenhouse systems. Serbian farmers, supported by favorable government tax incentives on agricultural robotics, transition to fully automated harvesting and precision fertilization, significantly increasing efficiency and reducing labor costs. Advances in AI-powered irrigation and satellite-monitored crop health assessment contribute to higher water use efficiency. Serbia achieves smart water management by deploying IoT-enabled drip irrigation systems that automatically adjust water levels based on real-time soil moisture and weather data. As a result, the agricultural sector reduces water waste while maintaining optimal crop yields, making it more resilient to climate change.

If this scenario materializes, Serbia emerges as a leader in smart agriculture in Southeast Europe, benefiting from higher yields, lower production costs, greater sustainability, and improved rural prosperity. The country reduces its reliance on traditional farming techniques and transitions into a fully digital agricultural economy.

Scenario B: In this scenario, Serbia experiences gradual but uneven progress toward Agriculture 5.0. Some technological advancements occur, but the pace of transformation remains moderate due to limited government support, inconsistent foreign investment, and slow adoption of digital farming practices. The transition to smart agriculture remains incomplete, with only partial adoption of modern technologies across the sector. Serbia maintains its current level of R&D investment (~0.95% of GDP), the funding is not significantly increased. Agricultural innovation receives some government support, but the allocation is not enough to drive large-scale adoption of AI-driven precision agriculture. The focus remains on traditional mechanization and conventional farm subsidies, but digital transformation efforts remain fragmented. FDI remains low but stable, averaging around 50 million EUR per year. International investors show interest in Serbia's agriculture sector, but lack of aggressive government incentives and policy clarity prevents large-scale investment inflows. Some agritech firms establish pilot projects in precision agriculture, but there is no nationwide adoption of high-tech farming. The adoption of IoT-driven smart agriculture remains concentrated in large agribusinesses, but smaller and mid-sized farms lag behind. Farmers experiment with basic IoT solutions, such as soil sensors, automated weather stations, and remote-controlled irrigation systems, but high costs and lack of digital literacy prevent widespread usage. Broadband access continues to expand, but rural connectivity remains uneven, with some remote agricultural regions still lacking high-speed internet. Major farming regions gain access to 4G and 5G networks, small-scale farmers struggle with connectivity issues, limiting their ability to integrate cloud-based farm management solutions. The use of tractors, harvesters, and automated irrigation systems increases, but fully autonomous farming equipment (robotic fruit pickers, AI-driven harvesters) remains rare. Traditional mechanization expands, but the transition to AI-assisted decision-making in agriculture remains slow. Many farmers continue to rely on experience-based decision-making rather than data-driven insights. Some farmers adopt smart irrigation techniques, but many still use traditional flood irrigation or outdated sprinkler systems. Water scarcity risks persist, especially in regions that lack AI-powered irrigation planning. The transition to fully automated, data-driven water management is delayed, limiting Serbia's ability to optimize water use. Serbia makes some progress in precision breeding and crop genetics, but lack of large-scale R&D funding and international collaborations prevents major breakthroughs. Some heat-resistant and drought-tolerant crop varieties are introduced, but not at a level that ensures long-term climate resilience.

This scenario results in moderate progress, where Serbia adopts Agriculture 5.0 at a slow pace. Some farms integrate smart technologies, but many remain reliant on conventional farming methods. Serbia fails to establish itself as a regional leader in digital agriculture, and productivity improvements are limited compared to leading agricultural economies.

Scenario C: In this scenario, Serbia falls behind in the global transition to Agriculture 5.0, resulting in technological stagnation, low investment, and declining productivity. The failure to adopt digital agriculture leads to reduced competitiveness, lower efficiency, and increased vulnerability to climate change and economic fluctuations. Without strong policy intervention and strategic investment, the agricultural sector remains reliant on outdated farming techniques, limiting growth and sustainability. Government expenditure on agricultural research and development falls below 0.7% of GDP, as priorities shift to other sectors. Without sufficient funding, technological innovation slows down, leaving farmers without access to advanced precision farming tools, AI-driven decision support systems, or genetic advancements in crops. Research institutions struggle to maintain agritech programs, and local agritech startups fail to scale due to lack of support. Foreign investment in agriculture collapses to below 20 million EUR annually, as investors lose confidence in Serbia's ability to modernize its agricultural sector. Without FDI, access to modern machinery, AI-powered automation, and blockchain-based supply chain solutions remains extremely limited. Agribusinesses become dependent on outdated farming practices, reducing export competitiveness. Less than 5% of farms integrate IoT technologies, as high costs, lack of digital skills, and poor infrastructure prevent the adoption of smart sensors, automated monitoring systems, and AI-powered farm analytics. Without IoT-driven precision farming, Serbian agriculture continues to suffer from inefficient water use, uncontrolled pest outbreaks, and suboptimal resource allocation. Rural broadband penetration stagnates below 85%, leaving many remote farming communities without reliable internet access. This prevents farmers from using cloud-based farm management systems, digital marketplaces, and online advisory services. The lack of connectivity exacerbates the technological gap between Serbia and other agricultural economies, further limiting growth. Farm mechanization remains outdated, with many small and medium-sized farms continuing to use manual labor and inefficient machinery. The lack of investment in modern agricultural equipment results in lower productivity and higher operational costs. Advanced automation, such as AI-powered tractors, robotic fruit pickers, and drone-assisted farming, remains inaccessible, reducing Serbia's ability to compete with digitally advanced agricultural nations. Inefficient irrigation practices persist, as AI-driven precision irrigation systems fail to gain traction. Farmers continue to rely on traditional flood irrigation and outdated sprinkler systems, leading to water wastage, soil degradation, and reduced long-term sustainability. As climate change worsens, the agricultural sector becomes increasingly vulnerable to droughts and extreme weather conditions. Serbia fails to develop new high-yield, climate-resilient crop varieties, as biotechnology research remains underfunded and poorly integrated into the agricultural economy. Without precision breeding and advanced genetic engineering, Serbia's crops struggle to withstand changing climate conditions and pest outbreaks, reducing overall yields.

Failing to transition to Agriculture 5.0 could set Serbia back decades, making it heavily dependent on traditional, low-tech farming methods while other nations fully integrate AI, automation, and precision agriculture into their food production systems.

Discussion

Based on the theoretical background and data analysis, the hypotheses are addressed as follows:

H1: Higher levels of foreign and domestic investment positively impact the digital transformation of agriculture. Partially Confirmed. The analysis showed that domestic investment (GFCF_Agri) had a strong positive impact on Agriculture 5.0 potential, as indicated by a significant regression coefficient ($\beta_2 = 0.3794$). However, foreign direct investment (FDI_Agri) exhibited volatility and a negative correlation (-0.757) with domestic investment, suggesting that when FDI declines, domestic investments compensate rather than complement. This indicates that FDI does not consistently contribute to digital transformation.

H2: Increased government R&D spending in agriculture accelerates the adoption of smart farming technologies. Confirmed. The regression model estimated that government R&D expenditure (R&D_Agri_Exp) had a strong positive impact on Agriculture 5.0, with an estimated coefficient ($\beta_3 = 2.5$). This highlights that investment in agricultural research directly supports digital transformation, innovation, and the adoption of smart farming solutions.

H3: Higher IoT adoption rates significantly contribute to the development of precision agriculture. *Confirmed.* The regression model estimated that IoT adoption (IoT_Adoption_Rate) had the highest impact among technology-related factors, with a coefficient of ($\beta_4 = 3.0$). This confirms that IoT-driven smart farming solutions, such as soil sensors and automated irrigation systems, play an important role in enhancing agricultural productivity and efficiency.

Furthermore, to transition toward Scenario A (Accelerated Growth) and avoid stagnation, Serbia needs a comprehensive national strategy for Agriculture 5.0. Below are key policy recommendations, categorized into investment strategies, infrastructure expansion, regulatory reforms, and capacity-building initiatives:

- R&D spending in agriculture should be increased to at least 1.5% of GDP to support the development of AI-driven farming solutions, automated irrigation, and climate-resilient crop varieties.
- Agriculture 5.0 Innovation Fund should be established to provide grants for agritech startups and research institutions working on smart farming technologies.
- University-industry collaborations in agritech should be encouraged, supporting knowledge exchange and commercialization of AI-driven agricultural tools.
- A national AI strategy for agriculture should be developed, incorporating machine learning algorithms for pest control, predictive analytics for yield forecasting, and drone-assisted crop monitoring.
- High-speed internet access is essential for the adoption of IoT-enabled smart farming and digital supply chains.
- Broadband coverage should be expanded to ensure 100% rural internet penetration by investing in fiber-optic networks and 5G deployment in agricultural areas.
- Tax incentives should be provided for telecom companies to extend high-speed internet to remote farms.
- "Smart Farms Connectivity Program" could be introduced subsidizing farmers to install IoT-enabled infrastructure (soil sensors, automated irrigation systems).

- Open-data agricultural platform should be developed where farmers can access real-time weather data, soil health analysis, and AI-driven market price forecasts.
- Traditional mechanization must evolve into AI-driven and autonomous farming systems.
- "Smart Agriculture Subsidy Program" should be launched, providing financial support for farmers purchasing precision tractors, robotic harvesters, and AI-powered irrigation systems.
- Public-private partnerships (PPPs) should be planned with agritech firms, making cutting-edge automation accessible to Serbian farms.
- Low-interest loans should be provided for mechanization upgrades, allowing small and medium-sized farms to afford drone-based monitoring, automated greenhouses, and robotic seeding systems.
- An "IoT for Agriculture Grant Program" should be created for funding smart farming solutions like remote soil sensors, GPS-guided drones, and automated irrigation.
- National IoT Agriculture Strategy could be developed promoting data-driven decision-making in farming operations.
- Training programs for farmers should be provided on how to use IoT dashboards, AI-based yield prediction models, and precision application of fertilizers.
- AI-powered irrigation management systems should be implemented, ensuring optimal water distribution.
- Subsidies for smart irrigation systems should be provided, including IoT-enabled drip irrigation and satellite-controlled water distribution networks.
- Serbia should be promoted as a hub for sustainable agriculture and AI-driven food production, attracting international partnerships.
- Agriculture 5.0 courses could be introduced in universities and vocational schools, training students in agri-data science, AI-powered farm management, and precision farming techniques.
- Digital literacy programs for farmers has to be developed, ensuring they can operate smart farm technology effectively.
- AI-powered climate risk analysis tools could be integrated, predicting droughts and extreme weather impacts.

These recommendations if applied in some capacity can significantly affect the trajectory of Agriculture 5.0 development in Serbia.

Conclusion

This study analysed Agriculture 5.0 potential in Serbia. Based on the available data it was found that the primary influencing factors are domestic investment, government R&D spending, IoT adoption, and rural internet penetration. These factors play an important role in the adoption of digital and precision farming technologies. However, foreign direct investment has shown volatility and does not consistently contribute to Agriculture 5.0 development, indicating that Serbia relies more on local investments for modernization. The findings highlight the need for policy measures that support smart farming initiatives, expand digital infrastructure, and increase funding for agricultural research and development. Strengthening investment in IoT-driven agriculture and AI-powered solutions will improve productivity, efficiency, and sustainability, ensuring Serbia remains competitive in the global agricultural sector.

Future research should focus on developing a comprehensive Agriculture 5.0 readiness index to better assess progress and identify areas for improvement. Comparative studies with other countries could provide benchmarks and best practices for Serbia's agricultural transformation. Additionally, long-term analyses on investment impacts, farmer adoption behavior, and sustainability benefits will help refine strategies for integrating advanced technologies in agriculture. Addressing these areas will contribute to a more data-driven and resilient agricultural sector in Serbia.

Acknowledgement

The authors declare no conflict of interest. This paper has been supported by the Provincial Secretariat for Higher Education and Scientific Research of the Autonomous Province of Vojvodina, number: 003099809 2024 09418 003 000 000 001-02.

Conflict of interests

The authors declare no conflict of interest.

References

1. Aggarwal, M., Khullar, V., & Goyal, N. (2024). Agriculture in society 5.0. In Artificial Intelligence and Society 5.0 (pp. 154-162). Chapman and Hall/CRC. https://doi.org/10.1201/9781003397052
2. Ayranci, A. A., & Erkmen, B. (2024, May). Edge Computing and Robotic Applications in Modern Agriculture. In 2024 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA) (pp. 1-6). IEEE. https://doi.org/10.1016/10.1109/HORA61326.2024.10550846
3. Bakator, M., Đorđević, D., & Ćoćkalo, D. (2019). Developing a model for improving business and competitiveness of domestic enterprises. Journal of Engineering Management and Competitiveness (JEMC), 9(2), 87-96.

4. Bissadu, K. D., Sonko, S., & Hossain, G. (2024). Society 5.0 enabled agriculture: Drivers, enabling technologies, architectures, opportunities, and challenges. Information Processing in Agriculture. https://doi.org/10.1016/j.inpa.2024.04.003
5. Catala-Roman, P., Segura-Garcia, J., Dura, E., Navarro-Camba, E. A., Alcaraz-Calero, J. M., & Garcia-Pineda, M. (2024). AI-based autonomous UAV swarm system for weed detection and treatment: Enhancing organic orange orchard efficiency with agriculture 5.0. Internet of Things, 28, 101418. https://doi.org/10.1016/j.iot.2024.101418
6. Ćoćkalo D., Đorđević D., Kavalić M., & Bešić C. (2019). Implementation of certification schemes in the Balkan agro-food sector. Ekonomika poljoprivrede, 66(1), 77-88.
7. Corallo, A., Latino, M. E., Menegoli, M., & Signore, F. (2024). Digital technologies for sustainable development of agri-food: implementation guidelines toward Industry 5.0. IEEE Transactions on Engineering Management. https://doi.org/10.1109/TEM.2024.3403251
8. Cvijanović, D. (2020). Support to rural tourism development in Vojvodina by local population. Knowledge International Journal, 41(1), 63 - 69. Retrieved from https://ikm.mk/ojs/index.php/KIJ/article/view/4420
9. Das, A., Debnath, B., Sengupta, A., Das, A., & De, D. (2024). Sustainability analysis of FarmFox IoT device towards Agriculture 5.0. Environment, Development and Sustainability, 1-29. https://doi.org/10.1007/s10668-024-05356-0
10. de la Parte, M. S. E., Martínez-Ortega, J. F., Castillejo, P., & Lucas-Martínez, N. (2024). Spatio-temporal semantic data management systems for IoT in agriculture 5.0: Challenges and future directions. Internet of Things, 25, 101030. https://doi.org/10.1016/j.iot.2023.101030
11. Demircioglu, P., Bogrekci, I., Durakbasa, M. N., & Bauer, J. (2023, October). Autonomation, Automation, AI, and Industry-Agriculture 5.0 in Sustainable Agro-Ecological Food Production. In The International Symposium for Production Research (pp. 545-556). Cham: Springer Nature Switzerland.
12. Đoković, F., Pejanović, R., Mojsilović, M., Boljanović, J. Đ., & Plećić, K. (2017). Opportunities to reimportantise rural tourism through the operation of agrarian cooperatives. Economics of Agriculture, 64(3), 1115-1132. DOI:10.5937/ekoPolj1703115D
13. Đurić, D., Ristić, J., Đurić, D., & Vujanić, I. (2017). Export of agricultural and food products in the function of economic growth of Republic of Serbia. Ekonomika poljoprivrede, 64(3).
14. Food and Agriculture Organization of the United Nations – FAO (2024). Data on agriculture domains. https://www.fao.org/faostat/en/#data

15. Fountas, S., Espejo-García, B., Kasimati, A., Gemtou, M., Panoutsopoulos, H., & Anastasiou, E. (2024). Agriculture 5.0: Cutting-edge technologies, trends, and challenges. IT Professional, 26(1), 40-47. https://doi.org/10.1109/MITP.2024.3358972
16. Haloui, D., Oufaska, K., Oudani, M., & El Yassini, K. (2024). Bridging industry 5.0 and agriculture 5.0: historical perspectives, opportunities, and future perspectives. Sustainability, 16(9), 3507. https://doi.org/10.3390/su16093507
17. Holzinger, A., Fister Jr, I., Fister, I., Kaul, H. P., & Asseng, S. (2024). Human-centered ai in smart farming: Towards agriculture 5.0. IEEe Access. https://doi.org/10.1109/ACCESS.2024.3395532
18. Imade, A., Ounacer, S., El Ghoumari, M. Y., Ardchir, S., & Azzouazi, M. (2024). Agricultural yield prediction using ML algorithms in the Industry 5.0. In Industry 5.0 and Emerging Technologies: Transformation Through Technology and Innovations (pp. 135-157). Cham: Springer Nature Switzerland.
19. Juwono, F. H., Wong, W. K., Verma, S., Shekhawat, N., Lease, B. A., & Apriono, C. (2023). Machine learning for weed–plant discrimination in agriculture 5.0: An in-depth review. Artificial Intelligence in Agriculture, 10, 13-25. https://doi.org/10.1016/j.aiia.2023.09.002
20. Kalpana, S., Babu, K. G., Padmavathi, T. V. N., Sharma, B., Hari, B. S., & Sudha, M. (2024). The Fusion of AI, IoT, and Agricultural Sensors for Self-Sustaining Agro-Technological Ecosystems: Industry 5.0. In Convergence of Human Resources Technologies and Industry 5.0 (pp. 274-299). IGI Global. https://doi.org/10.4018/979-8-3693-1343-5.ch015
21. Martos, V., Ahmad, A., Cartujo, P., & Ordoñez, J. (2021). Ensuring agricultural sustainability through remote sensing in the era of agriculture 5.0. Applied Sciences, 11(13), 5911. https://doi.org/10.3390/app11135911
22. Mesías-Ruiz, G. A., Pérez-Ortiz, M., Dorado, J., De Castro, A. I., & Peña, J. M. (2023). Boosting precision crop protection towards agriculture 5.0 via machine learning and emerging technologies: A contextual review. Frontiers in Plant Science, 14, 1143326.
23. Mishra, N., Bhandari, N., Maraseni, T., Devkota, N., Khanal, G., Bhusal, B., ... & Danuwar, R. K. (2024). Technology in farming: Unleashing farmers' behavioral intention for the adoption of agriculture 5.0. Plos one, 19(8), e0308883. https://doi.org/10.1371/journal.pone.0308883
24. Mohan, K. J., Mary, I. B., & Paul, J. J. (2023, December). IoT and industry 5.0 revolutionizing agriculture: a comprehensive review of sustainable advancements in precision farming. In International Conference on Computer Vision and Internet of Things 2023 (ICCVIoT'23) (Vol. 2023, pp. 169-175). IET.

25. Morchid, A., El Alami, R., Raezah, A. A., & Sabbar, Y. (2024). Applications of Internet of Things (IoT) and Sensors Technology to Increase Food Security and Agricultural Sustainability: Benefits and Challenges. Ain Shams Engineering Journal, 15(3), 102509. https://doi.org/10.1016/j.asej.2023.102509
26. Munir, A., & Elahi, H. (2023). An Interdisciplinary Approach to Artificial Intelligence in Agriculture. AI, 4(1), 1-20. https://doi.org/10.1080/27685241.2023.2168568
27. Pandrea, V. A., Ciocoiu, A. O., & Machedon-Pisu, M. (2023, June). IoT-based irrigation system for agriculture 5.0. In 2023 17th International Conference on Engineering of Modern Electric Systems (EMES) (pp. 1-4). IEEE. https://doi.org/10.1109/EMES58375.2023.10171631
28. Polymeni, S., Plastras, S., Skoutas, D. N., Kormentzas, G., & Skianis, C. (2023). The impact of 6G-IoT technologies on the development of agriculture 5.0: A review. Electronics, 12(12), 2651. https://doi.org/10.3390/electronics12122651
29. Ragazou, K., Garefalakis, A., Zafeiriou, E., & Passas, I. (2022). Agriculture 5.0: A new strategic management mode for a cut cost and an energy efficient agriculture sector. Energies, 15(9), 3113. https://doi.org/10.3390/en15093113
30. Razak, S. F. A., Yogarayan, S., Sayeed, M. S., & Derafi, M. I. F. M. (2024). Agriculture 5.0 and explainable ai for smart agriculture: A scoping review. Emerging Science Journal, 8(2), 744-760. https://doi.org/10.28991/ESJ-2024-08-02-024
31. Republički zavod za statistiku Srbije - RZSS (2024). Poljoprivreda, ribarstvo i šumarstvo. https://www.stat.gov.rs/sr-Latn/oblasti/poljoprivreda-sumarstvo-i-ribarstvo
32. Sharma, A., Singh, S. K., Kumar, S., Thakur, R., Gupta, B. B., & Arya, V. (2024). IoT-enabled smart farming with Industry 5.0. Journal of High Speed Networks, 30(3), 477-496. https://doi.org/10.3233/JHS-2302
33. Siddharth, D., Saini, D. K., & Kumar, A. (2021). Precision agriculture with technologies for smart farming towards agriculture 5.0. Unmanned aerial vehicles for internet of things (IoT) concepts, techniques, and applications, 247-276. https://doi.org/10.1002/9781119769170.ch14
34. Singh, D. K., & Sobti, R. (2022). Long-range real-time monitoring strategy for Precision Irrigation in urban and rural farming in society 5.0. Computers & Industrial Engineering, 167, 107997. https://doi.org/10.1016/j.cie.2022.107997
35. Sivagami, S., Hemalatha, D., Belinda, C. M., & Raja, A. S. (2024). Agricultural Development in Industry 5.0: Food Manufacturing and Development. In Intelligent Systems and Industrial Internet of Things for Sustainable Development (pp. 154-188). Chapman and Hall/CRC. https://doi.org/10.1201/9781032642789

36. Tiwari, R., Chand, K., Bhatt, A., Anjum, B., & Thirunavukkarasu, K. (2021). Agriculture 5.0 in India: opportunities and challenges of technology adoption. A Step Towards Society 5.0, 179-198. https://doi.org/10.1201/9781003138037

37. Victor, N., Maddikunta, P. K. R., Mary, D. R. K., Murugan, R., Chengoden, R., Gadekallu, T. R., ... & Paek, J. (2024). Remote Sensing for Agriculture in the Era of Industry 5.0–A survey. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. https://doi.org/10.1109/JSTARS.2024.3370508

38. Widianto, M. H., & Juarto, B. (2023). Smart Farming Using Robots in IoT to Increase Agriculture Yields: A Systematic Literature Review. Journal of Robotics and Control (JRC), 4(3), 330-341. https://doi.org/10.18196/jrc.v4i3.18368