ASSESSING THE DEGREE OF INNOVATION IN ROMANIAN AGRICULTURE: THE IMPACT OF MODERN TECHNOLOGIES ON PERFORMANCE AND SUSTAINABILITY

Ioana-Raluca Goldbach[1], Anișoara Duică[2], Andreea Anamaria Panagoreț[3], Biana Calagiu (Popescu)[4]

**Corresponding author E-mail: ioanagoldbach@gmail.com*

A R T I C L E I N F O

Original Article

Received: *09 February 2025*

Accepted: *25 March 2025*

doi:10.59267/ekoPolj2503851R

UDC 338.435(498)

Keywords:

agricultural innovation, technological adoption, farm performance.

***JEL**: C46, O13, M10, O44, Q01, Q56*

A B S T R A C T

This study investigates the adoption and perception of technological innovations and sustainable practices among farmers in the South-East region of Romania. The survey targeted mixed crop–livestock farms and post-harvest activities, providing a representative overview of the sector. Findings reveal a moderate uptake of digital tools, including farm management software, drones, and sensors, alongside notable reluctance toward biotechnologies. Conversely, respondents expressed greater receptivity to renewable energy solutions and organic farming. Overall, the level of digitalization remains low, with traditional practices prevailing, consistent with national patterns. These results highlight the need for targeted interventions—such as awareness campaigns, specialized training, financial incentives, pilot projects, and supportive public policies—to facilitate innovation and strengthen agricultural competitiveness. Future research should extend to a national scale and assess the specific economic and environmental impacts of individual technologies, thereby informing strategies to advance a more sustainable and resilient agricultural sector.

1 Ioana-Raluca Goldbach, Valahia University of Targoviste, PhD. Lecturer, street Aleea Sinaia, 022765, Romania, Phone: +407722887838, E-mail: ioanagoldbach@gmail.com, ORCID ID (https://orcid.org/0000-0003-2705-9216)

2 Anișoara Duică, Valahia University of Targoviste, PhD. Professor, street Aleea Sinaia, 022765 Romania, Phone: +40722997632, E-mail. anișoara.duica@valahia.ro, ORCID ID (https://orcid.org/0000-0003-1457-5764)

3 Andreea Anamaria Panagoreț, Valahia University of Targoviste, PhD. Lecturer, street Aleea Sinaia, 022765, Romania, Phone: +40762131197, E-mail: andreea.panagoret@yahoo.com, ORCID ID (https://orcid.org/0000-0002-7131-5398-5398)

4 Biana Calagiu (Popescu), Valahia University of Targoviste, PhD-student, street Aleea Sinaia, 022765, Romania, Phone: +40720291194, E-mail: biancacalagiu@yahoo.com, ORCID ID (https://orcid.org/0009-0000-9030-9068)

Introduction

Innovations in agriculture are essential for increasing productivity, improving sustainability and responding to global challenges such as climate change, population growth and increasing demand for food [6]. In the specialized literature, innovation is described as a process that involves the development, testing and implementation of new ideas, product models, processes or functional structures intended for application in industry [1]. [The main innovations in agriculture at European level relate to precision farming, vertical farming and hydroponics, biotechnology and genetic modification, automation and robotics, efficient irrigation systems, sustainable and regenerative agriculture, blockchain technologies and digital platforms, the use of drones and artificial intelligence (AI), alternative food production and renewable energy for farms [17,19]. Andrei & Darvasi (2012) emphasizes that the challenges of digitalization in Romanian agriculture are the subject of analysis in various scientific studies that analyze the challenges and opportunities associated with the implementation of digital technologies in the agricultural sector [6]. A recent study shows that in Romanian agriculture, farms are medium-sized, with an average area of 150 hectares [9].

GPS and drone technologies allow farmers to monitor and manage fields with greater precision. Drones can provide aerial images to assess crop health, while GPS facilitates accurate planting and fertilization. Soil and climate sensors provide real-time data on moisture, soil temperature and other variables, helping farmers make informed decisions about irrigation and fertilizer application. Vertical farming is a method of growing plants in vertically arranged beds, which allows for more efficient use of space and can be carried out in urban or inland areas. Hydroponics and aeroponics involve systems that grow plants without soil, using only nutrient solutions, which save water and space and allow continuous production. Genetically modified (GMO) crops create plants that are more resistant to pests, drought and disease, or with improved nutritional value. CRISPR and other gene editing techniques allow precise modification of plant DNA to achieve resistance to adverse conditions or to increase yields [13].

Agricultural robots are used for various tasks such as planting, harvesting and monitoring crops. They can improve efficiency and reduce the need for manual labor. Autonomous irrigation systems are managed by software and sensors that adjust irrigation according to the actual needs of the plants. Drip irrigation saves water by delivering exactly the right amount of water to plant's roots. Sensor-controlled irrigation monitors soil moisture and triggers irrigation only when needed, reducing water consumption. Permaculture practices emphasize crop and livestock integration to reduce environmental impact and enhance biodiversity. No-till farming is a technique that reduces soil erosion and better maintains moisture.

Blockchain for supply chain traceability allows the origin of agricultural products to be traced and ensures transparency and security in food trade. Digital trading platforms connect farmers directly to markets, reducing intermediation and increasing producer income [16].

Artificial intelligence for analyzing agricultural data uses algorithms that can analyze data collected from sensors and drones to provide precise recommendations on the optimal time to sow, irrigate or apply treatments. Drones for spraying and monitoring allow precise application of pesticides and fertilizers, reducing the amount needed and minimizing waste, the use of unmanned aerial vehicles in precision agriculture, focusing on innovations in the field of fertilization and their impact on agricultural efficiency and sustainability, as a recent study examines [3]. Lab-grown meat is an alternative to traditional meat, produced from animal cells in the lab, which can reduce the environmental impact of animal farming. Protein from insects and other unconventional sources may be a solution to the increased demand for protein, exploring alternative sources such as insects, which require fewer resources for production. Solar panels and wind turbines are being installed on farms to generate electricity, reducing dependence on fossil fuels. Bioenergy involves using agricultural residues to generate energy in the form of biogas or liquid fuel [19]. Khan et al. (2022) investigated the adoption of mobile internet technology among wheat farmers to support sustainable agricultural practices [5]. Zheng et al. (2019) and Done et al., (2012) analyzed technology adoption among farmers, focusing on the factors influencing this adoption [21]. Ruzzante and Bilton (2018) conducted a meta-analysis of the literature on the adoption of agricultural technologies in developing countries [12]. Wongsim et al. (2018) studied the factors influencing the adoption of agricultural management information systems [20]. Ciurea (2020) discusses considerations regarding the digitalization of Romanian agriculture [2]. Girip & Cojocaru (2021) explore the use of the Internet of Things in Romanian agriculture [4]. Markovits (2024) assesses Romanian farmers' motivation for digitalization, using a research model based on the Unified Theory of Technology Acceptance and Use [7]. Șerban et al. (2023) investigates digitalization in Romanian farms [17]. Petrescu-Mag et al. (2019) investigates Romanian farmers' opinions on the effects of pesticides and their willingness to pay for biopesticides [8]. Rodino et al. (2023) present the challenges of digital transformation in Romanian agriculture [10]. Russian et al. (2023) study the acceptance of digital transformation, analyzing data from Romania [11]. Stanciu & Sârbu (2016) analyze the sustainability and competitiveness of Romanian farms through organic farming and research the use of GMOs in Romanian food production [14-15]. Vărzaru (2025) analyzes the digital revolution in agriculture and the use of predictive models to improve agricultural performance through digital technology [18].

The role of university education in promoting research and innovation is essential, thus there are studies that highlight the success of a Romanian university in using European funds to develop a horticultural research institute of excellence, demonstrating the positive impact of investments in scientific infrastructure on research, innovation and technology transfer [11]. These innovations contribute to a more efficient and sustainable agriculture, better adapted to modern challenges.

Materials and methods

The aim of this research is to assess farmers' adoption and perception of technological innovations and sustainable practices in agriculture. Specifically, the research aims to:

- ✓ To identify the level of use of digital technologies (GPS, sensors, drones) and precision farming among farmers and their perceived impact on efficiency and productivity.
- ✓ To analyze attitudes towards biotechnologies and alternative production, such as genetically modified crops, vertical farming and unconventional protein sources, in order to assess farmers' openness to these innovative methods.
- ✓ The investigation of sustainability measures and renewable energy practices implemented on farms to understand the level of awareness and involvement in sustainable farming approaches.

The quantitative research method used was a survey, based on a questionnaire as a working instrument, applied on a representative sample of agricultural enterprises, mainly in the South-East of Romania. The sample consists of 157 agricultural farms from the South-East region of Romania, taken into account as individual or organized agricultural holdings, managed by people who have a decision-making role regarding the technologies applied. This represents a significant section of the national agricultural context, given that this region is characterized by a great diversity of types of agricultural holdings and varied geographical conditions, and the results may provide a partial but relevant picture for the entire agricultural sector in Romania. In addition to applying the questionnaire survey, the analysis of the collected data was carried out using descriptive and inferential statistical methods. Comparative analysis of mean scores was used to evaluate the perception of the impact of technologies, and t-tests for independent samples were applied to verify the statistical significance of differences between groups (e.g. farmers using vs. non-using digital technologies). Pearson correlations were also used to analyze the relationships between variables such as farm size, education level and degree of adoption of innovations. The research aimed at testing three hypotheses, as follows:

Hypothesis 1: Farm businesses that use digital and precision farming technologies have a more positive perception of farm efficiency and productivity compared to those that do not. This hypothesis explores the relationship between the use of modern technologies (GPS, sensors, and drones) and farmers' perceptions of the impact of these technologies on farming efficiency. The hypothesis can be tested by analyzing the agreement scores on the statements in the "Digital Technologies and Precision Farming" section of the applied questionnaire.

Hypothesis 2: Farm businesses that are open to the use of biotechnologies (such as GM crops or gene editing) and alternative production methods (such as vertical farming or unconventional proteins) believe that these practices can improve the competitiveness and sustainability of their business. This hypothesis examines farmers' openness to biotechnologies and innovative methods and assumes that adopters perceive a high potential for improving yields and sustainability. Analysis of the responses in the “Biotechnology and Alternative Production” section can provide insights into the link between the adoption of biotechnology innovations and perceived on-farm benefits.

Hypothesis 3: Adoption of sustainability and renewable energy practices on farms is influenced by the level of awareness and access to information on the benefits of sustainability in agriculture. This hypothesis investigates whether farmers with high awareness of sustainable practices (controlled irrigation, bioenergy, renewable energy) are more likely to adopt sustainable measures. The scores obtained in the “Sustainability and Renewable Energy” section can be correlated with respondents’ awareness and attitudes towards sustainability.

The questionnaire on the degree of innovation applied in agriculture was constructed to test the proposed working hypotheses and comprises three sections: Digital Technologies and Precision Farming, Biotechnology and Alternative Production and Sustainability and Renewable Energy. Each item corresponding to a section is constructed on a Likert-type scale with 5 response variants, regarding the degree of agreement on a scale from 1 (strongly disagree) to 5 (strongly agree). The questionnaire was distributed by means of a google-form to agricultural enterprises, predominantly with an activity related to plant cultivation combined with animal husbandry and ancillary activities after harvesting. 157 responses were validated. The results were analyzed and interpreted using data analysis tools in Microsoft Office Excell. The survey conducted in this study has significant scientific importance as it provides valuable information on the adoption of modern agricultural technologies in Romania, which is essential for understanding the country’s progress in agricultural innovation and sustainability. Professionally, the results can influence policy decisions, guide future investments in agricultural technology, and help develop strategies to support farmers in integrating sustainable practices, improving productivity, and enhancing overall farm performance.

Results

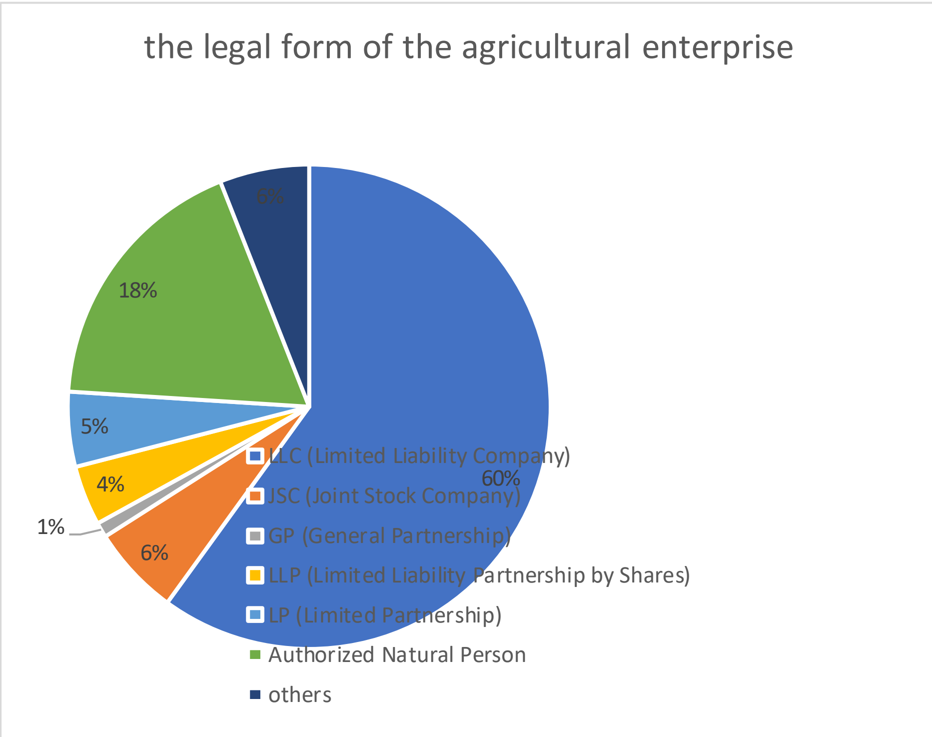
The dominance of Limited Liability Companies LLCs (60% of respondents) among farmers suggests that they prefer a business model that protects their personal assets, which is essential in a sector often plagued by risk and uncertainty. This choice may indicate an openness to adopting innovative technologies, as LLCs offer flexibility in managing resources and integrating sustainable practices.

The limited presence of JSCs, only 6% of total respondents, suggests that farmers are not attracted by more complex structures that impose strict requirements. This could reflect a reluctance to innovate in ways that require large investments and considerable financial risks. Only 1% of the surveyed enterprises have a GP as their legal form of organization, the rarity of the use of general partnerships may indicate a preference for structures that limit liability, which is important in the context of adopting risky technologies or experimenting with new farming practices.

In terms of Limited Liability Partnerships, 4% of respondents say they have this legal form. Close to 5% have Limited Partnership as their legal form, indicating that the limited use of limited partnerships may reflect a preference for simpler structures that are easier to manage in the context of implementing innovations. A significant share of 18% of ANPs suggests that many farmers opt for a simple structure, which allows them to test technological innovations and sustainable practices without engaging in the administrative complications of more complex organizational forms.

The 6% share for other forms of organization may indicate a diversity of approaches among farmers, which may include specific initiatives tailored to local needs, which is essential in the context of the adoption of technological innovations (Figure 1).

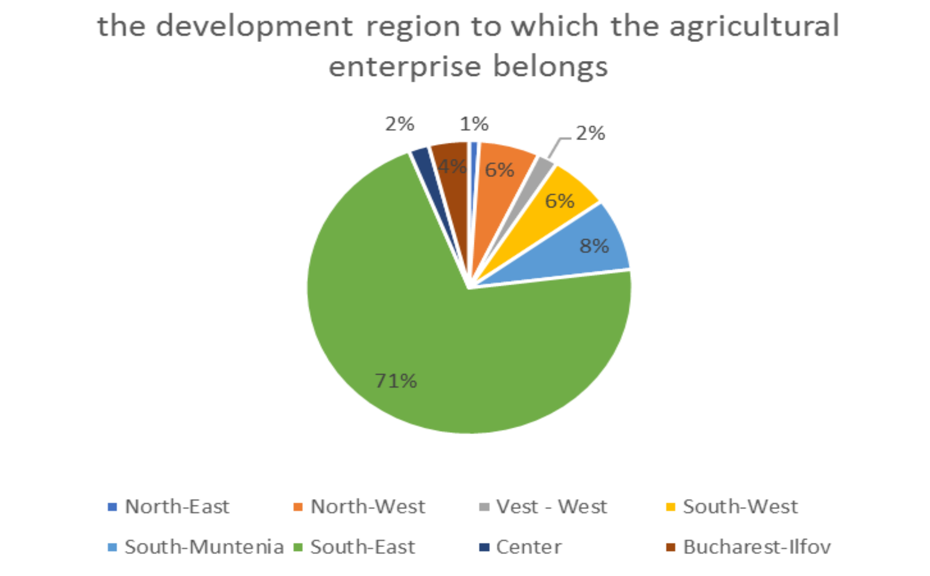
Figure 1. Distribution of responses by legal form of agricultural enterprises



Source: author's processing

In terms of the development region to which the agricultural enterprises participating in the survey belong, a majority 71% are from the South-East region, followed by a smaller percentage of 8% from the South-Muntenia region, then in equal percentages of 6% each from the North-West and South-West regions (Figure 2).

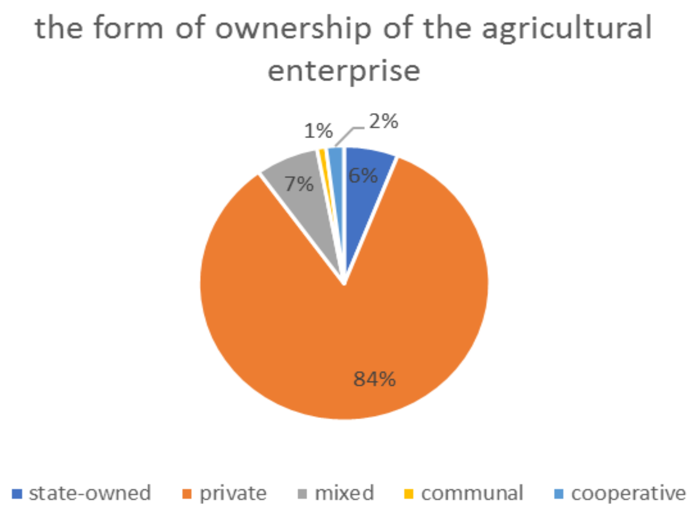
Figure 2. Distribution of responses by development region to which agricultural enterprises belong



Source: author's processing

With regard to the percentage distribution of responses for the form of ownership of the agricultural enterprises participating in the survey, the majority of 84% of the respondents had private ownership, followed by mixed and state ownership in relatively small percentages. (Figure 3)

Figure 3. Distribution of responses by form of ownership of agricultural enterprises



Source: author's processing

With regard to Section I of the questionnaire entitled "Digital technologies and precision farming", the distribution of responses and the score obtained for each of the statements in the section are presented in Table 1.

Table 1. Distribution of responses and score obtained for Section I

	Strongly Disagree (-2)	**Disagree (-1)**	**Neutral (0)**	**Agree (1)**	**Strongly Agree (2)**	**Total**	**Statement score**
We use GPS technologies for efficient field management.	17	22	20	74	24	157	0.420382
We constantly monitor soil moisture and conditions using sensors.	19	31	13	63	31	157	0.356688
We use drones to monitor crop health and optimize resources.	36	44	25	29	23	157	-0.261146
Digital technologies help us make more informed and quicker decisions regarding irrigation and fertilizer application.	29	28	2	67	31	157	0.273885
Digital platforms facilitate our access to markets and new clients.	6	16	3	41	91	157	1.242038

Source: author's processing

Claim 1 - "We use GPS technologies to effectively manage our fields" Score: 0.420. This positive but relatively low score indicates moderate agreement with the use of GPS technologies. GPS is probably used but is not an essential or very common element of field management.

Claim 2 - "We constantly monitor moisture and soil conditions using sensors" Score: 0.357

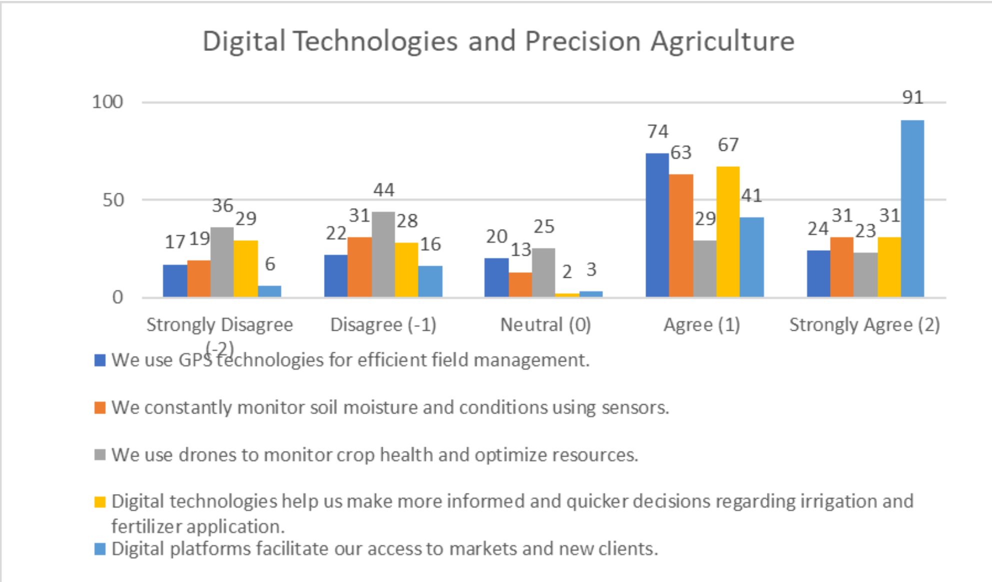
Similar to the first statement, this low positive score indicates poor agreement. Moisture and soil condition monitoring is probably used, but not intensively or consistently.

Claim 3 - "We use drones for crop health monitoring and resource optimization" Score: -0.261. The negative score indicates weak disagreement, suggesting that drones are rarely or only occasionally used, and their deployment for monitoring and optimization is not common practice in this context.

Claim 4 - "Digital technologies help us make more informed and faster decisions about irrigation and fertilizer application" Score: 0.274. A positive but low score, indicating a slight acceptance that digital technologies are useful in irrigation and fertilizer decisions, but they are not seen as a central solution in decision making.

Claim 5 - "Digital platforms facilitate our access to markets and new customers" Score: 1.242. This significantly positive score shows strong agreement, indicating that digital platforms are seen as a highly valuable tool for expanding access to markets and customers, likely to bring significant benefits to marketing and sales activities.

Figure 4. Distribution of responses Section I



Source: author's processing

Overall, the scores indicate a varied use of digital technologies in agriculture, with the highest appreciation for the impact of digital platforms in opening access to new markets.

Regarding Section II of the questionnaire entitled "Biotechnology and Alternative Production", the distribution of responses and the score obtained for each of the statements in the section are presented in Table 2.

Table 2. Distribution of answers and score obtained Section II

	Strongly Disagree (-2)	Disagree (-1)	Neutral (0)	Agree (1)	Strongly Agree (2)	Total	Statement score
We are implementing genetically modified crops (GMOs) to increase yield and pest resistance.	37	24	20	65	11	157	-0.070064
Genetic editing technologies such as CRISPR have been used to improve the quality of our production.	27	38	13	54	25	157	0.076433
We are interested in using insect proteins or other unconventional sources to expand our product range	61	30	25	23	18	157	-0.592357
We are considering integrating vertical farming or hydroponics into our production systems	54	51	2	33	17	157	-0.585987
We believe that no-till farming could enhance the sustainability of our farm	45	61	3	19	29	157	-0.471338

Source: author's processing

Claim 1 in section II: "We implement genetically modified crops (GMOs) to increase yield and pest resistance" scores -0.070063694, being close to zero, with a slight negative trend, indicating a rather balanced perception, where the potential advantages of GMOs are recognized, but there are also reservations about possible risks or disadvantages.

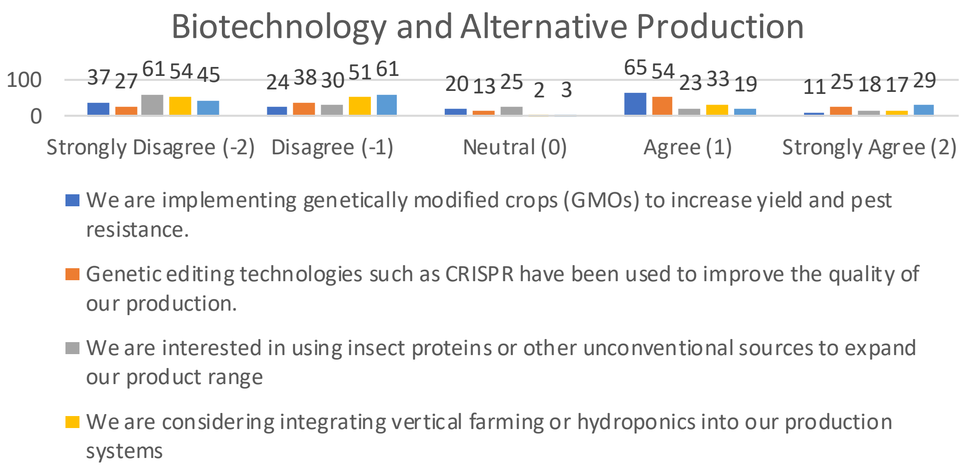
Claim 2 in section II: "Gene editing technologies such as CRISPR have been used to improve the quality of our output" scores 0.076433121, being close to zero, with a slight positive skew, reflecting a moderately favorable attitude towards the use of CRISPR, possibly due to the recognition of the advantages in terms of efficiency and quality, but also to a focus on ethics and safety.

Claim 3 in Section II: "We are interested in using insect protein or other unconventional sources to expand our product offerings" scores -0.592356688. This stronger negative score suggests a significant reluctance to introduce insect proteins, likely due to cultural perceptions and consumer acceptance concerns.

Claim 4 in Section II: "We are considering integrating vertical farming or hydroponics into our production systems" scores -0.585987261. This moderate negative score indicates a clear hesitancy towards the adoption of vertical farming or hydroponics, possibly due to high initial investment, yield uncertainty or technical limitations.

Claim 5 in Section II: "We believe that no-till farming could improve the sustainability of our farm" scores -0.47133758. The moderate negative score suggests a somewhat reserved stance towards no-till farming, perhaps due to implementation challenges on the farm or a perception that the benefits are not very clear in the current context.

Figure 5. Distribution of responses Section II



Source: author's processing

Overall, the scores reflect a cautious openness to modern technologies and innovative production methods, combined with a pragmatic assessment of risks and challenges.

As regards Section III of the questionnaire entitled "Sustainability and Renewable Energy", the distribution of responses and the score obtained for each of the statements in the section are presented in Table 3.

Table 3. Distribution of answers and score obtained Section III

	Strongly Disagree (-2)	Disagree (-1)	Neutral (0)	Agree (1)	Strongly Agree (2)	Total	Statement score
We use solar panels or wind turbines to generate energy on the farm.	11	31	1	77	37	157	0.624203822
We have implemented drip irrigation systems to reduce water consumption and improve efficiency.	15	19	0	47	76	157	0.955414013
Our irrigation systems are controlled by sensors, optimizing water resources.	30	47	0	39	41	157	0.089171975
Sustainability is a priority in our agricultural management decisions.	17	16	2	72	50	157	0.777070064
We use or are considering using agricultural residues to generate bioenergy.	19	35	18	51	34	157	0.292993631

Source: author's processing

Claim 1 in Section III: "We use solar panels or wind turbines to generate energy on the farm" scores 0.624203822, a moderate positive score, indicating good support for the use of solar or wind energy, suggesting that this practice is seen as beneficial, even though there may be some degree of reluctance to full or continued implementation.

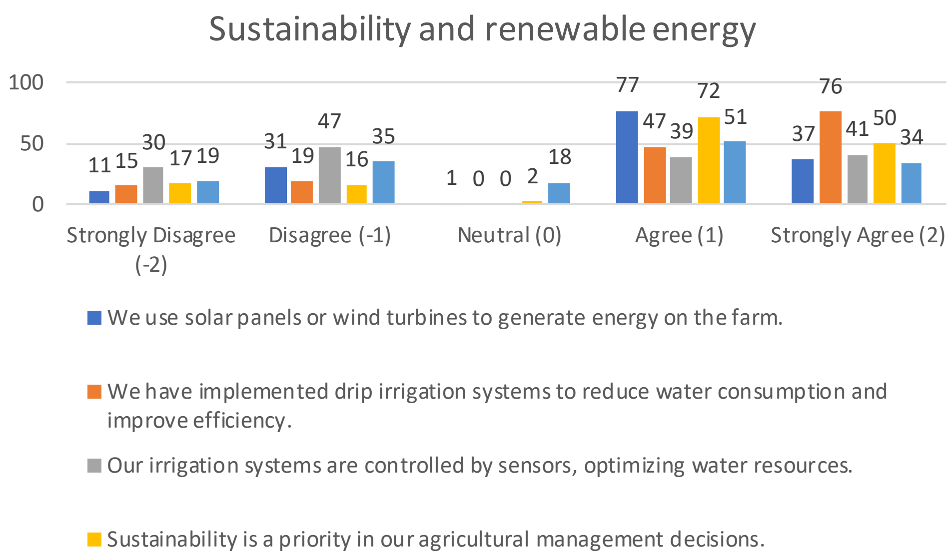
Claim 2 in Section III: "We have implemented drip irrigation systems to reduce water use and improve efficiency" scores 0.955414013, a high positive score, shows strong agreement, suggesting that drip irrigation is considered highly effective and desirable for the goals of saving water and increasing efficiency on the farm.

Claim 3 in Section III: "Our irrigation systems are controlled by sensors, optimizing water resources", gets a Score: 0.089171975, close to zero, this score suggests a neutral perception, perhaps with slight support for the use of sensors in irrigation. This may reflect some caution, either due to cost or a lower level of confidence in fully implementing the technology.

Claim 4 in Section III: “Sustainability is a priority in our agricultural management decisions” scores 0.777070064, a strong positive score suggesting high agreement, showing that sustainability is perceived as a clear priority in agricultural management decisions, although there may be a small reservation about implementation.

Claim 5 in Section III: “We use or are considering the use of agricultural residues to generate bioenergy” scores 0.292993631. This positive, but lower, score indicates moderate support, suggesting an interest in bioenergy, but perhaps a lack of full implementation at present, either due to technical challenges or costs involved.

Figure 6. Distribution of responses Section III



Source: author’s processing

Overall, these scores suggest a clear openness and support for renewable energy and sustainability practices, with varying levels of enthusiasm, but all in a positive direction, indicating a commitment to sustainable practices on the farm.

The results of this questionnaire contributed to the assessment of the degree of innovation in agriculture and the identification of potential areas for development. The interpretation of the scores obtained using the Likert scale is based on the analysis of the mean values of the responses, their trends and variation in order to understand the degree of agreement or disagreement of the respondents with different statements. The low or medium scores obtained indicate that innovation management requires additional support, such as funding, training or awareness campaigns to be better adopted in Romanian agriculture.

As regards the evaluation of hypotheses based on the results obtained, the following is observed:

Hypothesis 1: Partially confirmed. Farmers using digital technologies have a positive perception of efficiency and productivity, but the scores suggest varied and moderate use of these technologies. The use of digital platforms for market access scored highest, indicating an appreciation of their impact, but not all technologies (e.g. drones) have been widely adopted.

Hypothesis 2: Not confirmed. Farmers show reluctance towards biotechnologies and alternative production methods such as GM crops and insect proteins. Negative scores suggest considerable reluctance to adopt these innovations, which contradicts the hypothesis that these practices are seen to improve competitiveness and sustainability.

Hypothesis 3: Partially confirmed. There is evidence that levels of awareness and access to information affect the adoption of sustainability and renewable energy practices. Although farmers consider sustainability a priority, actual implementation of sustainable practices is not uniform, suggesting that information and awareness may influence their decisions, but are not sufficient to ensure full adoption. The present study highlighted that most farms in the South-East region of Romania use traditional technologies, with a limited adoption of advanced digital tools, which reflects the concordance with national trends, according to a recent report published by the Government of Romania [12], the level of digitalization in Romanian farms is low, although the use of advanced technologies such as sensors, drones, satellite imaging or artificial intelligence could significantly increase the profitability of the sector.

Conclusions

Based on the results obtained from research and the assessment of hypotheses, several recommendations are highlighted to support the adoption of digital technologies, biotechnologies and sustainability practices in agriculture: awareness and education campaigns, financial support and subsidies, partnerships with research institutions, implementation of favorable policies, pilot projects, feedback and continuous adjustments. The study on the adoption of innovative technologies in Romanian agriculture highlights a moderate degree of their use, confirming hypothesis H1 on the positive impact of digital technologies on farm performance. The results show that farmers using digital technologies, such as farm management software or drones for crop monitoring, reported significant improvements in efficiency and productivity. Also, larger farms, with a size of over 50 ha, play an important role in the adoption of modern technologies, which supports hypothesis H3 on the impact of farm size on the capacity to implement innovations. In contrast, reluctance towards biotechnologies and advanced technologies, such as genetically modified organisms, is mainly due to lack of information and restrictive regulations, and this aspect aligns with the perceptions of farmers reported in the survey.

Develop awareness campaigns to inform farmers about the benefits of using digital technologies, biotechnologies and alternative production methods. These campaigns could include training sessions, workshops and seminars addressing the myths and fears associated with these technologies. Implement subsidy and financial support programs for farmers willing to invest in digital technologies, biotechnologies and sustainable farming practices. This could include providing funds for the purchase of equipment, such as sensors or drones, and for the implementation of efficient irrigation systems. Increase collaboration between farmers, research institutions and universities to develop innovative solutions tailored to local needs. These partnerships could facilitate technology and knowledge transfer between researchers and practitioners. Advocate for agricultural policies that support the adoption of innovations, such as regulations favoring the use of genetically modified organisms (GMOs) and incentives for organic production methods. Pilot projects demonstrate the effectiveness and benefits of digital technologies and alternative production methods. These projects can serve as case studies for other farmers and encourage wider adoption. Create feedback mechanisms for farmers to share their experiences and challenges in adopting new technologies. This feedback could be used to adjust training and support programs.

These recommendations can contribute to increasing innovation and adoption of sustainable practices in Romanian agriculture, facilitating a transition towards a more competitive and sustainable agriculture. The results of the study suggest that, although there is a growing interest in sustainable technologies, such as renewable energy sources and organic farming, more support from authorities is needed to encourage the transition to digital technologies and to facilitate smallholder farmers' access to resources and training. Public policies need to focus on the education and continuous training of farmers, as well as on developing the infrastructure necessary for the large-scale integration of these technologies. Implementing subsidies and incentives for investments in digital technologies and renewable energy sources would significantly contribute to accelerating the modernization process of the Romanian agricultural sector. Steps for future research could include expanding the study to include a larger sample of farms from other regions of Romania, in order to obtain a complete picture of the adoption of innovative agricultural technologies at the national level. It would also be useful to analyze the specific impact of each technology on the sustainability and economic performance of farms, as well as the socio-economic factors that influence farmers' decision to adopt these technologies.

Conflict of interests

The authors declare no conflict of interest.

References

1. *** European Commission, Digitization of the European agricultural sector, available at https://digital-strategy.ec.europa.eu/ro/policies/digitalisation-agriculture

2. *** European Commission, Handbook on Smart Farming, available at chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://ec.europa.eu/programmes/erasmus-plus/project-result-content/55cdd1e8-711c-4d5a-a88f-069eabd8f947/RO_Habdbook_Smart_farming-_FINAL_with_more_pic_-_RO_translation-1.pdf
3. *** European Court of Auditors, Special Report 19/2024: Organic Farming in the EU, available at chrome-extension://efaidnbmnbmnnnnnibpcajpcglglclefindmkaj/https://www.eca.europa.eu/ECAPublications/SR-2024-19/SR-2024-19_RO.pdf
4. *** Institutul Național de Statistică. (2024). Hotărârea Guvernului privind aprobarea Programului statistic național anual 2024. https://insse.ro/cms/files/legislatie/Initiative%20legislative/2024/HG-PSNA-2024.pdf
5. Andrei, J. V., & Darvasi, D. (2012). Perspectives and challenges in financing the new Common Agricultural Policy, a new paradigm.
6. Cillo, V.; Petruzzelli, A.M.; Ardito, L.; Del Giudice, M. Understanding sustainable innovation: A systematic literature review. *Corp. Soc. Responsib. Environ. Manag.* **2019**, *26*, 1012–1025
7. Ciurea, M. (2020). Considerations Regarding the Digitalization of Romanian Agriculture. Proceedings of the 2nd International Scientific and Practical Conference on Digital Economy (ISCDE 2020), 542–546. https://doi.org/10.2991/aebmr.k.201205.090
8. Done, I., Chivu, L., Andrei, J., & Matei, M. (2012). Using labor force and green investments in valuing the Romanian agriculture potential. *Journal of Food Agriculture & Environment*, *10*(3-4), 737-741.
9. Gheorghe, G. V., Dumitru, D.-N., Ciupercă, R., Mateescu, M., Mantovani, S. A., Prisacariu, E., & Harabagiu, A. (2024). Advancing precision agriculture with UAV's: Innovations in fertilization. *INMATEH – Agricultural Engineering, 74*(3), 1057–1072. https://doi.org/10.35633/inmateh-74-89
10. Girip, M., & Cojocaru, D. (2021). Internet of Things in Romanian Agriculture. Proceedings of the International Conference on Business Excellence, 15(1), 570–583. https://doi.org/10.2478/picbe-2021-0053
11. Khan, N., Ray, R. L., Kassem, H. S., & Zhang, S. (2022). Mobile Internet Technology Adoption for Sustainable Agriculture: Evidence from Wheat Farmers. Applied Sciences, 12(10), 4902.
12. Kilcher, L. and collab. (2001) - *The Organic Market in European Union.* Uniware AG, Zurich
13. Markovits, P. Ș. (2024). Assessing Romanian Farmers' Motivation for Digitalization: A Unified Theory of Acceptance and Usage of Technology (UTAUT) Based Research Model. Oradea Journal of Business and Economics, 9(1), 98–112.
14. Milačić, D. (2024). Strategijski menadžment kao instrument razvoja održivog turizma u Srbiji. *Održivi razvoj*, *6*(2), 7-22. https://doi.org/10.5937/OdrRaz2402007M

15. Petrescu-Mag, R. M., Banatean-Dunea, I., Vesa, S. C., Copacinschi, S., & Petrescu, D. C. (2019). What Do Romanian Farmers Think about the Effects of Pesticides? Perceptions and Willingness to Pay for Bio-Pesticides. Sustainability, 11(13), 3628. https://doi.org/10.3390/su11133628
16. Pop, S.-B., Pop, N., & Rusu, T. (2023). Analysis of sustainable development of agricultural land in the North-West Development Region of Romania. *Agricultura*, 128(3–4), Article 14723 DOI: https://doi.org/10.15835/agr.v129i3-4.14723
17. Rodino, S., Buțu, M., Buțu, A., & Lazăr, C. (2023). Challenges of digital transformation in agriculture from Romania. *Romanian Agricultural Research, 40*(18), 713–721. https://doi.org/10.59665/rar4066
18. Rusu, B., Sandu, C. B., Avasilcai, S., & David, I. (2023). Acceptance of Digital Transformation: Evidence from Romania. Sustainability, 15(21), 15268. https://doi.org/10.3390/su152115268
19. Ruzzante, S. W., & Bilton, A. M. (2018). Agricultural Technology in the Developing World: A Meta-Analysis of the Adoption Literature. ASME 2018 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.
20. Samuil, C., (2007), *Tehnologii de agricultură ecologică*, Iași, pp. 7-10
21. Șerban, D.-G., Lungu, E., Trifan, D., & Turek Rahoveanu, M. M. (2023). Research On Digitization in Agricultural Farms from Romania. Information Systems Management Research: 41ISM 2023.
22. Stanciu, S., & Sârbu, R. (2016). Sustainability and Competitiveness of Romanian Farms through Organic Agriculture. Sustainability, 8(3), 245. https://doi.org/10.3390/su8030245
23. Stanciu, S., & Sârbu, R. (2019). Research on the Use of GMOs in Romanian Food Production. Journal of Eastern Europe Research in Business and Economics, 2019, Article ID 551068. https://doi.org/10.5171/2019.551068
24. Stojković, A., & Kocić, S. (2024). Analysis of stress disorders and public speaking. Finansijski savetnik - časopis za pravo i finansije, 1(29).27-38.
25. Vac, C. S., Andreica, I., & Roman, I. A. (2023). Prospects for Research, Development, Innovation and Technology Transfer in Romanian Horticulture. *Sustainability*, *15*(13), 10215. https://doi.org/10.3390/su151310215
26. Vărzaru, A. A. (2025). Digital Revolution in Agriculture: Using Predictive Models to Enhance Agricultural Performance Through Digital Technology. Agriculture, 15(3), 258. https://doi.org/10.3390/agriculture15030258
27. Wistinghauser S., (1994) - *Biodynamic farm*, Editura Enciclopedică, Bucharest, translated edition.
28. Wongsim, M., Sonthiprasat, R., & Surinta, O. (2018). Factors Influencing the Adoption of Agricultural Management Information Systems in Thailand. 2018 3rd Technology Innovation Management and Engineering Science International Conference (TIMES-iCON)

29. Zheng, S., Wang, Z., & Wachenheim, C. J. (2019). Technology adoption among farmers in Jilin Province, China. China Agricultural Economic Review, 11(1), 206–216.

Annex:1 Questionnaire

Instructions: For each statement, please indicate the degree of agreement using the scale from 1 (strongly disagree) to 5 (strongly agree).

Section I: Digital Technologies and Precision Farming

Claim	Total disagreement	Disagreement	Whatever	Agreement	Total agreement
1. We use GPS technologies for the efficient management of our fields	1	2	3	4	5
2. We constantly monitor moisture and soil conditions using sensors	1	2	3	4	5
3.We use drones to monitor crop health and optimize resources.	1	2	3	4	5
4. Digital technologies help us make more informed and faster decisions on irrigation and fertilizer application.	1	2	3	4	5
5. Digital platforms facilitate our access to markets and new customers.	1	2	3	4	5

Section II: Biotechnology and Alternative Production

Claim	Total disagreement	Disagreement	Whatever	Agreement	Total agreement
1. We implement genetically modified (GM) crops to increase yield and pest resistance.	1	2	3	4	5
2. Gene-editing technologies such as CRISPR have been used to improve the quality of our production.	1	2	3	4	5
3. We are interested in using proteins from insects or other unconventional sources to expand our product offering.	1	2	3	4	5

Claim	Total disagreement	Disagreement	Whatever	Agreement	Total agreement
4. We consider integrating vertical farming or hydroponics into our production systems	1	2	3	4	5
5. We believe that no-till farming could improve the sustainability of our farm.	1	2	3	4	5

Section III: Sustainability and Renewable Energy

Claim	Total disagreement	Disagreement	Whatever	Agreement	Total agreement
1. Use solar panels or wind turbines to generate energy on the farm	1	2	3	4	5
2. We have implemented drip irrigation systems to reduce water consumption and improve efficiency.	1	2	3	4	5
3. Our irrigation systems are controlled by sensors, optimizing water resources.	1	2	3	4	5
4. Sustainability is a priority in our agricultural management decisions.	1	2	3	4	5
5. We use or consider using agricultural residues to generate bioenergy	1	2	3	4	5