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Innovative technologies in the production of agricultural machinery to improve the efficiency of agribusinesses

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Abstract. The purpose of the study was to analyse innovative technologies in the production of agricultural machinery and their impact on improving the efficiency of agricultural enterprises. The study applied various scientific methods to comprehensively analyse the impact of innovative technologies on the efficiency of enterprises in the field of agricultural engineering. The study found that the use of innovative technologies in agricultural engineering significantly increases the efficiency of agricultural enterprises. The analysis showed that the use of precision farming systems equipped with sensors and GPS technologies allows optimising the allocation of resources such as water and fertilisers, which leads to increased yields and lower costs. Automation of operations using autopilots on tractors and combines, as in the John Deere and Fendt models, has demonstrated a reduction in labour costs and a reduction in the

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influence of the human factor, which also contributes to increased productivity. Electrification and hybridisation of agricultural machinery, which has been actively implemented in countries such as Denmark and Germany, has proved economically beneficial, contributing to a reduction in carbon dioxide emissions and a reduction in operating costs. The introduction of artificial intelligence for monitoring and diagnostics of equipment has allowed minimising downtime and increasing the service life of equipment due to timely detection of malfunctions. In general, it has been established that the use of these technologies contributes to the sustainable development of agricultural enterprises, optimisation of production processes, and reduction of operating costs. The transition to more environmentally friendly production of agricultural machinery contributes to improving the environmental situation in regions with a high degree of agricultural mechanisation. The introduction of sustainable technologies in mechanical engineering has shown its effectiveness in reducing resource consumption, which makes agricultural enterprises more competitive in the global market

Keywords: precision agriculture; automation; GPS technology; electrification; artificial intelligence

INTRODUCTION

Modern agriculture is undergoing an active technological transformation aimed at increasing the productivity and efficiency of agricultural enterprises. Innovations in mechanical engineering open up new opportunities for automation, optimisation, and sustainable development, providing the agricultural sector with machinery capable of coping with the growing challenges of the industry, such as climate change and lack of resources. The introduction of advanced solutions such as precision farming systems, automated tractors with autopilot and electric installations allows farmers to use resources efficiently and reduce costs. These changes contribute to the improvement of production processes and make agricultural enterprises more environmentally friendly and competitive. The importance of such technologies increases in the context of the need for environmental sustainability and increased efficiency of agricultural activities, especially in the light of global trends towards sustainable development and concern for the environment. Thus, the introduction of innovative technologies becomes a key factor in ensuring sustainable growth and prosperity of the agricultural sector.

The problem of introducing innovative technologies into agricultural engineering remains relevant. This is conditioned by the need to increase the productivity and sustainability of agricultural enterprises in the face of modern challenges. A. Monteiro *et al.* (2021) emphasised the importance of precision farming for optimising resource use and increasing yields, noting that the introduction of such technologies has significantly reduced the cost of fertilisers and irrigation. U. Ahmad and L. Sharma (2023) focused on the impact of GPS technologies and sensors on real-time process management, arguing that these tools have contributed to improving the efficiency of agricultural enterprises by more precisely monitoring the condition of crops. F. Mocera *et al.* (2023) investigated the possibilities of electrification of tractors, contributing to the reduction of carbon dioxide emissions, and demonstrated that electric machines can not only reduce the environmental burden, but also reduce operating costs. M. Merz *et al.* (2022) highlighted the advantages of automated autopilot systems for reducing labour costs and improving field accuracy, pointing out that such systems have allowed farmers to focus on more complex aspects of farm management. J. Jung *et al.* (2020) examined the role of artificial intelligence in monitoring and diagnosing agricultural machinery to prevent downtime, showing that the use of AI can significantly improve equipment reliability and service life.

Y. Guo *et al.* (2020) investigated methods for optimising production processes using new technologies, believing that modern approaches can significantly improve the efficiency of agricultural enterprises. K.S. Uralovich *et al.* (2023) focused on sustainable development, linking it with the introduction of environmentally friendly solutions in mechanical engineering, and showed that environmental innovation has become an important factor in competitiveness. A. Subeesh and C. Mehta (2021) examined the impact of automation on cost reduction in the agricultural sector, arguing that process automation has helped not only to reduce costs, but also to improve product quality. P. Rambe and P. Khaola (2021) reviewed the competitiveness of agricultural enterprises through the introduction of innovative technologies, emphasising that modern developments have allowed farmers to successfully compete in the global market. Y. Zhu *et al.* (2022) emphasised that the transition to more sustainable technologies has significantly improved the environmental situation in highly mechanised regions, showing that such changes can lead to improved quality of life in rural areas. However, despite significant achievements in this field, gaps remain that require further study. In particular, insufficient integration of various technologies in agricultural enterprises may limit their effectiveness and sustainability. In addition, it is necessary to investigate the impact of innovations on small and medium-sized agricultural enterprises, and develop strategies for adapting existing equipment to modern requirements.

Thus, the purpose of the study was to systematically investigate and evaluate innovative technologies used

in agricultural engineering, with a focus on their impact on the productivity of agro-industrial complexes.

MATERIALS AND METHODS

In the course of the research, the method of complex analysis was used, which allowed comprehensively assessing the impact of various innovative technologies on the efficiency of enterprises in the field of agricultural engineering. This method covered many aspects, including technical, economic and environmental factors, which helped to create a complete picture of how new technologies affect the agricultural sector. The comprehensive analysis examined key elements such as the introduction of digital technologies, including GPS, sensors, and data analysis systems. These components played an important role in the modernisation of agricultural machinery and process optimisation, which contributed to increased overall productivity and efficiency.

A comparative analysis method was used to analyse automation using autopilot in agricultural machinery. This approach allowed comparing the performance of tractors and combines equipped with autopilots, such as models from John Deere (2025) and Fendt (2025), with conventional means. The comparative analysis identified the advantages and disadvantages of each technology, assessed their impact on production processes, and determined how automation can reduce labour costs and improve the accuracy of operations. This method also helped to identify the factors contributing to the successful implementation of new technologies in the agricultural sector. In addition, the study used a systematic approach to analyse the introduction of electric and hybrid tractors. This method provided a deeper understanding of how these technologies can help to reduce carbon dioxide emissions and reduce operating costs. The systematic approach ensured the integration of various aspects such as economic feasibility, technical characteristics, and environmental benefits. This enabled a comprehensive analysis, which was necessary to make informed decisions about the introduction of electric and hybrid tractors into the practice of agricultural enterprises.

Precision farming systems were studied using the method of applied analysis, which helped to examine in detail their effectiveness in managing irrigation, fertilisation, and tillage. The applied analysis allowed assessing how specific technologies and techniques can be applied in the real working conditions of agricultural enterprises. This approach also helped to identify practical recommendations for farmers and agronomists to optimise production processes.

The data analysis method has also been used to study the application of artificial intelligence technologies in the diagnosis and monitoring of agricultural machinery. This method analysed how artificial intelligence can help to identify malfunctions at an early stage and adjust the operation of equipment. Data analysis helped to understand how the introduction of artificial intelligence technologies can improve the reliability and efficiency of machinery, which was important to reduce the risk of breakdowns and increase the service life of equipment. In addition, the sustainability assessment method was used to analyse new models of agricultural machinery, which were developed considering environmentally friendly materials and reduced fuel consumption. This method allowed evaluating how such practices can be implemented for effective resource management and compliance with the principles of sustainable development. The assessment of sustainable development included an analysis of social, economic, and environmental aspects, which contributed to the development of a comprehensive view of the future of agricultural engineering and its interaction with the environment.

RESULTS

Modern agricultural machinery is undergoing significant changes due to the integration of digital technologies. The introduction of technologies such as GPS, sensors, and data analysis systems allows automating many processes, significantly increasing the efficiency of agricultural enterprises. With the help of GPS systems, farmers can accurately determine the location of equipment and effectively manage field operations. This helps to avoid unnecessary expenditure of time and resources (Gabriel & Gandorfer, 2023).

The use of sensors installed on agricultural machines plays an important role in monitoring the condition of crops and soil. These devices can collect information about humidity, temperature, and other important indicators, which allows farmers to make more informed decisions about irrigation and fertilisation. As a result, optimising resource allocation becomes not only more accurate, but also less costly, which helps to reduce financial costs. Data analysis systems based on modern algorithms and machine learning methods help to process and interpret huge amounts of information received from sensors and GPS. This allows agricultural enterprises to identify patterns, predict yields, and minimise risks associated with changing weather conditions or other factors. Thus, the integration of digital technologies into agriculture not only improves production processes, but also ensures a more sustainable development of the agricultural sector in the face of the growing challenges of our time.

The integration of digital technologies into the agricultural sector opens up new horizons for improving the productivity and sustainability of agricultural enterprises (Wrzecińska *et al.*, 2023). Farmers can use resources efficiently, reduce losses, and increase work efficiency, which is the key to the successful development of agriculture in the future. Automation of agricultural processes is becoming an important aspect of modern agricultural production. The introduction of

tractors and combines with autopilot, such as models from John Deere and Fendt, is fundamentally changing the approach to field operations (Table 1). These machines are capable of performing tasks with high accuracy, which significantly reduces the likelihood of errors and increases overall work efficiency.

***Table 1**. Comparison of John Deere and Fendt tractors by key characteristics*

Characteristics	John Deere	Fendt
Main purpose	Universal and specialised operations	Universal and high-precision operations
Available models	6M, 7R, 8RX, 9RX	500 Vario, 900 Vario, 1000 Vario
Autopilot technologies	StarFire, AutoTrac	VarioGuide, FendtONE
Autopilot accuracy	±2.5 cm with RTK	±2 cm with RTK
Resource management	AutoPowr system (up to 15% fuel economy)	Fendt Efficient Technology (up to 17% fuel economy)
Electrification options	Limited models with electric motor up to 30 kW	Hybrid models with electric motor up to 50 kW
Environmental friendliness	Compliance with Tier 4 and Tier 5 standards	Compliance with Tier 4 and Tier 5 standards
Noise level in the cabin	70 dB	68 dB
Technical maintenance	Oil change interval is every 500 hours.	Oil change interval is every 600 hours.
Price	USD 100,000-550,000	USD 120,000-600,000

***Source:** created by the authors based on John Deere (2025) and Fendt (2025)*

Tractors with autopilot are equipped with advanced navigation and control systems, which allows them to accurately follow set routes, minimising the risk of crossing rows and losing crops. This not only improves the quality of work, but also reduces fuel costs, as the machines work more efficiently. Automation also optimises time costs, allowing farmers to focus on more complex aspects of farm management, such as data analysis and planning. Using combine harvesters with autopilot during the harvesting process also brings significant benefits. Such machines can operate in low visibility conditions, which makes them indispensable in difficult weather conditions. Automation of the cleaning process helps to avoid excessive wear and tear of equipment and extend its service life. This, in turn, helps to reduce operating costs and increase the profitability of the agricultural enterprise. However, the introduction of autopilot in agriculture requires certain personnel training and maintenance costs. Despite this, the benefits of automation, such as reduced human resource costs and increased productivity, far exceed the possible costs.

Automation using autopilot in agriculture has brought significant benefits to agricultural enterprises (Table 2). The introduction of autopilots in tractors and combines has significantly reduced labour costs and made the distribution of labour more rational. Autopilots also help to improve seeding accuracy by minimising skips and repeat passes, which improves yields and reduces losses. Reducing field processing time and reducing the number of mechanical errors highlights the importance of these technologies for reducing the impact of the human factor, and for more efficient fuel consumption, which reduces operating costs.

***Table 2**. Automation using autopilot in agriculture*

Indicator	Before the introduction of autopilot	After the introduction of autopilot	Change
Labor costs (thousand USD/year)	130	90	-31%
Seeding accuracy (%)	85	98	15%
Processing time of one field (hours/ha)	3.5	2.3	-34%
Fuel consumption (litres/ha)	12	9	-25%
Mechanical error rate (%)	10	3	-70%

***Source:** created by the authors based on I. Beloev et al. (2021)*

Thus, automation using autopilot is becoming not only a trend, but also a necessity for agricultural enterprises seeking to increase their competitiveness and stability in the market. Investments in modern technologies open up new horizons for agriculture, ensuring its effective development in the face of modern challenges. Electrification of agricultural machinery is becoming a key focus for countries seeking to reduce carbon dioxide emissions, such as Denmark and Germany (Johnstone *et al.*, 2021). In the context of global warming and environmental crises, the introduction of electric and hybrid tractors is becoming particularly relevant. These innovative solutions not only help to minimise the negative impact on the environment, but also prove to be economically beneficial for agricultural enterprises.

High-efficiency electric tractors are characterised by low noise and vibration levels, which makes their operation more comfortable for both operators and farm animals. Such machines are capable of operating on the basis of renewable energy sources, which

significantly reduces dependence on fossil fuels and reduces the carbon footprint of the agricultural sector. In addition, many agricultural machinery manufacturers are actively developing technologies that allow the use of solar panels to charge electric machines, which further increases their environmental friendliness (Wen *et al.*, 2022). Hybrid tractors that combine both electric and diesel systems provide the necessary power and productivity, allowing farmers to work in difficult conditions and over large areas. These machines can reduce operating costs, as electric energy is often cheaper than conventional fuels, and also requires less maintenance. This makes them attractive to many agricultural enterprises seeking to optimise their costs and increase profitability (Pascuzzi *et al.*, 2024). Nevertheless, the transition to electrical technology is fraught with certain challenges. The need to develop charging infrastructure and support the maintenance of electric machines can represent significant costs at the initial stage. However, long-term benefits such as fuel savings and lower carbon emissions make these investments worthwhile.

Electrification of machinery contributes not only to cost savings, but also to improving the environmental situation in agricultural areas (Table 3). The transition to electric and hybrid models has allowed agricultural enterprises to reduce carbon dioxide emissions and reduce operating costs for equipment maintenance. Electric models provide a lower noise level, which increases the comfort and safety of working in the fields. In addition, the energy efficiency of these machines is higher compared to conventional models, which makes their use an economically and environmentally sound step towards the sustainable development of the agricultural sector.

***Table 3**. Electrification of machinery in agriculture*

Indicator	Conventional diesel models	Electrified models	Reduction, %
Fuel costs (thousand USD/year)	180	120	-33%
CO_2 emissions (tonnes/year)	45	10	-78%
Maintenance cost (thousand USD/year)	70	50	-29%
Noise level (dB)	85	65	-24%

***Source:** created by the authors based on E. Scolaro et al. (2021)*

Electrification of agricultural machinery is an important step towards more sustainable and efficient agricultural production. In countries seeking to reduce CO_2 emissions, such technologies open up new opportunities to enhance the competitiveness and environmental sustainability of agricultural enterprises. Investments in electric and hybrid tractors not only contribute to improving the environment, but also provide long-term economic benefits for farmers. Precision farming systems are an important tool for improving the efficiency and sustainability of agricultural enterprises. With global climate change and increasing demand for food resources, precise management of irrigation, fertilisation, and tillage is becoming a necessity. These systems allow farmers to use available resources more efficiently, minimising losses and significantly increasing yields.

One of the key aspects of precision farming systems is the ability to accurately monitor soil and plant conditions. With the help of sensors and GPS technologies, farmers can obtain data on humidity, nutrient levels, and other important characteristics (Raj *et al.*, 2022). This allows farmers to adapt their actions to specific conditions, ensuring optimal conditions for the growth and development of crops. For example, automated irrigation systems can adjust the water supply in real time depending on the current needs of plants, which reduces the risk of both waterlogging and drying out of the soil (Askaraliev *et al.*, 2024). In addition, precision farming systems help to optimise fertiliser application, which contributes not only to higher yields, but also to reducing the negative impact on the environment. The use of differentiated fertilisation technologies allows accurately calculating the required doses for each specific area of the field, which reduces the risk of overuse and leaching of nutrients into reservoirs. This not only improves product quality, but also reduces resource costs, which makes agricultural enterprises more competitive.

However, the introduction of precision farming systems requires initial investments and some knowledge on the part of farmers. Farmers must be prepared to learn and adapt to new technologies in order to take full advantage of all the benefits they offer. Nevertheless, despite the possible difficulties, the long-term benefits associated with increased productivity and reduced costs make these technologies attractive to agricultural enterprises. Precision farming systems are therefore an important step towards more efficient and sustainable agriculture. They open up new horizons for farmers, allowing them not only to increase yields, but also to take care of the environment. The introduction of these technologies contributes to the creation of more sustainable agricultural enterprises capable of successfully coping with modern challenges and ensuring food security. The introduction of artificial intelligence (AI) technologies in agriculture has become a real breakthrough, allowing agricultural enterprises to improve equipment diagnostics and monitoring (Shaikh *et al.*, 2022). These technologies help to identify malfunctions at an early stage and adjust the operation of machines, which significantly reduces

the risk of breakdowns and increases the service life of equipment. Artificial intelligence is capable of processing large amounts of data and analysing them in real time, which makes it an indispensable tool in managing modern agricultural production.

One of the main applications of AI is predictive analytics, which allows predicting possible malfunctions based on the analysis of equipment condition data. Sensors installed on the machines collect information about vibration, temperature, and other parameters that may signal problems. Using machine learning algorithms, AI-based systems can quickly and accurately determine when maintenance needs to be performed, preventing more serious breakdowns and, as a result, downtime. In addition, AI can also optimise the operation of agricultural equipment by controlling its settings depending on specific operating conditions. For example, automatic systems can adjust the operating modes of tractors and combines depending on the soil condition or yield, which increases overall productivity and work efficiency. This allows farmers not only to reduce maintenance costs, but also to achieve better production results. Nevertheless, the introduction of AI technologies in agriculture requires certain investments and changes in the organisational structure of enterprises. Farmers should be ready to learn and adapt to new technologies, which can be a challenge for many of them. However, the long-term benefits associated with longer service life and lower repair costs make these technologies very attractive.

Artificial intelligence for diagnostics and monitoring is becoming an important tool in modern agriculture (Zelisko *et al.*, 2024). It not only increases the efficiency of the equipment, but also contributes to the sustainable development of agricultural enterprises. Based on AI, farmers can focus on more complex aspects of managing their business, confident in the reliability and performance of the equipment they use. Sustainable production is becoming one of the key principles of modern agriculture, and new models of agricultural machinery are playing an important role in this. The development of machines based on the use of environmentally friendly materials and reduced fuel consumption contributes to the implementation of the principles of sustainable development in agricultural enterprises. Such technologies not only help to reduce the negative impact on the environment, but also contribute to saving resources, which is beneficial for farmers in the long run.

Modern agricultural machinery manufacturers are actively researching and implementing eco-friendly materials such as recycled plastics and composites that reduce the overall carbon footprint of machine manufacturing (Cenci *et al.*, 2021). These innovations not only reduce the amount of waste, but also improve the operational characteristics of machinery. For example, lightweight materials reduce the weight of machines, which reduces fuel consumption and increases manoeuvrability, especially in difficult field conditions. In addition, new models of equipment are being developed with an emphasis on energy efficiency. Technologies aimed at reducing fuel consumption provide significant savings both at the level of individual farms and across the entire agricultural sector. This is especially true in the context of rising fuel prices and global efforts to reduce greenhouse gas emissions. The use of alternative energy sources such as solar panels and biofuels also contributes to more sustainable production and reduces dependence on traditional fossil resources.

Nevertheless, the transition to sustainable production and the introduction of new technologies requires farmers to make certain investments and changes in their usual approaches to farming (Melchior & Newig, 2021). Many farmers may face difficulties in mastering new technologies and integrating them into production processes. However, the long-term benefits associated with saving resources and improving environmental sustainability make these changes necessary and justified. Thus, sustainable production and resource conservation are becoming important aspects of modern agriculture. The development of new machinery using environmentally friendly materials and energy-efficient technologies opens up new opportunities for agricultural enterprises. These changes not only help to reduce the negative impact on the environment, but also ensure that farmers are more competitive in the face of growing demand for environmentally friendly products. Investments in sustainable production are becoming an important step towards creating a more responsible and efficient agricultural sector capable of meeting modern challenges.

DISCUSSION

The study found that the introduction of innovative technologies in the production of agricultural machinery has significantly increased the efficiency of agricultural enterprises. An analysis of the results showed that the use of precision farming systems and automated machines allowed farmers to significantly reduce the cost of resources such as water and fertilisers, while increasing yields. The introduction of new models of tractors and combines with autopilot function also helped to reduce labour costs and minimise the influence of the human factor on production processes. This problem was also investigated by Y. Liu *et al.* (2021), where the results confirmed that innovative technologies play a key role in increasing the productivity of agricultural enterprises, allowing them to optimise processes and reduce costs. The use of modern information systems, such as geoinformation technologies and the Internet of Things, allows farmers to obtain up-to-date information about the state of fields and plants, which contributes to more efficient resource management. In addition, automation of the processing and distribution

of agricultural products reduces labour costs and minimises the risks associated with the human factor.

D.M.K.S. Hemathilake and D.M.C.C. Gunathilake (2022) also showed that modern agricultural technologies, including precision farming and the use of genetically modified organisms, significantly contribute to increasing crop yields. These technologies ensure more efficient use of resources such as water and fertilisers, which reduces costs and improves product quality. The introduction of new methods of tillage and pest management also contributes to crop resistance to diseases and adverse weather conditions, which ultimately leads to an increase in the total yield. The integration of innovative technologies into the agricultural sector requires not only significant investments, but also the willingness of agricultural enterprises to make changes in the production process (Bulgakov *et al.*, 2017). It is important that employees are trained in new working methods, which will allow them to effectively use new tools and systems. In addition, it is necessary to consider the possible risks associated with the introduction of technologies, such as dependence on high technologies and potential failures in the system, which underlines the importance of an integrated approach to the modernisation of agricultural enterprises. In addition, the results of the study demonstrated that electric and hybrid tractors, which are actively being introduced in countries such as Denmark and Germany, not only contributed to reducing carbon dioxide emissions, but also proved economically beneficial for farmers. Farmers using such technologies noted a reduction in operating costs and an improvement in the environmental situation in regions with a high degree of agricultural mechanisation. This indicates that eco-friendly technologies can become an important tool for achieving sustainable development of agricultural enterprises.

M. Beligoj *et al.* (2022) concluded that electric and hybrid tractors represent a significant step towards reducing the carbon footprint in the agricultural sector, as they significantly reduce greenhouse gas emissions compared to conventional diesel models. The use of such tractors helps to reduce air and soil pollution, which contributes to improving the quality of the environment and preserving ecosystems. In addition, the low noise level generated by electric and hybrid machines contributes to a more comfortable working environment for operators and minimises the negative impact on wildlife. The study by H. Dzwigo *et al.* (2021) revealed that the introduction of environmentally friendly technology, such as electric and hybrid tractors, can lead to significant cost savings in the long term due to lower fuel and maintenance costs. Although the initial investment may be high, the operating costs become significantly lower, which makes such technologies economically attractive for agricultural enterprises. In addition, the use of environmentally friendly technology can open access to subsidies and tax benefits, which further increases the economic efficiency of its implementation.

These results confirm the above study, as they demonstrate a clear correlation between the introduction of environmentally friendly technology and the improvement of both economic and environmental performance of agricultural enterprises. This shows that switching to electric and hybrid tractors not only helps to reduce their carbon footprint, but also allows farmers to optimise their costs, making them more competitive in the market. Thus, investments in sustainable technologies not only contribute to environmental protection, but also represent a reasonable step towards economic stability and growth of the agricultural sector. Diagnostic and monitoring systems based on artificial intelligence have also shown their effectiveness in increasing the service life of equipment and reducing the risk of breakdowns. Due to the timely detection of malfunctions and adjustment of equipment, farmers were able to minimise downtime and reduce maintenance costs. The use of AI in the agricultural sector has become an integral part of successful management, allowing farmers to focus on the more important aspects of doing business. Noteworthy is the study by N. Gupta *et al.* (2020), who also found that artificial intelligence plays a key role in the diagnosis of agricultural equipment, allowing for more accurate and rapid identification of possible malfunctions and their causes. Machine learning-based systems can analyse data on the operation of machinery in real time, identifying deviations from normal operation and predicting potential failures before they occur. This significantly reduces equipment downtime and increases its efficiency, which is especially important in conditions of seasonal agricultural production.

In turn, A. Abid *et al.* (2020) concluded that early detection of malfunctions in agricultural equipment brings significant benefits, including reduced repair and maintenance costs. By knowing about potential problems in advance, farmers can plan maintenance and replacement of parts, which minimises unexpected breakdowns and increases the reliability of machinery during critical periods such as harvest. In addition, stable operation of the equipment helps to increase the overall productivity of agricultural enterprises, allowing them to use resources more efficiently and efficiently (Bulgakov *et al.*, 2019). These data are consistent with the theses given in the previous section, as they emphasise the importance of using artificial intelligence to improve the reliability and efficiency of agricultural equipment. As already noted, the introduction of AI technologies not only optimises diagnostic processes, but also significantly reduces equipment downtime, which is critical for successful farming. Thus, the results confirm that early detection of malfunctions, provided by modern technologies, is a key factor in improving the overall productivity of agricultural enterprises and the sustainability of their operations.

However, despite significant achievements, there are still gaps in this area that require additional study. One of the key problems was the lack of integration of various technologies, which limited the ability of agricultural enterprises to maximise the use of all available resources. The impact of innovations on small and medium-sized agricultural enterprises also requires a more detailed analysis, as they often face difficulties in adapting new technologies due to limited financial resources. N. Khan *et al.* (2021) also conducted a study, the results of which confirmed that the integration of new technologies into the agricultural sector faces many challenges, including lack of funding and limited access to educational resources for farmers. Many agricultural enterprises, especially in developing countries, are experiencing difficulties in implementing modern technologies due to high initial costs and a lack of qualified personnel capable of effectively using new tools. These barriers can lead to an uneven distribution of innovations, which affects the overall competitiveness of the sector. D. Radicic and S. Petkovich (2023) also found that innovations can significantly change the work of small and medium-sized agricultural enterprises, providing them with access to modern technologies that were previously available only to large agricultural companies. However, small businesses may face difficulties in implementing innovative solutions due to limited financial resources and lack of experience in managing new technologies. Nevertheless, successful integration of innovations can increase their competitiveness, improve production efficiency, and ultimately lead to higher incomes, which makes supporting such initiatives an important task for the state and agricultural policy.

Comparing the data obtained during the research, it is possible to identify a clear trend that the successful integration of new technologies into the agricultural sector directly depends on the level of training and support of small and medium-sized agricultural enterprises. This confirms that without proper training and access to finance, many agricultural enterprises may not take advantage of the benefits offered by modern innovations. Therefore, to achieve sustainable development of the sector, it is necessary to create conditions conducive to the introduction of technology and professional development of employees, which will ultimately have a positive impact on the entire industry. In addition, there were many questions regarding the adaptation of old equipment to new requirements and technologies. This became a serious obstacle for many farmers who were unable to upgrade their machines and use advanced solutions. The need to introduce new approaches to maintenance and modernisation of machinery also highlights the importance of supporting and training farmers so that they can adapt to changing conditions and effectively use innovative technologies (Karaiev *et al.*, 2021).

M.A. Ibrahim and M. Johansson (2021) concluded that adapting outdated equipment to modern requirements is becoming a necessary step for agricultural enterprises seeking to remain competitive in a rapidly changing market. This practice includes upgrading existing machines and technologies, which reduces the cost of new equipment and extends the life of old assets. However, for successful adaptation, it is necessary to consider the technical characteristics and capabilities of the equipment, and meet new safety standards and environmental requirements. A. Fleming *et al.* (2021) revealed that in the context of technological change, improving the skills of farmers is becoming a key factor for the effective use of new technologies and equipment. Modern agricultural enterprises require knowledge in the fields of information technology, agronomy, and resource management from employees, which makes training and retraining vital. By investing in the education of their employees, farmers not only increase productivity, but also contribute to the sustainable development of the agricultural sector, which ultimately affects the economic stability of the entire industry.

When analysing the results of the study, it becomes clear that the successful adaptation of outdated equipment and advanced training of farmers are interrelated processes that contribute to the overall efficiency of agricultural enterprises. Modernisation of machinery requires not only financial investments, but also awareness of new technologies on the part of employees, which underlines the need for an integrated approach to the development of the agricultural sector. To achieve sustainable results, it is important to simultaneously invest in equipment upgrades and staff training, which will effectively respond to the challenges of modern agriculture and improve its competitiveness. Thus, the results of the study confirmed the importance of introducing innovative technologies in the production of agricultural machinery to improve the efficiency of agricultural enterprises. These technologies open up new opportunities for automation, optimisation and sustainable development of the agricultural sector. Nevertheless, to achieve maximum effect, it is necessary to continue studying emerging issues to ensure the harmonious and sustainable development of agriculture in the modern world.

CONCLUSIONS

The results of the study confirmed that innovative technologies in the production of agricultural machinery play a key role in improving the efficiency of agricultural enterprises. The introduction of precision farming systems, process automation, and the use of electrified machinery has led to significant reductions in resource costs such as water and fertilisers, and increased yields. This indicates that farmers can use their resources more efficiently, which is especially important in the context of global climate change and the

growing need for food. The analysis showed that tractors and combines with autopilot function not only reduced labour costs, but also minimised the influence of the human factor, which increased the accuracy of operations. Automation of processes allowed optimising the allocation of resources and improving production performance. The use of modern technologies, such as artificial intelligence for diagnostics and monitoring, has provided farmers with the opportunity to detect malfunctions in a timely manner, which has helped to increase the service life of machinery and reduce maintenance costs. This, in turn, has improved overall productivity and reduced the risks associated with unforeseen breakdowns. However, despite the results achieved, the study also revealed gaps that require further investigation. For example, insufficient integration of various technologies limited their full use, especially in small and medium-sized agricultural enterprises facing financial difficulties. These enterprises often do not have the opportunity to invest in new technologies, which makes it difficult for them to compete in the market. Adapting old equipment to new requirements also remained an urgent problem, as many farmers use outdated machines, which hinders their development.

In general, the results obtained emphasise the need for further implementation and development of innovative technologies in agriculture. These changes not only contribute to increased productivity, but also create a sustainable and competitive agricultural sector that can effectively respond to modern challenges and market demands. To achieve these goals, it is important to continue studying emerging issues and support farmers in the process of implementing new solutions, which, in turn, will contribute to the creation of a more efficient and environmentally sustainable agricultural system. The limitation of the study is the lack of data on the long-term effects of the introduction of innovative technologies on the production processes and economic performance of agricultural enterprises. It is necessary to study the impact of innovative technologies on small and medium-sized agricultural enterprises to better understand how they can adapt to new conditions and effectively use available resources.

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Інноваційні технології у виробництві сільськогосподарської техніки для підвищення ефективності роботи агропідприємств

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Анотація. Дане дослідження спрямоване на аналіз інноваційних технологій у виробництві сільськогосподарської техніки та їх впливу на підвищення ефективності роботи агропідприємств. У дослідженні було застосовано різні наукові методи для всебічного аналізу впливу інноваційних технологій на ефективність агропідприємств у сфері сільськогосподарського машинобудування. Під час дослідження встановлено, що застосування інноваційних технологій у сільськогосподарському машинобудуванні значно підвищує ефективність роботи агропідприємств. Аналіз засвідчив, що використання систем точного землеробства, оснащених датчиками і GPS-технологіями, дає змогу оптимізувати розподіл ресурсів, таких як вода і добрива, що призводить до збільшення врожайності та зниження витрат. Автоматизація операцій за допомогою автопілотів на тракторах і комбайнах, як у моделях John Deere і Fendt, продемонструвала зниження трудовитрат і зменшення впливу людського фактора, що також сприяє підвищенню продуктивності. Електрифікація та гібридизація сільськогосподарської техніки, активно впроваджувана в таких країнах, як Данія та Німеччина, виявилися економічно вигідними, сприяючи зменшенню викидів вуглекислого газу та скороченню експлуатаційних витрат. Впровадження штучного інтелекту для моніторингу та діагностики обладнання дало змогу мінімізувати простій і збільшити термін служби техніки завдяки своєчасному виявленню несправностей. Загалом встановлено, що використання цих технологій сприяє сталому розвитку агропідприємств, оптимізації виробничих процесів і скороченню експлуатаційних витрат. Перехід на більш екологічне виробництво сільськогосподарської техніки сприяє поліпшенню екологічної обстановки в регіонах із високим ступенем механізації сільського господарства. Впровадження стійких технологій у машинобудуванні показало свою ефективність у скороченні ресурсоспоживання, що робить агропідприємства більш конкурентоспроможними на світовому ринку

Ключові слова: точне землеробство; автоматизація; GPS-технології; електрифікація; штучний інтелект