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Proven Solutions and Modern Methods of Sustainable Management of Agricultural Areas

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Abstract:

Purpose: *This article examines the solutions and methods used in sustainable management of agricultural areas. The main objective of the study is to assess the impact of proven and modern technologies on the efficiency of farms, while respecting the principles of sustainable development. The article fills a gap in literature concerning the integration of traditional practices and innovations in the context of precision agriculture.*
Design/Methodology/Approach: *A qualitative approach was applied, based on a literature review and bibliometric analysis of publications available in the Web of Science database. The analysis included works on the application of modern technologies, environmental protection and economic efficiency in farms. The VosViewer tool was used to visualize the relationship between key concepts.*
Findings: *The results point to the key role of integrating traditional methods of soil protection, water retention and erosion prevention with modern technologies such as the Internet of Things, artificial intelligence and precision farming. The lack of direct links between sustainability and digital technologies in literature has also been identified, which highlights the need for further research.*
Practical implications: *The results can be used by farmers and policy makers to improve the management of natural resources and increase the economic efficiency of farms. Furthermore, integrating new technologies with traditional methods can support long-term food security.*
Originality/Value: *The article contributes to research on sustainable agriculture, combining analysis of traditional and innovative solutions. It points to the importance of a harmonious approach in the management of agricultural areas, which takes into account both environmental and economic aspects.*

Keywords: *Sustainable agriculture, precision farming, environmental protection, water retention, agriculture 4.0.*

JEL Codes: *Q01, M11, Q15.*

Paper Type: *Research article.*

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1. Introduction

Sustainable agriculture is increasingly recognized as a key approach to ensuring food security while minimizing negative environmental impacts. These practices include methods that are economically viable, socially responsible and environmentally friendly, and are designed to meet current and future food needs.

As research highlights (Sikandar *et al.,* 2022), the need to combine food production with the protection of ecosystems is becoming a central topic of debate at both national and international level. Ensuring food security, both in the short and long term, requires efficient management of the resources necessary to achieve this objective.

In the past, sustainable management practices have been based on traditional solutions, known and used for decades, that have contributed to the conservation of resources and to ensuring agricultural productivity. However, the dynamic development of modern technologies has introduced new tools and methods that are just beginning to be implemented, but already now promise significant changes in the area of sustainable agriculture.

In order to implement them effectively, it is necessary to analyze both historically proven solutions and the most innovative ones, which can contribute to increasing the productivity of farms while maintaining the principles of sustainable development (Mitchell, 2024).

However, before the research on the degree of implementation of these solutions is carried out, it is necessary to analyze the current scientific achievements. A comprehensive review of the literature will give a better understanding of how environmental protection can be reconciled with agricultural production requirements. This aims not only to identify solutions desirable from the point of view of sustainable development, but also interesting for farmers who have their expectations of future financial results.

The main objective of the work is to review solutions used in running farms, which are in accordance with the principles of sustainable development. It takes into account both the ways of maintaining the high quality of used resources, which have been known for decades, and the most modern ones that are still being implemented.

This analysis is intended to serve as a basis for further research, as well as provide valuable guidance on balancing environmental, economic and social aspects in the management of agricultural areas. The thesis of the article is that a harmonious combination of proven and innovative methods is crucial for achieving sustainable agriculture, which will ensure long-term food security while preserving vital natural resources.

2. Literature Review

Changes in the environment that affect us all determine the growing need for sustainable development solutions. What sustainability is and how it can be understood has been sought by many authors (Dernbach, 1998; Cooper and Vargas, 2004; Elliott 2012; Baker, 2015; Blewitt 2017; Robertson, 2021). Understanding this concept depends, however, on the type of area of interest from which the author comes out, which is also noted in the literature (Egelston, 2013).

The most general definition is the one used for years, which presents sustainable development as such, „which meets the needs of the present without compromising the ability to meet the own needs of future generations" (Report of the World Commission *et al.,* 1987).

In particular, the Organization for Food and Agriculture the United Nations has defined sustainable agriculture as „consisting of such use and conservation of natural resources and such orientation of technologies and institutions to achieve and maintain the satisfaction of the human needs of present and future generations. This type of development (in agriculture, forestry and fisheries), preserving soil, water resources, plants and genetic resources of animals, does not degrade the environment, uses appropriate technologies, and, it is economically viable and socially accepted" (Żuchowska – Grzywacz, 2024).

2.1 Water Retention

Water retention on a farm is a key element in improving soil quality and preventing soil degradation. There are many technical and non-technical methods that can improve water retention at the water catchment level. The use of the natural conditions of the site and the appropriate adaptation of agricultural practices can significantly reduce the negative effects of climate change (Staccione *et al.,* 2021)

Adapting agricultural practices to the specific characteristics of the site is crucial for improving water retention and soil protection against erosion (Cueff *et al.,* 2021). These measures should adapt plowing to the morphology of the site, creating redlines across the slope, which promotes water retention and reduces erosion. In areas with higher gradients, terrace crops are particularly beneficial, which prevent water runoff.

Another important element is the introduction of diverse crop rotations, which, instead of monocultures, use plant mixtures and leave crop residues in the field, which helps protect the soil from erosion and improves its structure.

It is also worth introducing methods such as tillage and mulching, which reduce surface runoff and maintain adequate soil moisture (Eden *et al.,* 2017). In coastal areas and protected areas, grassland and buffer zones are a good solution, which can act as extensive meadows or pastures, promoting ecological balance.

Another way to improve water retention on a farm is to use natural land abscesses to create intrafield ponds (Staccione *et al.*, 2021). Such reservoirs stabilize groundwater levels while supporting biodiversity. In drainage systems, it is also worth using valves, but they should be used in a controlled manner, so as not to disturb the natural flow of water in the watercourses, which could lead to negative ecological consequences.

In addition, beavers can play a role in natural water retention, creating natural dams and reservoirs, which contributes to slowing the outflow of water and reducing the risk of flooding (Głodowski, 2020).

2.2 Prevention of Wind Erosion

Wind erosion is an increasingly common problem, especially in dry periods. In the fight against it, phytomelyorations, which consist in planting trees and shrubs to reduce wind power, improve water retention in the soil and reduce evaporation, are helpful.

Trees play an important role in soil protection, improving water retention and regulating microclimate (Kumarasinghe, 2021). The midfield trees form a natural wind shield, which not only limits the evaporation of water from the soil surface, but also improves the infiltration of water into its deeper layers. Additionally, tree crowns capture some of the precipitation, which reduces surface runoff and helps maintain soil moisture.

In areas with a higher slope, belt wind guard trees are an effective method of protection against wind erosion, the width of which varies from 5 m to 20 m, depending on the slope of the terrain. Such strips of trees provide a barrier that effectively protects the soil from degradation caused by strong winds (Durán and Rodríguez, 2008). Trees with high transpiration have a significant impact on the microclimate.

They regulate water relations, lowering the level of groundwater and creating a so-called depression funnel, which supports water retention in the soil. In addition, trees mitigate extreme temperature changes, especially during summer periods, when they can effectively protect against excessive soil heating, which helps to maintain the right conditions for plant growth. Trees cannot be too dense, because then the main mass of air flows over them, which limits the effectiveness of wind protection.

The optimal structure is trees with 20-30% clearances, which reduce the wind speed at a distance up to 30 tree heights (Nowocień and Wawer, 2021). Such actions allow to reduce evaporation and increase soil moisture, which has a beneficial effect on the yield.

2.3 Choosing Solution 4.0 Essential for Agriculture Agriculture 4.0 on the Way to Sustainability – Precision Farming

Today, there are several different agricultural systems that differ from one another (Klepacki, 2020). Conventional agriculture focuses on maximizing the profits and productivity of plants and animals, with a strong emphasis on specialization. It is a highly technologically advanced, mechanized and automated system that uses large external inputs, achieving high efficiency.

Organic farming is about managing the use of natural forces, taking care of natural resources, maintaining soil fertility and plant and animal health, as well as producing high-quality food without the use of industrial means. Integrated agriculture combines modern technologies, including biological progress, while striving to achieve economic and ecological goals.

Precision farming, on the other hand, is a modern system that uses advanced navigation and information technologies, such as satellite location systems (GPS) and GIS (Geographic Information Systems) methods.

2.4 Intelligent Irrigation Systems

Field irrigation is a key element in agriculture, especially during periods of prolonged drought, when yields are of poor quality due to dry and nutrient-poor soil. For this reason, different irrigation methods have been developed, which differ in efficiency and are adapted to the specifics of different types of crops, such as fields, greenhouses or orchards. As a result, intelligent irrigation systems are developed that can adapt to changing weather conditions and the type of crops grown (Roy *et al.*, 2019).

Artificial Intelligence (AI) is one of the most popular technologies used in the Fourth Industrial Revolution. In agriculture, AI optimizes the use of resources such as water, fertilizers and energy, and provides data on plant health and growth. Technologies such as fuzzy logic and machine learning analyze sensor data and make irrigation decisions (García, 2020).

Irrigation systems that do not have access to the traditional electricity grid use alternative energy sources. Even when power is available, the systems can only use energy during designated hours. In areas far from electricity grids, solar energy is widely used, which is becoming particularly important in areas with limited access to water, where irrigation efficiency is crucial for sustainable agriculture.

Countries with dry climates such as Australia and the United States are widely adopting these technologies, making production greener and more economical, and using solar energy reduces energy costs, which is particularly important in developing regions.

Internet of Things (IoT) systems generate huge amounts of data, especially those related to irrigation, which requires effective management. A sustainable approach to data management is needed, including the use of solar energy to power devices, the selection of relevant data, information clustering, time algorithms and resource savings. The analysis of sensor data plays a key role in optimizing irrigation systems.

There are even Big Data algorithms that support farmers in choosing the right crops. Technologies such as AI, fuzzy logic and machine learning are used to analyze data and optimize water use. Fuzzy logic improves irrigation schedules in greenhouses and controls water outflow, while machine learning accurately predicts soil moisture. Water demand forecasting techniques help estimate the available water resources for irrigation (García *et al.,* 2020).

Thanks to specialized sensors, data on weather conditions are collected, which have a key impact on plant irrigation. Factors such as air temperature, affecting the evaporation of water from the soil, and humidity, determining the amount of water vapor in the air, shall be monitored and expressed in appropriate units. In the event of rain, irrigation systems can automatically stop the watering process to avoid excessive hydration. Rain sensors, based on optical technology, detect rainfall and this data is transmitted to the user via mobile applications (Kabilan, 2016).

2.5 Application of Modern Research to Care for Soil Quality

Many changes in the climate situation require more thorough and more frequent research related to maintaining high quality soils. For this purpose, it is necessary to analyze it comprehensively, not only horizontally, but also vertically. By taking multiple samples on a selected site and using appropriate calculation systems, it is possible to develop soil maps in terms of their quality and the demand for specific components.

The process of each operation begins with the measurement of the research area, which allows to determine the number of trials and determine their distribution. The use of a soil scanner allows to obtain a soil variability profile, which allows to designate zones for field management.

Precision cultivation is based on accurate recognition of soil structure and nutrient content, which are then presented on maps developed using GPS (Global Positioning System) technology and GIS (Geographic Information System) systems for the acquisition and analysis of spatial data. In addition, application maps are used that calculate the amount of seed or fertilizer to be applied, as well as software that synchronizes the location of machines and controls their operation (Jugaj, 2023).

The effect of IoT systems on a farm can be the current forecast, a report on agronomic treatments, an analysis of agricultural production costs and an assessment of its labor intensity (Symeonaki *et al.,* 2020). This creates a farm that can be managed remotely.

2.6 Automatic Vehicles and Self-Driving Agricultural Machinery

The development of agriculture is leading to an increasing workload in rural areas, which has led to the use of tractors and other heavy automated machinery in the agricultural sector. Although automated vehicles are modern technology, they are not entirely new, as semi-automatic cars appeared on the market much earlier than autonomous tractors. Self-driving tractors are part of the concept of Industry 4.0, which includes modern technologies related to automation, machine communication and data analysis.

Modern agricultural machines, such as tractors and combines, are equipped with dedicated controllers that enable monitoring of various aspects of work in the field. You can also use mobile devices, computers and software to enter management decision data and perform analysis. The collected information is stored in a cloud, where it can be combined with data from other agricultural activities, enabling analysis and optimization of farm management processes.

Thanks to these technologies, some manufacturers have access to earlier yield data and other field management information, which can be supplemented with satellite images and data from drones and meteorological stations (Capalbo *et al.,* 2017).

These technologies allow you to perform a variety of farming tasks without the need for physical operator presence, which significantly increases efficiency and precision. These technologies are particularly used in highly developed countries, such as the United States, Canada, Germany and Japan, and are a key tool for large farms with vast areas.

The potential of these solutions covers a wide range of production, from agricultural crops to animal husbandry and fruit farming. Self-driving machines are particularly effective in plain and large fields, although in hilly areas they are more difficult to use. Agricultural holdings with suitable terrain characteristics can therefore, use, these machines to optimize field operations (Ayaz et al., 2019). Although there are no fully autonomous tractors on the market, work on their creation is ongoing.

2.7 Autonomous Sources of Energy

Implementing green energy solutions that are more sustainable than traditional methods is crucial. Research carried out by Gotkiewicz and Lewczuk (2006) showed that farmers already saw the potential of development of their farms through the implementation of modern technologies. Table 2 lists these solutions and shows the level of interest among farmers.

Table 2. *Farmers' interest in green energy solutions*

Solution	% of respondents
Biomass incinerator	47.1
Solar collectors	38.4
Wind power plant	27.0
Use of biogas	18.5

Source: *Own study based on Gotkiewicz and Lewczuk, 2006.*

The above list shows that farmers are particularly focused on obtaining “clean” energy, which is at the same time cheaper, which translates into lower farm operating costs and increased competitiveness. These benefits result not only from cost and revenue analysis, but also from the growing interest of customers, who increasingly appreciate sustainability.

Today, the use of solar energy on farms can have many aspects. As this is a rapidly growing renewable energy method, photovoltaic technology offers a potentially viable alternative to sustainable farming, as it can meet both electricity and heat demand in agriculture through the use of photovoltaic-thermal (PVT) systems (Helmers *et al.*, 2014).

There are many alternative sources of renewable energy, and solar energy stands out from them because of its universal availability worldwide. Modern agricultural practices are also a source of greenhouse gas (GHG) emissions. The use of solar energy helps to reduce emissions of these gases, prompting developing countries to adopt it.

This energy can be used for a variety of purposes, such as growing plants, irrigation, heating, drying or adding value to agricultural products, growing in greenhouses and ventilation, which contributes to reducing the negative impact on the environment. In agriculture, various solar-powered devices are increasingly used (Majeed *et al.*, 2023).

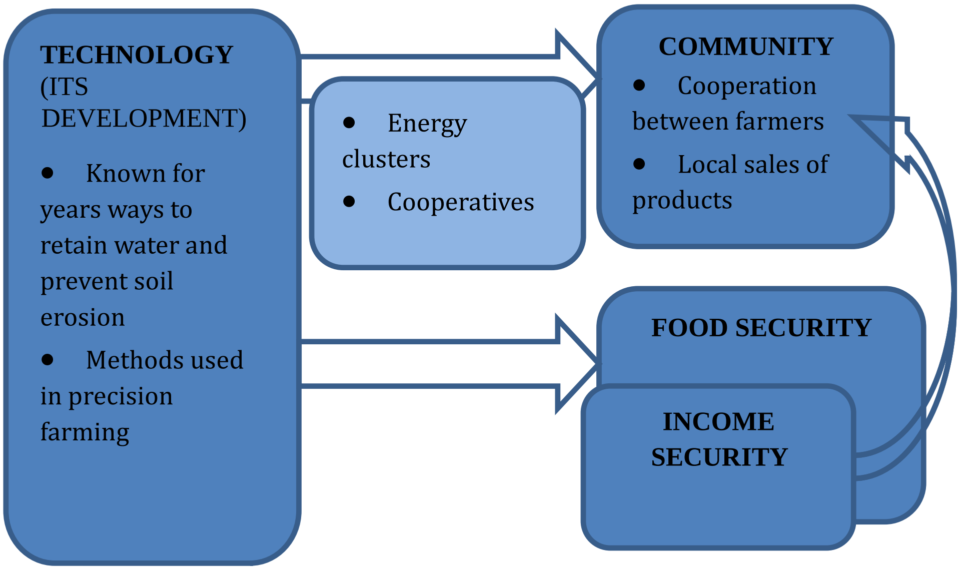
Wind energy differs from solar energy in that it is available around the clock, 24 hours a day. Wind energy technologies can be used to generate both electricity and mechanical energy. Wind technologies are recognized as the fastest growing renewable energy technology, combined with the use of biomass. Irrigation water pumps can be powered by wind turbines, eliminating the need and cost of installing electrical equipment such as transformers, power lines and poles (Hasan *et al.*, 2019a; 2019b)

Bioenergy is a key energy source that can meet the needs of the agri-food sector and other industries for heat, electricity and transport fuels (Harris et al., 2014; Sanz Rodrigo et al., 2017). Biomass by-products from the agri-food sector can be used to obtain energy necessary for processing, storage and household needs.

3. Research Methodology

The considerations presented in this publication concern broader analyzes related to the implementation of the assumptions of sustainable development of agricultural areas. This assumes the need to compile several aspects (Figure 1).

Figure 1. *Aspects Affecting the Ssustainable Development of Agricultural Areas*



Source: *Own study.*

The first is the application of techniques and technologies in a way that will support the systematic reduction of environmental pollution and offset existing effects. The second aspect is to ensure food security at every scale – both globally and locally.

This local dimension concerns not only the production of the right quantity and quality of products, but also the production by farms and their managers of income that will enable them to meet their own needs and the development of the units they manage. The third aspect of sustainable development is the community, most often understood locally. It is about selling products, shortening the distribution channels, which affects the price of goods and often in the case of food goods, its freshness, as well as local cooperation between farmers.

In this article, a literature analysis was carried out in the technological area, trying to determine what methods of action are used and postulated to be used in the course of the development of technology supporting the improvement of the management of agricultural areas. The analysis first identified its purpose, posed a research question and established key concepts that formed the basis for search in literature resources.

The results presented in this study have been selected by adopting a microeconomic perspective, i.e., a view from the point of view of the agricultural producer, which is the person managing the farm. A slightly different selection of publications would take place in the case of the meso- or macroeconomic approach. Such analyzes shall also be provided before appropriate empirical research is undertaken. The main considerations were the ways of farming, as the predominant form of doing business in the area where it is planned to conduct research among owners and managers of agricultural holdings (Poznański, 2022).

The main research question is: How is the relationship between the care for the implementation of the principles of sustainable development using modern technologies used in precision agriculture and methods proven in the past, and the production capacity and incomes of agricultural holdings shaped?

The criteria used in the selection of publications are as follows:

- publications from the last 5 years – this is important in the dynamically changing IT technology,
- presenting the results of research on highly developed and developing areas,
- research covering the theory and practice of agricultural land management,
- publications available in English and Polish, the latter in particular covering empirical research conducted in the area of Wielkopolska,
- publication in the form of an article.

4. Research Results

The search for publications was based on the key words: sustainable agriculture/farming in combination with technology/precision farming, water retention/soil erosion and profits/income. The choice of these phrases resulted from the assumption that farmers interested in implementing solutions supporting sustainable development attach great importance to the economic stability of their farm. A numerical summary of the results obtained in the Web of Science database is presented in Table 1.

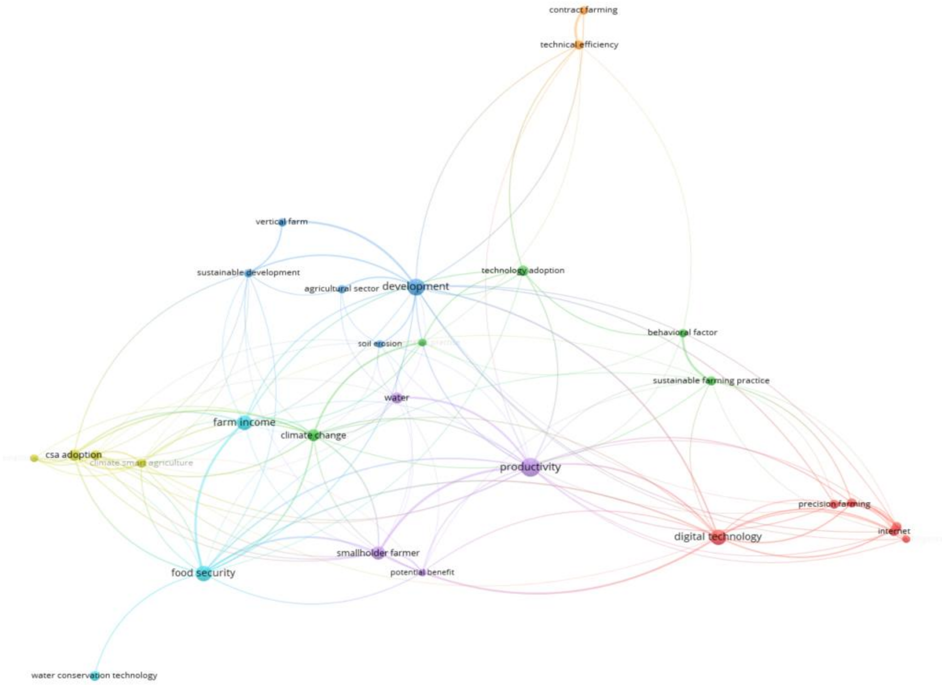
Table 1. *Numerical summary of the results of the searched terms*

	Concept	**List sought**	**Number of indications**
A.	sustainable agriculture/farming	A.	88 385
B.	technology/precision farming	A and B	24 556
C.	water retention / soil erosion	A and C	2 702
D.	profits/income	A and D	5 264
		A and (B or C) and D	1 496
		A and B and C and D	38

Source: *Own study.*

Figure 2 presents the results of a literature analysis conducted in the Web of Science database. VosViewer, a specialized software for bibliometric analysis, was used to analyze the keyword network.

Figure 2. *Results of the Literature Analysis in the Form Generated Using VosViewer.*



Source: *Own study.*

There are numerous links between the concepts, among others farm income and sustainable development, which at the same time shows a connection with both productivity, as well as the implementation of new technologies and community-supported agriculture.

What is interesting is the lack of a direct link between sustainable development and precision farming or digital technologies. The latter shows a connection in the analyzed literature with productivity or the concept of development as such, but it is only such elements that connect them both with the analysis of farm incomes and sustainable management.

The results indicate the existence of seven clusters of concepts, four of relatively high importance, grouped around the concepts of development, productivity, digital technologies and food security (equivalent to farm income). All these key concepts have interconnectedness, which can be interpreted as their co-existence in the analyzed literature.

The main node in the analyzed publications is the development, from which many connections emerge, which emphasizes its central role. Other important concepts, such as productivity, farmers' incomes, food security and digital technologies, form their own subgroups, but are strongly linked to the concept of development.

By analyzing key clusters, several main areas can be distinguished. Blue includes words related to agriculture, sustainability and modern technologies. The green cluster focuses on concepts such as behavioral factors and sustainable agricultural practices. The yellow cluster covers the impact of agriculture on farmers' incomes and technologies. The red cluster contains words related to modern technologies, such as precision farming and the internet. The purple cluster focuses on agricultural products and climate change.

The relationship between these clusters shows that digital technologies have strong links to productivity and agricultural practices. Food security is particularly linked to farm incomes as well as technological solutions and climate change. Development and agriculture issues have broad links with other areas, highlighting their interdisciplinary nature.

5. Discussion

5.1 Sustainable Development in the Context of Agricultural Production

From the analysis obtained, it can be concluded that in order to ensure food security, it is necessary to care for high productivity possible thanks to the development of farms using digital technologies. The lack of sustainable development as an important aspect noted in the analyzed publications may raise some doubt. However, the individual elements that are indicated in the analysis constitute important elements in the principles adopted in the development of sustainable agriculture.

Looking through the prism of the agricultural area, it is necessary to combine many different aspects in the pursuit of its sustainable development. This is largely due to pressure from the EU, for which the development of sustainable agriculture is a priority. The European Commission is pushing for the sustainable development of agriculture in rural areas across the EU through the common agricultural policy, first of all, pointing to the need to achieve the goals set out in the Agenda for Sustainable Development 2030 (Hurduzeu *et al.*, 2022).

This agenda not only touches on agricultural issues, but also points to the link between all activities in the pursuit of such development. It is primarily aimed at reducing hunger, food insecurity and adequate nutrition. This is possible by increasing the productivity and income of food producers, especially small ones, as well as ensuring the stability of the food production system and implementing sustainable agricultural practices and increasing investment and facilitating timely access to market information (Fanzo *et al.*, 2018; Firoiu *et al.*, 2021).

Similar conclusions were formulated by the Ngo team on the basis of the conducted research, indicating as factors determining the involvement of farmers in maintaining sustainable development, first of all obtaining the expected gross production efficiency, and, maintaining adequate economic capacity and the possibility of limiting the use of agricultural inputs (Ngo *et al.*, 2020).

The achievement of high results of the indicated factors is mainly influenced by the age and level of education of farmers. In particular, the chances of achieving high economic performance are significantly higher in countries with a well-trained population, such as the Netherlands and Germany, compared to countries with poorly trained economies, an ageing agricultural population, as identified for example in Portugal and Bulgaria (Giannakis and Bruggema, 2015).

It is also necessary to emphasise that agriculture is the source of about a quarter of global greenhouse gas emissions. In order to reduce it, it is necessary to develop ways to reduce this emission. Therefore, it is necessary to provide organizational support – legal and financial for agriculture, which will focus primarily on climate protection by increasing the effective use of land and other natural resources. The main focus should be on innovation-driven projects that are essential for sustainable farm management (Searchinger *et al.*, 2020).

At the same time, due to the growing population, estimates here say that the world population will increase to about 9 billion in 2030 and to 10 billion in 2050., a significant increase in demand for food is expected. As a consequence, population growth will require a significant increase in food production: it is believed that it will have to increase by 50% by 2030, 70% by 2050 and 100% to 110% by 2050. (UNDESA, 2017).

These data should all the more lead to the implementation of solutions that will increase the volume of production, and at the same time reduce its harmful impact on pollution and environmental degradation. Production volumes should be increased while integrating economic and environmental objectives. In this context, striving for sustainable agricultural development means at the same time preserving and protecting valuable agricultural resources.

5.2 Application of Industry 4.0 Solutions in Sustainable Development in Agricultural Production

Industry 4.0, which assumes the autonomous operation of numerous devices containing elements of artificial intelligence, includes, among others, the following elements: industrial Internet of Things, the use of data stored in the cloud for the implementation of production tasks, or the construction and organization of smart factories. The solutions adopted in Industry 4.0 are increasingly used in numerous industries, including agriculture. On this basis, an attempt is made to distinguish the concept of Agriculture 4.0. Due to the specificity, they are influenced not only by the aspirations related to the need to modernize and automate tasks, but also by issues involving care for the condition of a particularly important resource, which is soil, rational management and avoidance of waste (Dabrowska *et al.*, 2021).

Sustainable agriculture is based on several key principles (Żmija, 2014), which aim to ensure long-term efficiency and minimize negative impact on the environment (Czerwińska-Koral, 2020). First of all, the emphasis is on the protection and improvement of soil quality, including the prevention and regular analysis of erosion, as well as the use of varied rotation (crop rotation), which helps to maintain soil fertility.

An important element is also fertilization, which should be adapted to the specificity of a specific soil and carried out on the basis of the developed fertilization plan. In addition, farmers should support local social initiatives and actively share their knowledge and experience, which promotes the development and integration of rural communities.

An important aspect is also the observance of health and safety rules on the farm, which ensures the health and comfort of work. Finally, the responsible financial management of the farm, including cost and income control, is the foundation for the long-term sustainability and viability of the farm.

The management method based on the assumptions of Industry 4.0 is precision agriculture, which is one of the pillars of sustainable development. Precise farmer-two is an approach based on the use of advanced navigation or information technologies for the acquisition and processing of spatial data. In practice, it includes a variety of techniques such as satellite navigation, variable fertiliser dose and crop mapping. In addition, it uses spectral analysis of electromagnetic radiation reflected from agricultural objects.

The aim of precise or interchangeable smart agriculture is primarily to optimize the agricultural production process itself and its management, and in addition, in accordance with the slogan of sustainable development, it aims to minimize expenditures, as well as, respect for the environment, protection of natural resources and care for safe working conditions.

In order to optimize agricultural production, which is the pursuit of a precise approach in agriculture, intelligent mini-robots are used, among others, performing field work. Their use allows to perform a number of works while ensuring a reduction in energy expenditure for their implementation.

This is primarily due to the reduction of soil kneading, work also in difficult conditions for humans, the implementation of precision sowing tasks and, if necessary, its supplementation, and, or selective harvesting without damaging other plants (Pawlak, 2010).

One of the basic challenges associated with the implementation of precision agriculture is its economic profitability. Although the environmental benefits are visible, it is often difficult to determine how financially viable it is.

However, the general awareness of the need to introduce sustainable development solutions is not always enough to convince potential implementers. The implementation of these rules involves numerous barriers. The most important of these seems to be financial. Implementation of a level-headed development requires numerous investments, especially in the early years. They result from changes in production technology or obtaining proper certification. Even in the course of production, its costs often turn out to be higher than before, which affects decision-makers rather discouragingly (Kata and Kusz, 2015).

However, the financial barrier is not the only one. Agricultural producers are also lacking support in acquiring knowledge related to implementable sustainable development solutions and ways to mitigate the associated risks. Technical support or specialist assistance (Cederholm, 2018) and access to relevant information are insufficient or none at all. The legal regulations and detailed regulations on sustainable development in the agricultural economy are also not always clear.

6. Limitations of the Study

The research was conducted primarily on the basis of the Web of Science database, which somewhat limits the obtained results. In order to develop them comprehensively, it is necessary to develop them on the basis of other databases.

The analysis of individual solutions that could be used in agricultural farms was based primarily on those that can be used in Polish climatic conditions. As a result, the above considerations will be true for similar regions. The paper mainly dealt with the issue of agricultural crops, leaving such issues as breeding pigs or fish to be further elaborated.

7. Conclusions

The analysis of the presented results allows to indicate the need for further research in the field of application of solutions used in agricultural holdings carried out in accordance with the assumptions of sustainable development. What is important here is the compilation of methods known for years, used in watering fields and preventing their erosion and modern tools included in precision farming.

However, the economic aspect cannot be ignored, and the implementation of these methods should at the same time allow for an increase in agricultural productivity and profitability. Many of the proposed changes to implement new technologies in agriculture, such as automation, robotics and artificial intelligence, do not have significant support in documents, either nationally or nationally.

Changes in the development of Agriculture 4.0 are determined by international strategic documents, in particular those developed by the European Union, such as the Strategic Plan for the Common Agricultural Policy 2023-2027, the European Green Deal Strategy and national plans, including the Strategy for Sustainable Rural Development, Agriculture and Fisheries 2030, national Strategic Plan for the Common Agricultural Policy 2023-2027, and Productivity Strategy 2030. Nevertheless, these documents still take limited account of the use of such new technologies (Kordowska *et al.*, 2023).

Modern tools used in agriculture are most often associated with the need for high investments. Looking at this aspect on a long-term basis, it is clear that it is likely that, if properly applied, these investments will prove profitable. In the short term, however, the balance, or even the financial sustainability, can be undermined. In this context, new agricultural technologies may not be available (Pastusiak *et al.*, 2021). Sustainable farm management also ensures long-term economic stability by increasing the resilience of the farm to economic crises, both local and global. Moreover, agricultural activity based on social responsibility and ethics, focusing on environmental and health protection, strengthens social trust and improves consumer opinions (Żuchowska-Grzywacz, 2024).

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