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POTENTIAL INTEREST IN AGRICULTURAL WATER MANAGEMENT INVESTMENTS IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

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ABSTRACT: This article contributes to the discussion on water management in agriculture and investment needs in this area. Water is a key resource for agricultural production. Contemporary economic, social, and environmental challenges require farmers to implement modern drainage and irrigation solutions that will increase the efficiency of agricultural water use and produce food in line with sustainable development principles. The aim of the study was to determine the potential interest of farmers in modern irrigation and drainage investments (regarding both traditional solutions and digital innovations, including specialised software). Primary data were collected by survey method using an electronic questionnaire in 2021–2022. The research group consisted of 784 Polish farmers. Secondary source data was supplemented by analysis of specialised literature. The research results were analysed using a descriptive method. Additionally, statistical methods were used (Pearson's chi-square test of independence, Wald-Wolfowitz runs test, Kruskal-Wallis test). The study results indicate a significant need for irrigation and drainage investments on Polish farms. The results also indicated that farmer age and farm size significantly influence farmers' interest in modern solutions supporting sustainable water use for agricultural purposes.

KEYWORDS: water for agricultural purposes, agricultural use of water, drainage investments, irrigation investments, sustainable water economy

Introduction

Water is a key resource essential to the existence of humankind and the proper functioning of the natural environment. Without it, food production is impossible, and therefore, food security for the human population is impossible. Although the world physically possesses vast amounts of water, in many cases, it is becoming scarce, either due to natural environmental and climatic processes, local overpopulation, political and military conflicts, or due to the misuse of available water resources and the waste of this valuable and crucial resource. Access to sufficient quality and quantity of freshwater is a particular problem. Therefore, in this case, special attention should be paid to ensure that water is managed in an efficient, fair, and sensible way as possible. We should also seek and implement concepts and solutions that will facilitate proper water management. Sustainable development is such a concept, and implementing principles consistent with it in water resource management makes profound sense. Taking economic, environmental, and social aspects into account in the right balance when making decisions about water resource management should bring benefits to both the economy and the natural environment. A key issue is the search for new, innovative solutions, methods, devices, and equipment useful for the sustainable use of water resources. This applies largely to agriculture, which, as a sector of the global economy, requires the greatest amount of freshwater.

Farmers are a professional group that, in practice, uses water for economic purposes and also directly observes nature. They depend on water availability and face various constraints that hinder proper water management. The opinions presented by farmers can be a valuable source of information and suggest proposals that will help find the right path towards sustainable water resource use. This means it will be economically efficient, environmentally sound, and socially beneficial. It will also enable quantitatively and qualitatively safe production in the food sector. The scarcity of water resources and the inefficiency of the irrigation systems constrain agricultural development. This situation calls for innovative solutions, including the introduction of water-saving technologies, rehabilitation of infrastructure, and the establishment of an effective water economy system.

The aim of the research was to identify investment needs and determine potential interest in modern solutions supporting the efficient and sustainable use of water for agricultural purposes on farms. The research directly addressed farmers' interest in modern investments in irrigation and drainage (both traditional and digital, including specialised software). The following research questions were formulated during the work:

- 1) What are the main problems in water management for agricultural purposes?
- 2) What is the level of investment needed to ensure proper water management in agriculture?
- 3) What can be done to improve the technical infrastructure necessary for proper water management for agricultural purposes?
- 4) What product groups supporting proper water management are farmers particularly interested in using on their farms?

The novelty of this research lies in its unique contribution to market data, which can be used in planning the commercial launch of new product solutions for irrigation and drainage in agriculture and in shaping agricultural policy, particularly in the area of proposed instruments for sustainable water management and increasing the efficiency of water use in agricultural practice.

An overview of the literature

In economic theory, water has for centuries been viewed as a free good, with access to it requiring no costs or labour. Agriculture was primarily located in areas where access to water was unlimited and free (Falkenmark & Rockström, 2004). Human population growth and the spread of humanity into new areas have made water an economic good (a scarce resource). With the continuous increase in agricultural demand for water in many parts of the world, access is rationed and subject to fees. Simultaneously, agricultural demand for water is increasing. The ability to fully meet the needs of plants and animals in this regard promotes higher yields and productivity (Chawla et al., 2023). Both long-term water shortages and excesses lead to deterioration of agricultural products, reduced productivity, and in extreme cases, crop destruction and animal death. Recurring crisis situations result in a reduction in the scale of production, an increase in costs, and often force its liquidation, which

significantly affects the economic situation of farmers and sometimes even entire regions (Forouzani & Karami, 2011).

Sustainable development is a concept that integrates economic, social, and environmental activities to improve the standard and quality of life of communities living in a given area. Improving quality of life is a primary goal, achieved through economic growth and environmental protection while maintaining social equality, biodiversity, and an adequate supply of natural resources (Dobrzański, 2002; Adamska & Minta, 2019). Sustainable development should be understood as a dynamic process based mainly on quantitative and qualitative changes in the economic, social and ecological spheres. It should be consistent with the needs and preferences of the inhabitants of a given area (Kozłowski & Turkowski, 2024). Sustainable development may also mean equalising opportunities between regions with high development potential (usually urban agglomerations) and peripheral (mostly agricultural areas) with lower development potential (Minta et al., 2013).

One of the key elements of sustainable development is water. It is essential in all areas of plant and animal life, as well as in all types of human socio-economic development processes. Water is a renewable natural resource with regenerative properties. However, this resource is not constant. Depending on its use, its quantity can increase or decrease (Woś, 1995). Favourable water relations are determined not only by water revenues but also by the ratio between revenues and expenditures. Dry years cause a deepening water deficit in the environment (Przybyła & Szafranski, 2004). Thier (2016) believes that the main factors contributing to water shortages are population growth, consumption, living needs, increased demand for agricultural and industrial products, and inappropriate human activity. Therefore, proper water management becomes essential, as water is perceived as a strategic asset.

Sustainable water management should meet various needs: water supply and sewage disposal, use of water resources for energy, marine, agricultural, fishing and tourist purposes. It should also provide adequate protection against the element of water and the effects of drought. It should also ensure the correct quantity and quality of water resources, which helps to function and protect aquatic ecosystems and water-dependent systems (Lorek & Lorek, 2018). Sustainable development requires rational water management in rural areas. Water is crucial for agricultural production. Globally, approximately 70% of freshwater is used for agriculture, 20% for industrial purposes, and the remaining 10% in the municipal sector (Kamiński & Pusz, 2023).

One of UNESCO's 2021 reports is dedicated to the water valuing (UNESCO, 2021). When combining agricultural water use and the implementation of the concept of sustainable development, it is worth noting that rational water management in agriculture has a key impact on ensuring food security, public health and natural values, and not only in agriculturally used areas (Hoover et al., 2023). It is important to note that food security is one of the most important challenges facing the world today, as many factors (population growth, climate change, new food technologies, foodborne diseases, human migration, etc.) have a significant impact on the quality and quantity of food (Alexandratos & Bruinsma, 2012). Emphasising that water is critical for sustainable development, the period from 2005 to 2015 was declared as the International Decade for Action, "Water for Life" by the UN General Assembly (United Nations General Assembly, 2004). Climate changes on agriculture are multi-factorial, but one of the most fundamental here is the severe decrease in the availability of irrigation water in different regions. This is connected with the drying up of water sources intended for irrigation and decreasing the water amount in them, ruthless use of underground water etc. Climate change and changes in the quantity and quality of irrigation and drinking water have a huge impact on food security and human health. (Gupta et al., 2021): It's becoming more vulnerable, especially in countries where traditional agriculture is still dominated: when the irrigation process is not controlled by smart devices and huge amounts of water are used in irrigation, as well as the absence of double water use for the same or other purposes. In order to solve these issues, appropriate changes in agricultural policy and water management systems are necessary, which will contribute to the implementation of smart agriculture, obtaining more products with relatively little water, reuse of used water, and also reduce the negative impact of agriculture on the environment (Ahmed, 2020; Fernandes et al., 2022; Kaddoura & el Khatib, 2017; Lee et al., 2020; Mahlknecht et al., 2020).

In recent decades, phenomena known as climate change have become particularly dynamic, also affecting the availability and management of water in agriculture. These changes are particularly noticeable among farmers, who are completely dependent on nature. In Poland, these changes

include: increasingly frequent extremely high temperatures (not only in summer, but also, though to a lesser extent, in spring and autumn), decreasing snowfall in winter (which subsequently reduces soil water reserves during the growing season), recurring rapid weather changes (especially large daily temperature fluctuations that cause thermal shock in crops), and the disappearance of the typical division of the year into four distinct seasons (the disappearance of the classic spring and autumn – winter ends abruptly and temperatures immediately rise, while autumn, after the high temperatures, is followed by the dynamic arrival of winter). Furthermore, weather cycles are unpredictable, and spring is increasingly experiencing long periods of cold, dry winds, which inhibit plant growth (Kuryluk, 2020).

Climate change is redefining the functioning of the modern world. This applies to both the economic landscape and the way we produce food and manage natural resources. Agriculture is highly dependent on the variability and unpredictability of weather conditions, which necessitate adaptive measures to new natural conditions. The agricultural sector in Poland, particularly crop production, is increasingly exposed to droughts, torrential rains, and other extreme weather phenomena, as well as turbulence during growing seasons (Michalak, 2025).

The problem of water deficit in Poland is growing. Limited access to water and increasingly frequent periods of drought in agriculture demonstrate that it is a more and more valuable resource. Climate change is making this situation worse. Therefore, in Polish conditions, there is a need for various actions to increase water retention and the efficiency of its use (Berkowska & Gwiazdowicz, 2020).

Water management in Poland requires systemic reform and investment. This stems, among other things, from simulations of climate change scenarios and the development of the hydrosphere's balance, which indicates a growing risk of rainfall deficits in the future. These deficits could be so significant that they will force Poland to switch to widespread irrigation. However, this will result in a rapid increase in water abstraction for agricultural purposes. The current system of allocating water permits and water law is not ready for this. Changes are also necessary in spatial planning and land taxation, improving the organisation and maintenance of the drainage network, increasing water retention in the landscape and soil, optimising irrigation practices, water reuse, and rainwater harvesting. Furthermore, there is a lack of systemic assurance of equitable water distribution and allocation, as well as the renewable nature of water resources in Poland. (Wawer, 2020).

Research methods

Primary and secondary source materials have been used to prepare this paper. Documentary method and critical analysis of literature sources have been used to collect secondary data. A survey method has been used to collect primary data. Respondent selection was purposive (non-random), and the choosing criteria were as follows: respondents had to be farmers managing farms, and they had to conduct agricultural activities in Poland during the data collection period (between November 2021 and March 2022). Participation in the study was voluntary and anonymous, and respondents could withdraw their responses and not submit completed questionnaires at any time. After verification of the survey data, responses from 784 respondents have been used for detailed research.

Due to the fact that the survey was conducted during the SARS-COV-2 pandemic and the threat of COVID-19, as well as the associated restrictions and difficulties, it was decided to distribute the survey via electronic channels (email, posts on social media). Because of that, the survey was conducted using the CAWI method (Computer Assisted Web Interview), and a specially designed electronic research questionnaire was used to collect data. It should be noted that the method of selecting the research sample and choosing an electronic data collection method had its limitations, as farmers who do not use the internet or electronic communication channels were not allowed to participate in the data collection process. The CAWI method used in the research has certain limitations, particularly problems with the representativeness of the sample, low researcher control over the data collection process, and possible technical limitations (e.g. lack of compatibility with mobile devices, difficulties in navigating the survey, and the need for an appropriate internet connection). This limited the representativeness of the results obtained in the study group compared to the entire farming population. Furthermore, budget constraints and pandemic restrictions during the study period did not allow for other methods of collecting fully representative primary data.

The collection of survey data was made possible thanks to participation in the Polish research program “Natural Environment, Agriculture, and Forestry – BIOSTRATEG III” for the project entitled “Technological Innovations and a System for Monitoring, Forecasting, and Operational Planning of Land Improvement Operations for Precise Water Management at the Land Improvement Facility Scale” (acronym “INOMEL” and financially supported by the Polish government agency “The National Centre for Research and Development” (acronym NCBR).

The research questionnaire contained various types of questions (closed and semi-open, with single or multiple-choice responses). The first part of the questionnaire included questions to help characterise respondents and their farms. Subsequent questions allowed for obtaining opinions on the main problems related to water management in agriculture, suggestions for improving the technical condition of agricultural water infrastructure and increasing the level of investment in this area, determining the potential level of respondents’ interest in modern solutions that could support proper water management in agriculture, and indicating the potential interest of respondents in specific product groups that could support water management on their farms. The questionnaire design was tailored to the specific water issues related to problems and solutions for irrigation and drainage in agriculture, as well as the requirements of the INOMEL project, ensuring efficient collection of all necessary data. Respondents completed the surveys via a Google form, and the source data was then downloaded from the server and saved in Excel format. The data were then subjected to preliminary analysis and verification, and then processed using a descriptive method.

The descriptive method and the graphical method have been used to develop and present the research results. Additionally, the collected source materials have been statistically analysed using the program Statistica 13.3. Nonparametric statistical procedures have been used, including the Pearson chi-square test of independence, the Wald-Wolfowitz runs test, and the Kruskal-Wallis test. Results with a significance level of $p < 0.05$ were considered statistically significant (Szwed, 2008; Pułaska-Turyna, 2011). Respondents’ responses to questions regarding ratings and opinions were coded on a five-point ordinal scale (1–5), with numerical values corresponding to subsequent response categories. Unifying the qualitative data in this format enabled quantitative analysis and statistical analysis. The use of nonparametric tests was justified by the nature of the research material: the data consisted of evaluations and opinions, and thus had a qualitative and ordinal character, which excluded the possibility of treating them as quantitative variables. Moreover, the distribution of the studied variables deviated from normality (verified with the Shapiro–Wilk test), which further supported the choice of nonparametric methods (Schnuerch et al., 2022). The research results have been presented in descriptive, tabular, and graphical formats.

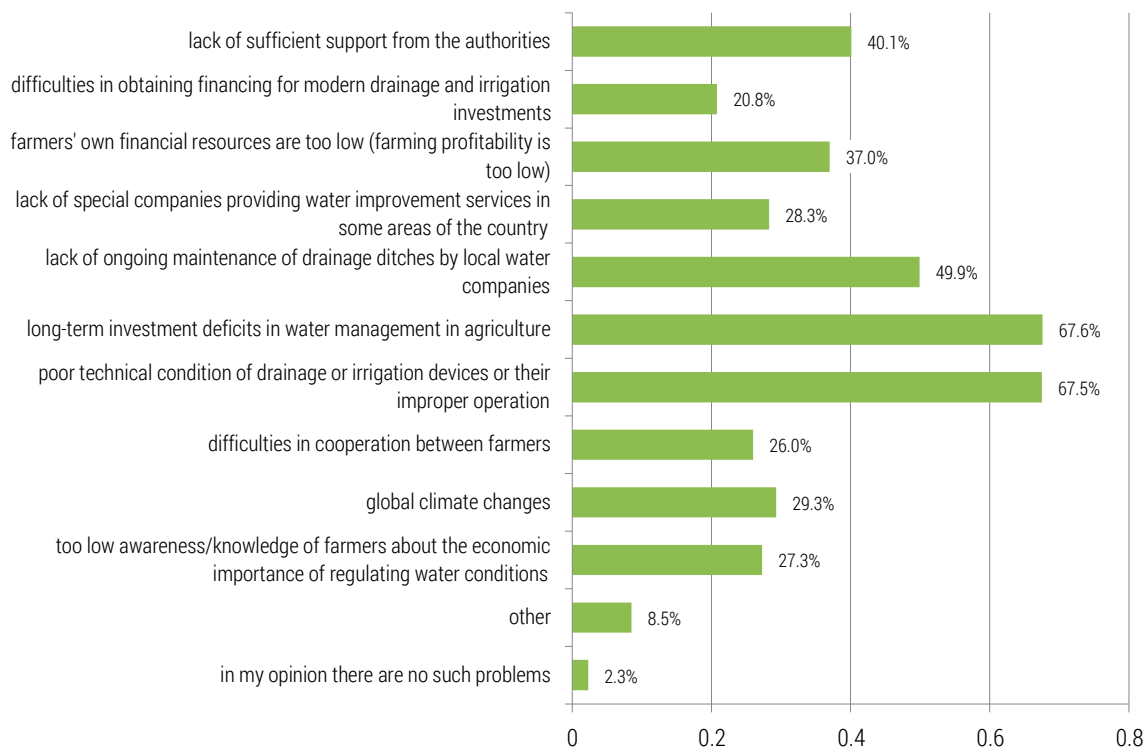
Results of the research

A total of 784 people participated in the survey. Respondents were first asked to provide demographic data and information describing their farms. Detailed results regarding the characteristics of respondents and their farms are presented in Table 1.

The survey population consisted of 70.1% men and 29.9% women. All respondents were adults (aged 18 or over). The largest age group was 36-45 years old (just over 30%), followed by 46-55 years old and 26-35 years old (22.3% and 20.0%, respectively). The youngest age group (18-25 years old) comprised 8.7%, and the remaining 3.2% were over 65 years old. The majority of respondents had long experience in managing farms (59.2% of people had been running farms for 11 years or more, while 19.9% of people had no more than 5 years of experience). 28.8% of the individuals managed farms smaller than 10 ha, and 50.9% came from farms with a total area between 10 and 50 ha. In the study group, 20.3% represented farms larger than 50 ha. In terms of legal form, the vast majority represented the most popular individual family farms in Poland (96.5%). The study group also included 13 farms owned by the State Treasury, 12 farms incorporated as commercial companies, and 2 with other legal forms. The majority of surveyed farms had crop production as their dominant activity (48.5%), with another 30.6% involved in a similar mix of crop production and animal husbandry. Farms with dominant animal production represented 14.0% of the surveyed farms. The survey group was completed by 6.9% of persons managing orchards, intensive vegetable production, or other specialised agricultural production (Table 1).

Table 1. Characteristics of respondents taking part in the survey (n=784)

| Specification | | Number of respondents | [%] |
|--|---|-----------------------|------|
| Gender | female | 235 | 29.9 |
| | male | 549 | 70.1 |
| Age | 18-25 years | 68 | 8.7 |
| | 26-35 years | 157 | 20.0 |
| | 36-45 years | 238 | 30.4 |
| | 46-55 years | 175 | 22.3 |
| | 56-65 years | 121 | 15.4 |
| | over 65 years | 25 | 3.2 |
| Period of experience in farm management | Up to 5 years | 156 | 19.9 |
| | 6-10 years | 164 | 20.9 |
| | 11-20 years | 197 | 25.1 |
| | over 20 years | 267 | 34.1 |
| Total farm area | up to 10 ha | 226 | 28.8 |
| | 10-50 ha | 399 | 50.9 |
| | over 50 ha | 159 | 20.3 |
| | average farm area | 127.64 ha | - |
| | median of the farm area | 19.73 ha | - |
| Legal form of farms | individual family farms | 757 | 96.5 |
| | State Treasury farms | 13 | 1.7 |
| | commercial law company | 12 | 1.5 |
| | other | 2 | 0.3 |
| The dominant direction of production on the respondents' farms | field crop production | 380 | 48.5 |
| | animal husbandry | 110 | 14.0 |
| | crop and animal (no clear dominance) | 240 | 30.6 |
| | other (including orchards, vegetable production, special agricultural production) | 54 | 6.9 |

**Figure 1.** The main water problems in agriculture, according to the opinions of surveyed Polish farmers

In the next step, respondents were asked to indicate their opinions on the main problems related to water management in agriculture. In this case, respondents had the option of selecting multiple answers, and the detailed results are presented in Figure 1.

Respondents gave the most indications for two options describing difficulties in proper water management in agriculture: (1) long-term investment deficits in water management in agriculture, (2) poor technical condition of drainage or irrigation devices or their improper operation. These options were selected by over 67% of respondents (Figure 1). Almost 50% of the indications concerned the lack of ongoing maintenance of drainage ditches by local companies specialised in water service. In the opinion of the surveyed farmers, insufficient support from the authorities and insufficient financial resources of farmers due to low profitability in agriculture were also major difficulties (40.1% and 37.0% of responses, respectively). Only in sixth place as a problem for managing water for agricultural purposes was global climate change (29.3% of responses). At a similar level, farmers indicated the lack in many parts of the country of companies specializing in maintenance services and infrastructure improvement enabling the effective management of agricultural water resources, too little awareness/knowledge of the economic importance of regulating water conditions in agricultural areas, as well as difficulties in cooperation between farmers (these options received from 26.0% to 28.3% of responses). Other reasons were chosen by 8.5% of farmers. This option mentioned the damage caused by beavers, focusing only on drainage even during drought in the absence of irrigation and low water retention, as well as the lack of retaining water in periods of large amounts of water and releasing it during periods of drought. Among other obstacles, farmers also indicated certain difficulties in cooperation with the government company “Wody Polskie”, responsible for proper water management on a national scale, as well as restrictions due to requirements regarding protected areas, and others. Only 2.3% of farmers didn't see any water problems in agriculture (Figure 2).

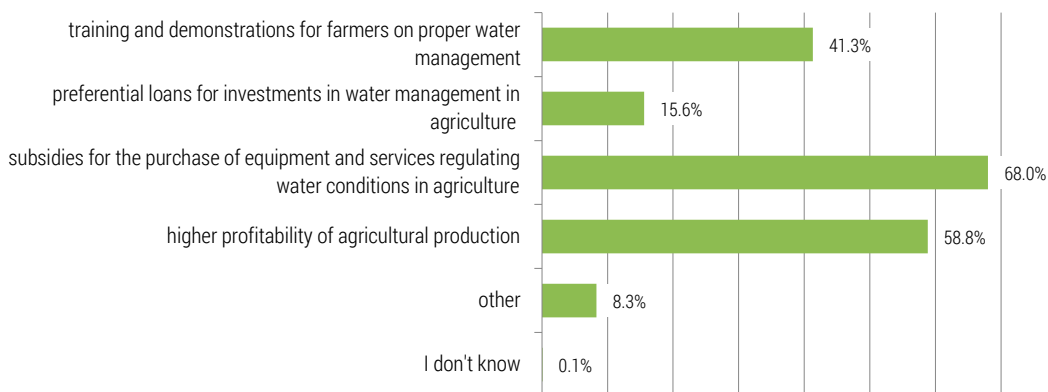


Figure 2. Respondents' suggestions on how to improve the technical condition of agricultural water infrastructure and increase the level of investment in this area

Figure 2 shows respondents' suggestions on how to improve the technical condition of agricultural water infrastructure and what to do to improve the level of investment in this area. Here, the most popular answer was the possibility of obtaining subsidies for the purchase of equipment and services helping to obtain proper water conditions in agricultural areas (68.0%). In second place, farmers indicated higher profitability of agricultural production (58.8%), which is understandable, because it determines farmers' investment opportunities without waiting for external support. The option of training and demonstrations for farmers on the proper management of water for agricultural purposes was also very popular (41.3% of responses). Additionally, 15.6% of responses concerned the availability of preferential loans for investments in water management in agriculture.

During the next stage of the research, data from farmers was collected, which allowed to determine the general potential level of interest in modern solutions that can help in proper water management in agriculture, as well as to indicate specific product groups of particular interest to farmers as possible investments related to water management in agricultural areas. Details are shown in Figures 3 and 4.

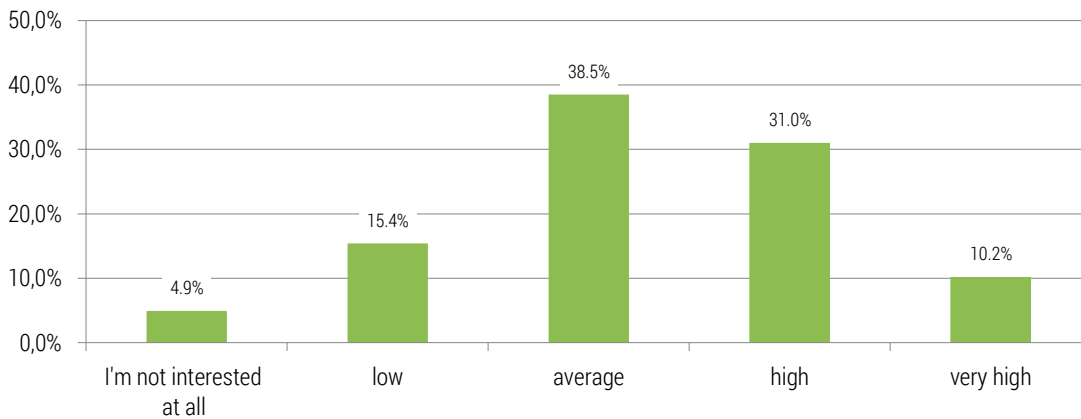


Figure 3. Determining the potential level of interest of respondents in modern solutions that can help in proper water economy in agriculture

The results in Figure 3 show that the surveyed farmers chose most frequently an average level of interest in modern water management solutions. However, overall, the group declaring a high and very high level of interest was much larger than the group not at all interested or with a low level of interest (41.2% vs. 20.3%). Indirectly, it can be concluded that there is quite a large potential on the market for selling products and services that help manage water for agricultural purposes in a modern, appropriate and sustainable way.

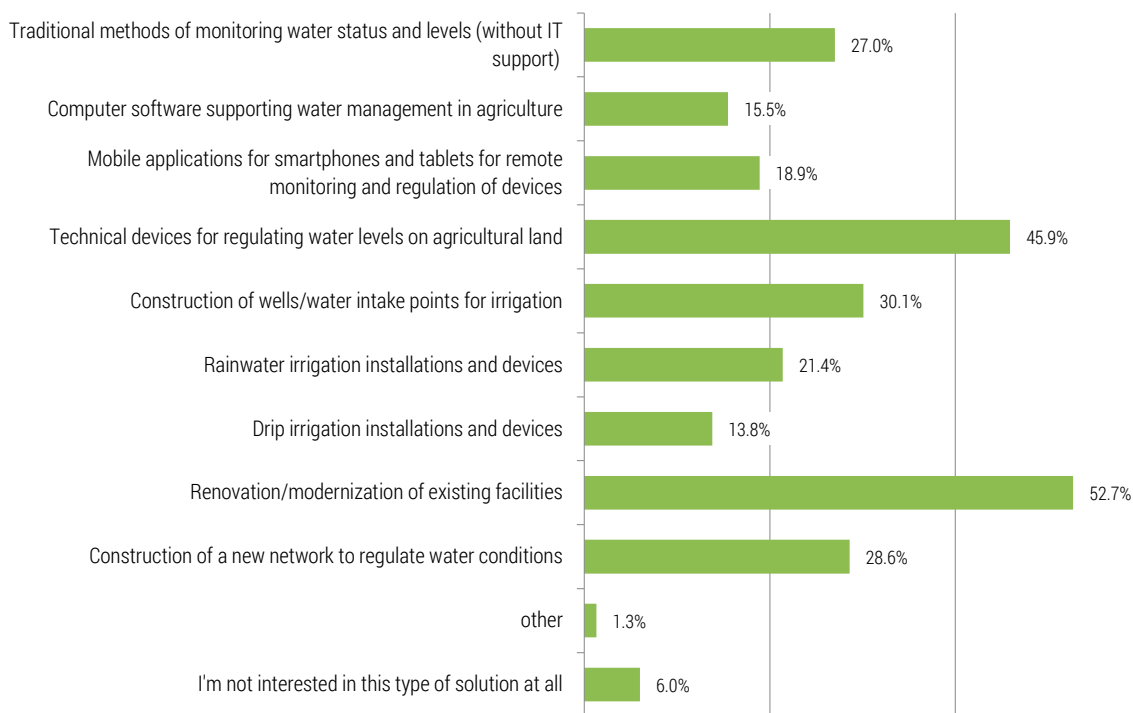


Figure 4. Respondents' indications regarding product groups supporting water management in their farms in which they are potentially interested

Renovation or modernisation of existing facilities was the most popular option among surveyed farmers in terms of their potential interest in investing in water management (52.7% of indications). Almost 46% of respondents chose technical devices to regulate the water level in agricultural land. Just over 30% of people expressed interest in the construction of wells or water intake points for irrigation, and 27% about traditional methods of monitoring water status and levels (without IT support). Just over 30% of people expressed interest in the construction of wells or water intake points for irrigation, 28.6% – construction of a new network to regulate water conditions in agricul-

tural land and 27% about traditional methods of monitoring water status and levels (without IT support). Despite the apparent greater interest in traditional technical solutions, respondents were also interested in potential IT improvements. Mobile applications for smartphones and tablets for remote monitoring and regulation of devices were reported by 18.9% of respondents, while computer software supporting water management in agriculture was reported by 15.5% (Figure 4).

In a further stage of the research, statistical analyses were conducted to determine the interest in specific groups of solutions supporting water management in agriculture and the influence of four analysed variables (gender, age, length of farm management, and farm area). The results are presented in Table 2.

Table 2. The Pearson chi-square test of independence regarding the interest of the surveyed farmers in water management solutions

| Specification | Number of respondents (n = 784)* | Gender | Age | Period of experience in farm management | Total farm area |
|--|----------------------------------|--------|---------|---|-----------------|
| 1 Traditional methods of monitoring water status and levels (without IT support) | 212 | 0.95 | 21.55** | 1.12 | 1.72 |
| 2 Computer software supporting water management in agriculture (for remote monitoring and regulation of devices) | 123 | 1.43 | 12.65* | 3.42 | 5.56 |
| 3 Mobile applications for smartphones and tablets for remote monitoring and regulation of devices | 148 | 2.15 | 23.67** | 5.15 | 5.33 |
| 4 Technical devices for regulating water levels on agricultural land | 360 | 1.94 | 5.26 | 9.44* | 3.35 |
| 5 Construction of wells/water intake points for irrigation | 236 | 1.52 | 16.95** | 21.02** | 0.23 |
| 6 Rainwater irrigation installations and devices | 156 | 0.10 | 3.86 | 1.32 | 0.26 |
| 7 Drip irrigation installations and devices | 108 | 5.78* | 3.42 | 1.61 | 12.56* |
| 8 Renovation/modernization of existing facilities on used agricultural land | 413 | 2.34 | 2.53 | 2.99 | 14.02** |
| 9 Construction of a new network to regulate water conditions on used agricultural land | 225 | 1.28 | 15.01* | 2.98 | 0.22 |
| 10 I'm not interested in this type of solution at all | 47 | 1.65 | 3.89 | 3.76 | 4.67 |

* respondents could indicate more than one answer; *p<0.05, **p<0.001

Source: author's work based on survey data.

Statistical analyses showed a significant correlation between the age of respondents and interest in traditional methods of monitoring water status and levels (without ICT support) ($\chi^2=21.55$, $df=5$, $p=0.000$), computer software supporting water management on farms (for remote monitoring and regulation of devices) ($\chi^2=12.64$, $df=5$, $p=0.027$), mobile applications supporting water management in agriculture ($\chi^2=23.67$, $df=5$, $p=0.000$), construction of wells/water draw-off points for irrigation ($\chi^2=16.95$, $df=5$, $p=0.004$) and construction of a new network to regulate water conditions on used agricultural land ($\chi^2=15.01$, $df=5$, $p=0.010$). Moreover, a significant relationship was found between the duration of farm management and interest in technical devices regulating water levels on agricultural land ($\chi^2=9.44$, $df=3$, $p=0.024$), as well as a strong relationship with the construction of wells/irrigation water intake points ($\chi^2=21.02$, $df=3$, $p=0.000$). In particular, the shorter the duration of farm management, the greater the interest in this topic. It is worth emphasising that respondents running small farms (up to 10 ha) were more interested in using drip irrigation systems and devices ($\chi^2=12.56$, $df=2$, $p=0.001$). On the other hand, farmers operating medium- and large-sized farms were more interested in renovating or modernising existing facilities on their agricultural land.

The last stage of the research consisted of a statistical analysis of the impact of four selected variables (gender, age, length of running the farm and farm area) on investment needs and interest in solutions useful in the use of water for agricultural purposes (Table 3).

Table 3. Statistical analysis of investment needs and interest in water management solutions among surveyed farmers

| Specification | Mean | Median | Skewness | Gender | Age | Period of experience in farm management | Total farm area |
|--|------|--------|----------|--------------------------|---------------------|---|-----------------|
| | | | | Wald-Wolfowitz runs test | Kruskal-Wallis test | | |
| The level of water and drainage investment needs on the farm | 3.69 | 4 | -0.468 | -0.44 | 6.55 | 5.57 | 2.43 |
| Level of interest in modern water and drainage solutions on the farm | 3.26 | 3 | -0.221 | -2.48* | 16.67** | 2.98 | 12.43** |

*p<0.05, **p<0.001

Source: author's work based on survey data.

Statistical tests showed a significant impact of three of the four chosen variables on the level of interest in modern water solutions on the farm (Table 3). The Wald-Wolfowitz runs test showed significant differences in the distribution of responses between men and women ($Z = -2.48$; $p = 0.013$). The calculations show that gender differentiated the way this aspect was assessed, even though the average rating values in both groups were similar ($\bar{x}_m=3.27$ and $\bar{x}_k=3.26$). The results suggest that women and men may have different levels of interest in modern water management solutions. The Kruskal-Wallis test showed a significant influence of the respondents' age and the area of the farm used. The tests selected for the study confirmed that younger respondents are more interested in modern solutions and that, as the farm area increases, the interest in these solutions also increases.

Discussion/Limitation and future research

As agriculture is the largest global consumer of water but also a major source of water pollution through the discharge of nutrients, pesticides, and various contaminants (Guth et al., 2024), farmers play a key role in managing water resources and addressing limited access to water (United Nations, 2024). Therefore, the literature contains numerous publications examining farmers' opinions. This paper is an example of quantitative research, which helps determine the scale of phenomena and the prevalence of opinions. However, the literature is dominated by research articles based on qualitative research (expert interviews, focus groups). These articles focus on farmers' attitudes toward water management practices, factors influencing the implementation of water-saving practices, perceptions of climate change, and the role of farmer support policies as drivers of water management (Guth et al., 2024). Few articles focus on the impact of farmers' behaviour on water use efficiency in agricultural production (e.g., Piedra-Muñoz et al., 2018) or the impact of new irrigation technologies on the economic performance and technical aspects of agricultural production (e.g., Vrachioli et al., 2021).

Some issues related to water management and farmers' needs are global, but they also vary by region. For example, in Armenia (Caucasus region), the main problem with the irrigation system is outdated infrastructure. Most of it was built during the Soviet era and no longer meets modern requirements. Water losses reach about 40% during delivery, mainly due to open canals and worn-out pipelines. In addition, irrigation practices are inefficient, as surface irrigation methods dominate over modern water-saving technologies.

In the case of Poland located in Central Europe and its fragmented agriculture, a modern approach to land consolidation processes should play a greater role, in which, in addition to production and income effects, social and environmental goals should also be achieved, including water management goals, as this increases the economic efficiency of these costly investments (Wojewodzic et al., 2021). It should be noted that agriculture in Poland has been experiencing the effects of both increasingly frequent periodic droughts and recurring, mainly local, water surpluses resulting from heavy rainfall (Bański & Błażejczyk, 2005).

Another example is Central Asia, including Uzbekistan. The situation there is defined by the transboundary context and water resources in the Amu Darya and Syr Darya rivers. Hydropower

goals in the upper reaches of the river (winter discharges) conflict with irrigation needs in the lower reaches (summer discharges). This creates seasonal imbalances and political friction between the countries of the region (Mukhammadiev, 2013). Central Asia has experienced the devastating consequences of poor water management, including the drying up of the Aral Sea, water shortages, and soil salinity problems. The Aral Sea disaster remains the starkest consequence of decades of over-abstraction and poor drainage management (Saiko & Zonn, 2000). Three persistent constraints recur across Central Asia: (1) ageing infrastructure and high conveyance losses; (2) institutional capacity gaps at WUA and canal-operator levels; and (3) policy misalignments (state-mandated crop plans, limited price signals) that mute farmer incentives to adopt efficient technology. Until these are addressed in tandem, gains from hardware alone will be partial.

When considering issues related to sustainable water economy, it is essential to seek and implement modern, comprehensive solutions. It is about of water retention, intelligent irrigation systems, two-way drainage, renaturalization and protection of water systems, proper soil water management, and the use of digital technologies. However, these activities require appropriate knowledge and, very often, investment, which significantly increases the costs of agricultural operations (Alharbi et al., 2024). Among solutions, innovations and pathways to sustainable water management, there can be also proposed for example: crop and area planning (shift away from the most water-intensive crops and water balancing (Kazbekov et al., 2007), field-level water saving (laser land leveling; conversion from furrow to drip/sprinkler on orchards/vegetables; irrigation scheduling by crop growth stage; and salt-tolerant rotations) (Vinokurov et al., 2023), and using of measurement & transparency (low-cost flow meters, telemetry on main canals, and farmer-facing dashboards for delivery schedules and water accounts to cut conflict). There can also be a helpful use of economic instruments. Australia is a good example, where tax breaks and direct support are used to modernise farm infrastructure, improve irrigation efficiency, better use of natural resources and manage the environment (OECD, 2019).

Rational water economy is a challenge for all social groups. Ensuring adequate water quality and quantity requires consideration of both technological and educational issues. Implementing sustainable water use practices in agriculture requires understanding them, and therefore implementing appropriate educational programs tailored primarily to local needs, taking into account climatic conditions but also the values of a given community (Tójar-Hurtado et al., 2017). The use of new technologies can solve many problems in modern agriculture. It's worth noting that implementing such solutions must be responsible and sustainable – especially considering the potential impact on small farms and the natural environment (Tace et al., 2023). It's important to remember that this generates costs and requires specialised knowledge. Therefore, alongside investments, farmers should also be educated on how to fully utilise these solutions for the benefit of themselves, society, and the environment. This suggests that further research should also address the educational and training needs of farmers and other stakeholders for whom proper use of water for agricultural purposes is one of the key issues.

Conclusions

Based on the presented research, the following conclusions can be drawn:

- there is significant potential interest in investing in modern solutions that support the efficiency and sustainable use of water for agricultural purposes;
- the research results indicate significant interest among farmers in modern investments, primarily in traditional elements of water infrastructure, but almost 19% of respondents were interested in mobile applications for remote monitoring and regulation of devices, and 15.5% of respondents indicated interest in computer software supporting water management in agriculture;
- surveyed farmers most often indicated two reasons of Polish water problems in agriculture: long-term investment deficits in water management in agriculture and poor technical condition of drainage or irrigation devices or their improper operation;
- respondents most often suggested the following solutions to improve the technical condition of agricultural water infrastructure and increase the level of investment in this area: subsidies for

the purchase of proper equipment and services, higher profitability in agriculture, training and demonstrations for farmers on proper water management;

- prepared statistical analyses confirmed that interest in modern water solutions was age-dependent (younger farmers showed greater interest). Statistical tests showed also that respondents running small farms (up to 10 ha) were more interested in using drip irrigation systems and devices and farmers operating medium- and large-sized farms were more interested in renovating or modernising existing facilities on their agricultural land;
- modern technical solutions, including those related to precision agriculture and the use of IT solutions, require significant investment and appropriate knowledge. This highlights the need for appropriate educational programs that will help farmers fully utilise the benefits of new solutions and enable them to use water in a sustainable manner;
- climate change increases the need for irrigation, increased retention and increased water use efficiency in agriculture;
- the need for various activities to mitigate the effects of water shortage is increasing, which is a factor potentially increasing the demand for irrigation and drainage equipment and technologies, but on the other hand, the interest and investment possibilities of farmers are limited by the level of profitability in agriculture and the possible availability of public financial support for this type of investments;
- the proactive and scientific potential of the research concerns, on the one hand, the possibility of using the data to shape the product policies (including those related to the introduction of new products to the market) of businesses offering irrigation and drainage solutions for farmers, on the other hand, for comparative studies of similar scope internationally, and as source material for research and conceptual work on creating agricultural policy (particularly regarding instruments and activities supporting sustainable development and proper water management for agricultural purposes).

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POTENCJALNE ZAINTERESOWANIE INWESTYCJAMI W GOSPODARCE WODNEJ W ROLNICTWIE W KONTEKŚCIE ZRÓWNOWAŻONEGO ROZWOJU

STRESZCZENIE: Niniejszy artykuł stanowi przyczynek do dyskusji na temat gospodarki wodnej w rolnictwie i potrzeb inwestycyjnych w tym zakresie. Woda jest kluczowym zasobem dla produkcji rolnej. Współczesne wyzwania ekonomiczne, społeczne i środowiskowe wymagają od rolników wdrażania nowoczesnych rozwiązań melioracyjnych, które zwiększą efektywność wykorzystania wody w rolnictwie i pozwolą produkować żywność zgodnie z zasadami zrównoważonego rozwoju. Celem badania było określenie potencjalnego zainteresowania rolników nowoczesnymi inwestycjami w melioracje i melioracje (zarówno tradycyjnymi, jak i cyfrowymi, w tym specjalistycznym oprogramowaniem). Dane pierwotne zebrano metodą ankietową z wykorzystaniem kwestionariusza elektronicznego w latach 2021–2022. Grupę badawczą stanowiło 784 polskich rolników. Dane ze źródeł wtórnych zebrano dzięki analizie literatury specjalistycznej. Do opracowania wyników wykorzystano metodą opisową. Dodatkowo wykorzystano metody statystyczne (test niezależności chi-kwadrat Pearsona, test przebiegów Walda-Wolfowitza, test Kruskala-Wallis). Wyniki badania wskazały na znaczną potrzebę inwestycji wodno-melioracyjnych w polskich gospodarstwach rolnych. Wyniki wskazały również, że wiek rolnika i wielkość gospodarstwa mają istotny wpływ na zainteresowanie rolników nowoczesnymi rozwiązaniami wspierającymi zrównoważone wykorzystanie wody w rolnictwie.

SŁOWA KLUCZOWE: woda na cele rolnicze, inwestycje melioracyjne, odwodnienia, nawodnienia, zrównoważona gospodarka wodna