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# Possibilities of Using Decision Support Systems for Agriculture in Areas with High Agrarian Fragmentation

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# Possibilities of Using Decision Support Systems for Agriculture in Areas with High Agrarian Fragmentation

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## Abstract

The capabilities of farms often limit the possibility of using technologically advanced agricultural digital solutions. However, the experience of many countries shows that several easily accessible digital solutions can bring results in the form of optimising agricultural production processes. Hence, the research aimed to recognise the usefulness of digital solutions for systems supporting decision-making in farms operating in areas with sizeable agrarian fragmentation and to determine the barriers to their implementation. In order to achieve the research objective, the survey questionnaire method was used—389 farms from the Małopolskie and Podkarpackie voivodeships (areas with the most significant scale of agrarian fragmentation in Poland) were examined. The study showed that 34% of the surveyed farms used at least one technology that can be classified as a decision-support system. Financial constraints, insufficient equipment, and insufficient IT knowledge were indicated as the most critical barriers to their use. From the perspective of the surveyed farms, the functions of the systems above considered to be the most useful were the possibility of estimating resource consumption, the possibility of receiving information on the occurrence of the risk of plant diseases and access to an accurate weather forecast for individual agricultural plots. It is worth noting that respondents noticed the usefulness of the systems mentioned above in the remote exchange of information.

## Keywords

agriculture | agrarian fragmentation | small-scale farms | decision support systems

## JEL Codes

O33, Q10, Q16

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## 1. Introduction

Small farms encounter multiple development problems. These are technical limitations (lack of appropriate equipment) and those resulting from the lack of knowledge and underdevelopment of integration ties between agricultural producers. Developing digital technologies can help overcome these barriers. Digital technologies in the agricultural sector are mainly associated with concepts such as precision farming, smart farming or agriculture 4.0 (Foray, David & Hall, 2009; Hänisch, 2017; Hornung & Hofmann, 2017; Reichardt et al., 2009; Runowski, 2019; Runowski & Kramarz, 2025). In addition, the so-called information and communication technologies (ICT) play a unique role in the development of modern agriculture. The use of ICT is associated with the possibility of accelerating communication, intensifying knowledge transfer

processes between farmers and transferring scientific knowledge to agricultural practice, improving access to data and enabling their use in decision-making processes (Czapiewski et al., 2012; Dutta et al., 2023; Daum, 2018). ICT includes, among others, media-enabling communication, information recording technologies, IT systems processing and transmitting data (Tomaszewska, 2013), and cloud-based farm management platforms (Fountas et al., 2020).

According to Bourrnaris and Papathanasiou (2012), farmers are a professional group facing significant limitations in access to information, while at the same time, the level of difficulty in the decisions they must make is constantly increasing (due to factors such as changing climatic conditions, growing consumer awareness, and legal regulations). Additionally, the conditions for conducting agricultural activities in areas with high land fragmentation, as is the case in the study

area (Poland), typically result in a lower propensity to adopt modern technologies. When agricultural land within a farm is divided into multiple plots (a phenomenon known as land fragmentation (Bentley, 1987)), and these plots are small, there is generally less interest in new production methods. Such conditions also require greater labour input (Demetriou, 2013). According to Eder (2024), the average distance between agricultural plots negatively affects a farm's level of technical efficiency. However, the mere dispersion of plots does not show a statistically significant impact. The topic of implementing digital technologies in such farms to improve their functioning and facilitate the adaptation of production profiles to market needs remains largely unexplored. Discussions mainly focus on barriers to implementing advanced digital technologies (including those based on artificial intelligence), the most frequently cited of which is the limitation of financial resources. However, the experience of developing countries shows that overcoming social resistance and increasing willingness to share information can enable solutions that help improve agricultural efficiency without requiring high investment outlays. These include primarily applications that support decision-making and facilitate farmer communication (Balkrishna & Deshmukh, 2017). Such technologies are regarded as a tool for improving agricultural productivity through more efficient resource management (Sridevy & Djanaguiraman, 2023). This potential may be particularly significant in challenging farming conditions, such as extensive agrarian fragmentation or low socio-economic development in rural areas. Therefore, the analyses aimed to recognise the usefulness of digital solutions for systems supporting decision-making in farms operating in areas with sizeable agrarian fragmentation and to determine the barriers to their implementation. The analyses sought answers to the following questions: 1. To what extent are decision support systems used on farms located in highly fragmented areas of Poland? 2. What functions of decision support systems can be used in the operation conditions of farms from highly fragmented areas? 3. What factors determine the implementation of decision support systems on farms from highly fragmented areas, and what limits it?

## 2. Literature review - application of decision support systems in agriculture

Challenges related to running agricultural activities appear, especially in areas with a high level of agrarian fragmentation and significant land fragmentation. Agrarian fragmentation is closely tied to land configuration, which hinders progress and results in low production efficiency (Szymańska, 2021). In Poland, the regions experiencing the highest levels of agrarian fragmentation are the Małopolskie and Podkarpackie voivodeships. In the Małopolskie voivodeship, farms covering less than 5 hectares (ha) make up 81% of all farms, while in the Podkarpackie voivodeship, this figure stands at 79%. In Poland as a whole, this percentage is 52%. These areas, which were part of the Austrian partition, implemented legal and organisational solutions that contributed to the consolidation of an unfavourable structure of farms. Additionally, they are characterised by the most diverse terrain in the country, including mountain ranges (Szymańska, 2024; GUS, 2020). Highly fragmented agricultural areas are typical in Poland and many countries globally. Consequently, efforts are being made to enhance the efficiency of farms in these regions. However, the agrarian fragmentation of agriculture is currently perceived not only in the context of problems related to its impact on the economic development of regions but also in the context of its positive impact on the state of the natural environment - especially regarding the need to build resilience to climate change and the desire to preserve biodiversity (Dhillon et al., 2023; Stępień et al., 2022). Therefore, efforts are being made to improve small farms' efficiency and increase production profitability while maintaining these areas' environmental importance. Digital technologies—especially ICT—may prove helpful in this respect. Other types of digital technologies, such as those related to precision farming or forms of plant production automation on small farms, are challenging to apply, mainly due to financial barriers or disproportion of the investment that would have to be made to the expected effects (Runowski & Kramarz, 2025; Geppert, Krachunova & Bellingrath-Kimura, 2024). According to some authors (Rybicki, 202; Kadigi, 2017), fragmentation of agricultural plots means that the land used is in different ecological zones, which in turn allows for diversification of production, adjustment of the schedule of agrotechnical treatments and helps to

minimise production risk. When plots are located at different heights, crops ripen at different rates, which allows for spreading the work over time. Ecological values include fitting smaller plots with diversified crops into the landscape and limiting soil erosion (Demetriou, 2014). These assumptions are somewhat at odds with the economic goals of agricultural policy. However, at the same time, the results of the analyses indicate problems arising from land consolidation, which may affect their productivity. According to Rybicki (2021), in Western Roztocze (Poland), the consolidation of plots located on a slope with high intensity led to the elimination of terraces and transverse slopes present on them, with soil erosion increased several times as a result.

Another problem is the high intra-regional diversification of soil quality in Poland (Krasowicz et al., 2011), and in Southern Poland, the diversification of the terrain of agricultural plots. The key to supporting small-scale farms may be using decision support systems. In particular, these so-called decision support applications and modular cloud-based farm management systems can be distinguished here. The history of using electronic systems and computer software to support agricultural decisions dates back to the 1980s. The development of digital technologies to the point that can be observed today has caused these systems to become highly advanced (Bellon-Maurel et al., 2022; Gonzalez-Andujar, 2020). Their operation is possible thanks to the dynamic technological progress—especially in digitisation. Decision support systems are designed to integrate information from various sources. The Internet of Things and the possibility of using artificial intelligence are helpful in this process. It is about accelerating the decision-making process, increasing the accuracy of decisions, and striving to be based on data collected in real-time (Fountas et al., 2020).

To achieve high efficiency in decision support systems, sensors that collect data in real-time are helpful. The main types of data obtained using sensors include time series, remote sensing data, and satellite images. The high number and heterogeneity of data collected in the field pose particular challenges. They are, firstly, related to recognizing deviations and detecting which results may be related to sensor error. Secondly, they are related to aggregating data at the stage of preparing them as support for decision-making and modelling (Bellon-Maurel et al., 2022). In the absence of the possibility of using sensors, it is possible to use satellite data provided by software developers or agricultural data banks created in the

cloud, as indicated by the specifications of many systems available on the market.

Decision support applications allow for receiving recommendations regarding the selection of crop type, use of plant protection products or fertilisation. They help increase farm resource management efficiency and improve the profitability of agricultural production. Some also enable access to financial services, building a history of financial transactions or credits (Kassambara, Mondal & Nguyen, 2019; Singh et al., 2023; Zhai et al., 2020). All this helps improve the quality and accuracy of decisions (González-Andújar, 2020). There are many types of decision support applications. These include irrigation management applications, pest and disease recognition applications, weather forecasting applications, crop simulations, agricultural marketing applications, and nutrient optimisation applications (Sridevy & Djanaguiraman, 2023; Ivanochkoa, Greguša & Melnykb, 2024). Many other possibilities for creating this type of solution include, among others, illustrating the relationships between meteorological conditions and plant pathogens (Wójtowicz et al., 2016), the use of plant protection products or applications dedicated to various aspects of animal production (CDR, 2019), applications focusing exclusively on one type of crops (Ara et al., 2021). A frequently noticed problem that hinders the popularisation of decision-support applications is their design according to a top-down idea with a simultaneous lack of interest in feedback on the effectiveness of their operation coming from farmers (Ara et al., 2021). This approach often results in a lack of intuitiveness in the operation of decision-support systems or their failure to adapt them to the real needs of farmers (Iakovidis et al., 2024).

Therefore, the challenges in improving the operation of applications include simplifying their use, increasing intuitiveness, and adapting functionality to external factors whose changes are dynamic—e.g., weather or characteristic only for certain regions, enabling historical data analysis and increasing the scope of forecasting. It is worth noting that research on this subject both increases farmers' awareness of the possibilities of using this type of technology and communicates the need to supplement them with additional options (Zhai et al., 2020). As a result, applications dedicated to specific problems are created. Here, we can distinguish, for example, the free programme Nawozy-5, which was created in Poland in 2018 to support mineral fertilisation, dedicated to small farms that are not equipped with devices enabling the use of precision agriculture and do not use any



commercial software supporting farm management (Cupiał & Kowalczyk, 2018). Observations leading to such solutions appear in various regions of the world. Jiao et al. (2019), referring to the mode of introducing technological innovations that promote productivity and sustainable development goals, propose a model in which advisors from an organisation operating in rural areas of China verify the actual technological needs of farmers from small farms, thanks to which it is possible to adapt the technology. This mainly concerns technologies that allow for better resource management and reduced fertilisation. Then, the solutions developed based on the grassroots initiative are presented to farmers, and in this way, the technology transfer takes place. According to Singh et al. (2023), using the local language is also essential—especially since mobile applications are sought to accelerate the transfer of scientific knowledge to agricultural practice. Applications that provide access to agricultural information and raise farmers' awareness are also prevalent. For example, the Polish application *Hektar Wiedzy*, highly rated by users, has been downloaded by over 10 thousand farmers since its creation. Meanwhile, digital technology offers even more advanced solutions enabling the optimisation of agricultural production. Cloud computing technology allows for information collection through information platforms and data banks (Choudhary, Jadoun & Mandoriya, 2016), provides new possibilities in remote sensing (Gokool, 2024), or creates space for interaction between experts and agricultural producers. Aspects of the production process can be observed and assessed in real-time (Lin et al., 2024).

Cloud-based farm management systems are systems composed of many modules covering various tasks performed by a farm. Usually, software suppliers offer the farmer a combination of modules best suited to his farm's potential. The cost of using a cloud-based farm management system depends on the combination of selected modules, sensors that collect data in real-time, and specific databases. Several free applications and systems constitute a simplified test system supporting farm management (e.g. xFarm or 365FarmNet, within which additional options can be purchased). Their availability can facilitate farmers' familiarisation with the technology. Small drones (UAVs) can be considered as a complement to these possibilities. They are gaining popularity in the agricultural sector and have great potential for applications in small farms, which is noticed globally (Lin et al., 2024; Dhillon et al., 2023).

A more far-reaching formula for ensuring knowledge transfer in agriculture is creating a network of intelligent, connected farms. This involves the possibility of sharing data between farms to improve the functioning of all participants in the network. The operation formula somewhat resembles a virtual organisation's objectives, in which the cooperators join together to optimise the use of resources. In the case of farms, the benefits of participating in a virtual network include, for example, early and effective pest control, reducing losses and supplementing specialist knowledge. Such solutions seem particularly useful for farmers with limited resources and experience. Another type of solution ensuring interactions between farms is applications that allow them to be compared (e.g. Lely Benchmark). As with other systems based on cloud data processing, the challenge is to protect data and provide participants with a sense of security. Cost may also be a barrier, which may be the subject of consideration in the justification for subsidising such solutions or determining the price proportional to the benefits (Herd, 2014; Singh et al., 2024). Other challenges include the need for constant access to a good quality internet connection, the need to supplement farmers' digital skills, lack of trust in technology (including fear of sensor measurement errors), hardware shortages, infrastructure problems, additional work time related to system implementation and data entry, lack of adaptation to the actual needs of farmers, lack of advisory support, errors in the use of technology, and reluctance to abandon traditional agricultural production practices (Choudhary et al., 2016; Dhillon et al., 2023; Gebresenbet et al., 2023; Dibbern, Santos Romani & Silveira Massruh, 2024; Herhem et al., 2017; Eastwood et al., 2023). The lack of farmers' experience using digital technologies is also a significant factor, particularly in areas with less developed agriculture, where such technologies remain relatively unpopular and unfamiliar. Additionally, the failure to consider farmers' actual needs when designing the functionalities of digital systems, in conjunction with an inflexibility of adapting to changing soil and climatic conditions, further contribute to the issue (Zhai et al., 2020).

### 3. Materials and methods

Two Polish voivodeships were designated as the study area—the Małopolskie and Podkarpackie voivodeships. The area of the Małopolskie and Podkarpackie

**Table 1.** The area structure of the surveyed farms in comparison to Poland

| Area                        | Number of farms<br>[GUS, 2020] | Farm structure by size [%] |          |           |            |                |
|-----------------------------|--------------------------------|----------------------------|----------|-----------|------------|----------------|
|                             |                                | up to 1 ha inclusive       | 1 - 5 ha | 5 - 10 ha | 10 - 15 ha | 15 ha and more |
| Poland                      | 1 316 759                      | 1.87                       | 50.15    | 21.95     | 9.91       | 16.12          |
| Małopolskie<br>voivodeship  | 126 172                        | 2.54                       | 78.37    | 13.24     | 2.79       | 3.06           |
| Podkarpackie<br>voivodeship | 114 182                        | 2.30                       | 76.86    | 13.75     | 2.96       | 4.14           |
| Farms surveyed              | 389                            | x                          | 62.98    | 20.05     | 7.20       | 9.77           |

Source: own study

voivodeships is uniform in terms of natural and historical conditions, which, among other things, result in their high level of agrarian fragmentation (Jałowiecki, 1996). In both voivodeships, the average size of a farm, according to GUS (2020), was similar and amounted to 5.97 in the Podkarpackie voivodeship and 5.26 in the Małopolskie voivodeship, respectively (with the national average of 12.65 ha). There are 240,392 farms in the study area (GUS 2020).

The study was conducted using a questionnaire method with stratified random sampling. The number of questionnaires collected from the voivodeships was proportional to the number of farms operating in each area: 53% of the questionnaires were from the Małopolskie voivodeship, while 47% came from the Podkarpackie voivodeship. A stratified random sampling method was employed for this process. First, six counties were randomly selected from each of the provinces, resulting in a total of 12 counties chosen out of the 40 located within the surveyed provinces (cities with county rights were excluded from the study). Following this selection, surveys were conducted among the owners of the randomly selected farms. The study covered 389 farms. It was conducted using the PAPI method in direct conversation with the surveyed farms' owners. The study was entirely anonymous. The average area of the surveyed farms was 8.4 ha. The area of individual farms ranged from 1 ha to 390 ha. The structure of the surveyed farms was dominated by those whose area did not exceed 5 ha—they constituted 62.98% of all surveyed farms. The structure of the surveyed farms according to the size classes included in the Central Statistical Office reports (GUS, 2020), is presented in Table 1.

The analysis considered dividing the surveyed farms into two groups based on their area. The basis for the division was the median value (4 ha). In this way, the following farm groups were created:

- Up to 4 ha inclusive: farms with an average area of 2.64 ha (199 farms surveyed).
- Over 4 ha: farms with an average area of 14.38 ha (190 farms surveyed).

In the surveyed farms, crop production was the primary activity, accounting for 79% of the total surveyed farms, and even higher at 90% for farms up to 4 hectares in size. Among the 389 farms surveyed, 11% produced exclusively for their own use, while 42% had owners who worked both on the farm and in other professional roles. This dual employment was notably more common among the smaller farms. Characteristics for this group of farms were also the education profiles of the farmers managing the farms—more often than in larger farms, they declared education in profiles other than agriculture. Characteristics of respondents and surveyed farms in the group in general and depending on farm size are presented in Table 2.

The analysis also referred to the age of the respondents (separating the group before and after the age of fifty—51% and 49% of respondents, respectively) and the direction of their education—divided into respondents with agricultural and non-agricultural education—33% and 67% of respondents, respectively. Conclusions resulted from analysing data referring to aspects related to the barriers to implementing decision support systems perceived by respondents and assessing the usefulness of the functions offered by cloud-based farm management systems. The conclusions presented were confirmed by the chi-square test of independence (Table 5). The results presented in the article come from a study conducted as part of the MINIATURA7, scientific activity financed by the National Science Centre in Poland.

**Table 2.** Characteristics of respondents and surveyed farms in the group in general and depending on farm size [% of responses]

| Specification                 |                                    | Farm size |        |       |
|-------------------------------|------------------------------------|-----------|--------|-------|
|                               |                                    | Total     | ≤ 4ha  | >4ha  |
| Age                           | up to 35                           | 10.80     | 11.56  | 10.00 |
|                               | 35-50                              | 39.59     | 32.16  | 47.37 |
|                               | >50                                | 49.61     | 56.28  | 42.63 |
| Respondents' education        | Elementary                         | 6.43      | 9.55   | 3.16  |
|                               | Vocational agricultural            | 16.71     | 9.05   | 24.74 |
|                               | Vocational other than agricultural | 26.99     | 36.68  | 16.84 |
|                               | Secondary agricultural             | 14.14     | 3.02   | 25.79 |
|                               | Secondary other than agricultural  | 23.65     | 28.64  | 18.42 |
|                               | Higher agricultural                | 1.80      | 0.00   | 3.68  |
|                               | Higher other than agricultural     | 10.28     | 13.07  | 7.37  |
| Employment                    | On the farm exclusively            | 58.61     | 45.73  | 72.11 |
|                               | On and off the farm                | 41.39     | 54.27  | 27.89 |
| Organisational form           | Individual farm                    | 99.74     | 100.00 | 99.47 |
|                               | Agricultural enterprise            | 0.26      | 0.00   | 0.53  |
| Type of farm                  | Conventional Farm                  | 96.14     | 97.49  | 94.74 |
|                               | Organic farm                       | 2.83      | 2.51   | 3.16  |
|                               | Farm with integrated production    | 1.03      | 0.00   | 2.10  |
| Dominant production direction | Crop production                    | 79.18     | 90.95  | 67.08 |
|                               | Animal production                  | 20.57     | 9.05   | 32.92 |

Source: own study

## 4. Results

In the studied area of the Małopolskie and Podkarpackie voivodeships, the implementation of digital technologies in agriculture has been minimal. In total, any digital technology was used in 34% of the surveyed farms, and solutions in the field of precision farming, the use of drones, or plant production automation systems were prevalent—such solutions were indicated by less than 1.5% of the respondents. The most commonly used digital technologies included applications enabling the recognition of plant diseases (used by 26% of the surveyed farms) and decision support applications (used in 19% of the surveyed farms). In third place were animal production automation systems, present in 9% of the surveyed farms, and fourth place was a technology of similar popularity, present in 8% of the surveyed farms—cloud-based farm management systems. In total, the

systems mentioned above, which can be classified as decision support systems—applications enabling the recognition of plant diseases, decision support applications and cloud-based farm management systems—were used by 33% of farms (and 16% used at least two of the solutions listed).

The most frequently indicated barriers to using decision support system solutions (including decision support applications and cloud-based farm management software) included the financial barrier—reported by 55% of respondents (Table 3). According to 43% of respondents, decision-support applications and cloud-based farm management systems are not needed in their agricultural activities, and 13% were unfamiliar with this tool before the survey. A high percentage of respondents (38%) indicated that the problem with their implementation was hardware shortages, and for 22%, the barrier was the need to improve IT skills. The hardware shortages

noticed in farms were accompanied by technical problems related to the quality of local infrastructure and the lack of high-speed Internet access (indicated by 16% of respondents). As for barriers on the farm side, 7% of farms were also afraid of sharing data on their agricultural activities with applications, and 6% of respondents declared a lack of time to operate these systems. The perceived barriers differed slightly depending on the characteristics of the farm—specifically its area and the age and education of the farmer managing the farm. The lack of need to implement the discussed solutions was indicated more often by farmers from farms with a smaller area—up to 4 ha (67% of responses), farmers who were over 50 years old (60% of responses), farmers with education other than agricultural (56% of responses).

For comparison, among respondents with agricultural education, the lack of need to use the discussed systems was indicated by 16% of respondents. The situation was similar to the lack of trust—this was a barrier significantly more often indicated by respondents over 50 years old and respondents with non-agricultural education. The lack of trust in decision-support systems in the surveyed group was declared by as many as 19% of respondents. It is also worth noting that the lack of trust in decision support systems was expressed by as many as 65% of respondents among those who declared no need to use them on their farm.

The study also revealed barriers to the functioning of decision-support applications and cloud-based farm management systems. Problems related to their lack of intuitiveness and complex operation were reported, which turned out to be essential for 16% of respondents, as well as problems related to the lack of systems that fully meet the needs of the respondents' farms (13% of responses). These two problems were particularly evident in the group of owners of farms with an area of over 4 ha (28% of responses), respondents under 50 years of age and respondents with an agricultural education. This is probably the result of greater interest in the above technologies in these groups and better knowledge of how they function.

In verifying the usefulness of individual functions available within agricultural decision support systems, the focus was on cloud farm management systems due to their high complexity and wide range of offered functions. Farmers were asked to indicate which functionalities of cloud farm management systems listed in Table 4 they are inclined to consider necessary in their farms. In the study group, the most

frequently indicated usefulness was the possibility of receiving information on the occurrence of the risk of infection/plant disease (78%), access to an accurate weather forecast for individual agricultural plots (62%), the possibility of estimating the consumption of raw materials (e.g. consumption of seed material, plant protection products, fodder (62%). The number of indications between 59% and 48% was recorded by functionalities such as predicting the amount of crop (depending on the resources used, detailed weather forecasts), collecting and storing data sent by sensors on soil moisture, air temperature, nutrient content in crops, remote exchange of information with other farmers, records of sales, stocks, payments, profits. Slightly less popular were the possibilities of examining the impact of the conducted activity on the natural environment (37%), the possibility of collecting and processing information from systems tracking the behaviour, condition and motor activity of animals (32%), remote assignment of tasks to employees in the field (20%), remote receipt of information from employed employees (19%). In the perception of the usefulness of elements of cloud farm management systems, the size of the farm and the education profile were important. In farms with an area of over 4 ha, it was rated much higher. Particularly noteworthy is the recognition of the significance of the function allowing for the study of the impact of the conducted activity on the natural environment in this group—55% of respondents considered it worthwhile. The fact that among farmers declaring that they had an agricultural education, this percentage was even higher—62%, may indicate a greater awareness of the importance of this aspect for the sustainable development of the farm. Functionalities related to the possibility of remote communication between the person managing the farm and employees (the last two items in Table 4) were also valued more by farmers from farms with an area of over 4 ha and with an agricultural education, which may result from the need to coordinate a larger group of seasonal or permanent employees. The possibility of remote exchange of information with other farmers was valued by 68% of respondents with an agricultural education. Cloud-based farm management systems enable sharing of information and knowledge, among other things, by granting access to data and documents or the ability to create networks.

The group of respondents who declared that they used at least one decision-support system on their farm at the time of the survey rated the functionalities characteristic of cloud-based farm management systems highly. The percentage of indications



**Table 3.** Barriers to the use of decision support applications and cloud-based farm management systems in the study group in general and depending on selected farm and respondents' characteristics [% of responses]

| Specification                                                                                             | Total        | Farms with an area of up to 4 ha | Farms with an area of over 4 ha | Respondents up to 50 years of age | Respondents over 50 years of age | Respondents with agricultural education | Respondents with education other than agricultural |
|-----------------------------------------------------------------------------------------------------------|--------------|----------------------------------|---------------------------------|-----------------------------------|----------------------------------|-----------------------------------------|----------------------------------------------------|
| Financial barrier                                                                                         | <b>55.01</b> | 37.19                            | 73.68                           | 66.84                             | 43.01                            | 78.57                                   | 43.51                                              |
| The belief that there is no need to implement such solutions                                              | <b>43.19</b> | 67.34                            | 17.89                           | 26.02                             | 60.62                            | 15.87                                   | 56.49                                              |
| Hardware shortages                                                                                        | <b>38.05</b> | 26.63                            | 50.00                           | 47.45                             | 28.50                            | 55.56                                   | 29.39                                              |
| The need to improve IT skills                                                                             | <b>22.11</b> | 9.05                             | 35.79                           | 26.02                             | 18.13                            | 31.75                                   | 17.56                                              |
| Lack of trust in such systems and their creators                                                          | <b>19.02</b> | 20.60                            | 17.37                           | 9.69                              | 28.50                            | 11.11                                   | 22.90                                              |
| Technical problems (the quality of local infrastructure makes it difficult to access high-speed Internet) | <b>16.20</b> | 11.56                            | 21.05                           | 23.47                             | 8.81                             | 27.78                                   | 10.69                                              |
| These systems are not intuitive/ difficult to use                                                         | <b>16.20</b> | 5.03                             | 27.89                           | 21.43                             | 10.88                            | 26.19                                   | 11.45                                              |
| Lack of systems that fully meet the needs of farm (too few options available)                             | <b>13.11</b> | 7.54                             | 18.95                           | 20.41                             | 5.70                             | 18.25                                   | 10.69                                              |
| Lack of knowledge of such solutions until taking part in the study                                        | <b>12.85</b> | 19.10                            | 6.32                            | 5.10                              | 20.73                            | 9.52                                    | 14.50                                              |
| Lack of access to training in the use of this type of solutions                                           | <b>8.23</b>  | 1.51                             | 15.26                           | 12.24                             | 4.15                             | 15.87                                   | 4.58                                               |
| Concern about sharing agricultural activity data with applications                                        | <b>7.46</b>  | 4.02                             | 11.05                           | 8.16                              | 6.74                             | 8.73                                    | 6.87                                               |
| Lack of time to learn how these systems work                                                              | <b>5.66</b>  | 3.52                             | 7.89                            | 7.14                              | 4.15                             | 7.94                                    | 4.58                                               |
| I do not see any barriers to using these solutions                                                        | <b>1.29</b>  | 1.01                             | 1.58                            | 2.04                              | 0.52                             | 0.79                                    | 1.53                                               |

Source: own study

confirming the usefulness of individual solutions ranged from 51% in the case of remote receipt of information from employees and the possibility of remote assignment of tasks to employees to 100% in the case of the possibility of receiving information on the risk of plant infection/disease. The number of indications exceeding 90% was obtained by functions such as access to accurate weather forecasts for individual agricultural plots, the ability to estimate the consumption of raw materials, predict the number of crops, record sales, stocks, payments, profits and the collection and storage of data sent by sensors on soil moisture, air temperature, nutrient content in

crops. Around 80% of indications obtained the ability to share information with other farmers, and 77% the ability to study the impact of the conducted activity on the state of the natural environment. The ability to collect and process information from systems tracking animals' behaviour, condition and motor activity was necessary for 67% of respondents from this group. Among the respondents from this group, 32% declared the dominance of animal production in their agricultural activity. Users of at least one of the decision-support systems ran farms with an area of 1.1 ha to 390 ha. These respondents indicated the financial barrier as the most significant barrier to

**Table 4.** Assessment of the usefulness of functions available within cloud-based farm management systems in the surveyed farms in general and depending on selected farm and respondents' characteristics [% of responses]

| Specification                                                                                                            | Total        | Farms with an area of up to 4 ha | Farms with an area of over 4 ha | Respondents with agricultural education | Respondents with education other than agricultural | Users of at least one decision support system in total (n=127) | Not using decision support systems (n=262) |
|--------------------------------------------------------------------------------------------------------------------------|--------------|----------------------------------|---------------------------------|-----------------------------------------|----------------------------------------------------|----------------------------------------------------------------|--------------------------------------------|
| Possibility to receive information about the risk of plant infection/disease                                             | <b>77.63</b> | 65.83                            | 90.00                           | 91.27                                   | 70.99                                              | 100.00                                                         | 66.79                                      |
| Access to an accurate weather forecast for individual agricultural plots                                                 | <b>61.95</b> | 48.24                            | 76.32                           | 80.95                                   | 52.67                                              | 92.91                                                          | 46.95                                      |
| Possibility to estimate the consumption of raw materials (e.g. consumption of seed, plant protection products, fodder)   | <b>61.70</b> | 42.71                            | 81.58                           | 86.51                                   | 49.62                                              | 96.85                                                          | 44.66                                      |
| Yield prediction (depending on the resources used, detailed weather forecasts)                                           | <b>58.61</b> | 39.20                            | 78.95                           | 80.95                                   | 47.71                                              | 95.28                                                          | 40.84                                      |
| Collecting and storing data sent by sensors about soil moisture, air temperature, and nutrient content in crops          | <b>55.27</b> | 35.18                            | 76.32                           | 80.16                                   | 43.13                                              | 95.28                                                          | 35.88                                      |
| Remote information exchange with other farmers                                                                           | <b>48.33</b> | 31.66                            | 65.79                           | 68.25                                   | 38.55                                              | 81.10                                                          | 32.44                                      |
| Records of sales, inventories, payments, profits                                                                         | <b>47.56</b> | 24.62                            | 71.58                           | 72.22                                   | 35.50                                              | 91.34                                                          | 26.34                                      |
| Research on the impact of farm activities on the natural environment                                                     | <b>37.28</b> | 20.10                            | 55.26                           | 61.90                                   | 25.19                                              | 77.17                                                          | 17.94                                      |
| Possibility to collect and process information from systems tracking animals' behaviour, condition and physical activity | <b>32.13</b> | 13.57                            | 51.58                           | 58.73                                   | 19.08                                              | 66.93                                                          | 15.27                                      |
| Remotely assigning tasks to employees                                                                                    | <b>19.54</b> | 5.53                             | 34.21                           | 38.89                                   | 9.92                                               | 51.97                                                          | 3.82                                       |
| Remotely receiving information from employees (about the progress of work, problems)                                     | <b>19.28</b> | 5.53                             | 33.68                           | 38.10                                   | 9.92                                               | 50.39                                                          | 4.20                                       |

Source: own study

implementing decision-support technologies (87% of indications). This may be related to the need to incur expenses at subsequent stages of implementation related to the desire to use additional paid modules or the need to supplement technological equipment, e.g., additional sensors collecting data in real-time. About 9% of respondents from this group expressed fear of sharing data. Barriers such as the lack of intuitiveness

and difficulty of using systems and the lack of systems that fully meet the needs of the business were indicated more often than in the group as a whole—24% of indications compared to 16% and 13% respectively in the group studied in general. This indicates a broad scope for action in improving this type of system.

Respondents using both cloud-based farm management systems, decision-support applications,

**Table 5.** Chi square test of independence results

| Criterion                                                                     | $\chi^2$ |
|-------------------------------------------------------------------------------|----------|
| <b>Assessing the usability of cloud-based farm management system features</b> |          |
| Farm size (up to 4 ha; over 4 ha)                                             | 28,91*   |
| Education type (agricultural; non-agricultural)                               | 21,39*   |
| Use of decision support systems (Yes; No)                                     | 48,80*   |
| <b>Assessment of Barriers to Implementation of Decision Support Systems</b>   |          |
| Age (up to 50; under 50)                                                      | 97,55*   |
| Farm size (up to 4 ha; over 4 ha)                                             | 65,92*   |
| Education type (agricultural; non-agricultural)                               | 64,36*   |

Source: own study. \* Statistically significant  $\alpha = 0.05$

and applications recognizing plant diseases showed interest in many sources of agricultural information, combining information obtained from social media and official sources. Many respondents from this group (89%) reached for social media materials published by other farmers (60% of the total group), 58% used the trade press (34% of the total group), 40% used scientific publications (14% of the total group), 58% used manuals and guides (41% of the total group studied), 86% used internet forums (55% of the total group studied). This group was also distinguished by a high percentage of farmers using courses and training to gain knowledge (38% compared to 18% of the total group studied). The percentage of farmers who treated direct conversation with other farmers as a source of information was similar in both groups—55% in the total group and 51% in the group using decision support systems. Digital means of facilitating the exchange of information and knowledge are becoming very popular and gaining importance. This relationship requires further analysis and consideration of how decision support systems can be supplemented with functions related to communication and knowledge exchange.

The chi-square test of independence confirmed conclusions that resulted from analysing data pertaining to aspects related to respondents' perceptions of barriers to implementing decision support systems and to the assessment of the usefulness of the functions offered by cloud-based farm management systems (Table 5).

## 5. Discussion

Data-based systems—such as decision support systems—enable farmers to participate in decision-making. It promotes their activity and strengthens their sense of agency (Yadav et al., 2024). In the study area, decision support systems were among the most frequently used digital technologies (their use was reported by 34% of respondents), primarily due to the significant division of agricultural plots and the small average size of agricultural holdings, which limits their investment potential. Numerous studies indicate that a key factor influencing farmers' decisions about the extent of digital technology adoption is their expectations regarding the outcomes and the perceived usefulness of these solutions. This includes how well these technologies are adapted to the specific needs and local conditions of agricultural practices (Wang & Dong, 2023; Caffaro et al., 2020; Dittmer et al., 2022). In the study area, respondents showed exceptionally high interest in such functionalities of decision support systems as the ability to receive information on the occurrence of plant disease risk. These are considered essential DSS solutions. However, it should be emphasised that the scale of their popularity in the study area remains limited. Trendov (2019) points out that education level and income influence the way digital solutions are utilised. Optimizing resource use with the help of DSS is typically the primary goal of their adoption in developing countries (Kamai & Bablu, 2023; Elbehri & Chestnov, 2021). This may be particularly relevant for interpreting research results from the studied area, where the implementation of digital technologies remains a relatively new phenomenon. According to Cupiał & Kowalczyk (2018), an important factor triggering interest in decision support systems is the belief that the benefits associated with implementing a digital programme will not exceed its purchase costs. Especially since farmers with small farms usually do not need applications of very high complexity. The scale of work involvement when implementing a new solution is also important (Dhehibi et al., 2020). Similar conclusions can be drawn from the study conducted in the Małopolskie and Podkarpackie provinces, where the barriers to implementing decision support systems were mainly financial, related to the lack of conviction about the justification for implementing these systems in the farms managed by the respondents and resulting from equipment shortages. Additionally, simple decision support systems were often used, such as applications that enabled the recognition of plant diseases.

Insufficient financial resources are frequently highlighted in studies addressing the barriers to implementing digital technologies, a challenge that extends even to highly developed countries (Geppert et al., 2024). This situation may stem from a general lack of resources hindering the adoption of digital technologies and farmers' heightened awareness of their associated costs. In the study area, respondents with a greater propensity to use decision-support systems—i.e., those managing farms over 4 ha, as well as respondents under 50 years of age—more often indicated the existence of a financial barrier. It is worth noting that simple DSS systems, which are particularly popular, do not require significant financial outlays, while more advanced modules of cloud-based farm management systems or solutions requiring sensors to collect data are associated with a higher level of investment. The importance of phone applications is appreciated primarily in developing countries, where the financial potential of farms is far lower than in the situation of farms operating in Western countries. Hence, it may also be possible to overcome the financial barrier, for example, by creating solutions dedicated to specific activities that do not require the use of advanced technological equipment or by providing cheaper access to them—for example, thanks to institutional support (Stępień et al., 2023; Cordel, 2021). Respondents declared a relatively high interest in the impact of farm activities on the state of the natural environment (37% of respondents). Due to the simultaneous interest in optimizing resource consumption or tracking weather changes, it can be assumed that there is potential in the studied area to use DSS systems (especially cloud-based farm management systems) in building resilience to climate change or to adapt to the increased unpredictability of weather phenomena.

According to Piwowar (2018), all ICT systems help direct agriculture towards low carbon footprint activities. In a study conducted in Germany, Geppert et al. (2024) identified the most important goals related to the use of digital technologies as field monitoring, improving operational management, implementing solutions supporting environmental protection, and supporting knowledge and data transfer. Research conducted in Chinese farms by Chi et al. (2022) showed that ICT technologies can indirectly reduce the intensity of chemical fertiliser use—promoting both resource optimisation and reducing the impact on the natural environment. This happens by influencing farmers' awareness and faster dissemination of knowledge. ICT technologies have

been identified as those that reduce the increased use of fertilisers in highly fragmented areas (in China, an increase in fertilisation has been observed in areas with highly fragmented land, resulting from challenges in implementing precision farming technologies). The tendency to use Decision Support Applications in the studied, agrarian-fragmented Polish voivodeships (Małopolskie and Podkarpackie) may be conducive to achieving similar effects. The scale of popularity of these solutions is still too low, but the high interest in the functionalities of cloud-based farm management systems may support their further popularisation.

On a global scale, problems related to the implementation of digital technologies include infrastructure and hardware deficiencies and limited access to high-speed internet (Cordel, 2021; Geppert et al., 2024), which in the studied area was revealed as a problem with the implementation of decision-supporting systems in the case of 16% of farms. Few respondents expressed concerns about sharing data with these systems. However, some were accompanied by a general lack of trust in decision-support systems (19%)—particularly characteristic of farmers over 50 (29%).

The lower propensity to use digital technologies in older age groups has been revealed in many studies. In addition to lower levels of trust in technology, older farmers often declare insufficient digital skills, which may be discouraging (Irish Farm Centre, 2019; Dibbern et al., 2024; Subejo et al., 2019). This area requires further research, especially since the spectrum of effects related to lack of trust may be broad. Linsner et al. (2021) expand the context of concerns about data sharing by pointing to farmers' resistance to the additional effort required to collect data. Linsner's study in Germany also identified concerns regarding heightened competition from agricultural companies, uncertainty about the data processing, and apprehensions that companies providing such solutions may exploit the shared data for profit. Such barriers will be robust in situations of low trust in digital technologies. In the study conducted in the Małopolskie and Podkarpackie voivodeships, one in five respondents stated that the lack of trust was the reason for not using decision support systems. On the other hand, respondents often declared their interest in exchanging information via decision support systems with other farmers (48%). Despite concerns resulting from limited trust, farmers are increasingly willing to seek information digitally (Kramarz & Runowski, 2025; Colussi et al., 2022). The role of decision support systems and applications is primarily to



facilitate access to information, enable more informed decisions, optimise resource management, and, as a result, strengthen the market position (Kamai & Bablu, 2023; Shilomboleni et al., 2020; CTA, 2018, Dhehibi et al., 2020). According to many authors, knowledge sharing promotes the implementation of technology in agricultural practice (Wayessa, 2017; Gebresenbet et al., 2023; Dibbern et al., 2024). This trend is also noticeable in the studied area, where a greater interest in information from formal and informal sources was revealed among respondents using decision support systems than in the general group. It is worth noting that in areas dominated by small-scale farms, learning through direct observation is challenging. Hence, DSS systems may prove invaluable in implementing this function in such areas. They can also help build trust. As Fisher (2013) points out, the regularity of contact is one of the key determinants of trust, and farmers are more likely to use acquired knowledge when they believe it comes from a trusted source.

Dhehibi et al. (2020), in a study on the effectiveness of agricultural technology diffusion measures in Tunisia, found that the most effective advisory methods are demonstrations and farmer-farmer interactions. Therefore, the range of functions related to establishing contacts has the potential to accelerate knowledge transfer in agriculture. Such functions of decision support systems should be promoted first, starting with those with no concerns related to data transfer. It will facilitate the gradual overcoming of resistance and help familiarise farmers with how these technologies function.

## 6. Conclusion

The use of digital technologies creates new development opportunities for farms. In addition to improving the efficiency of agricultural production processes, it helps increase the flexibility of operations, improve work comfort and reduce the scale of the impact of agricultural activities on the natural environment. An essential aspect of the digitalisation of agriculture is the possibility of providing easier access to data and information and advanced systems for their processing. Raising farmers' awareness and knowledge gives them a chance to improve the accuracy of decisions made in farm management. A feature of agricultural digital technologies is their diversity—from advanced production robotisation systems to the possibility of using decision support

systems available using smartphones or laptops. The latter has enormous potential to build a trend of farm management based on knowledge and information. The opportunity that can be associated with using decision support systems is the possibility of their implementation in small-scale farms.

A study conducted in two Polish voivodships, characterised by the smallest average farm size in the country, showed that farms in this region tend to reach for decision-support systems. In total, the use of systems such as decision-support applications, cloud-based farm management systems or applications enabling the recognition of plant diseases was declared in 34% of the surveyed farms. Although the most popular technology, which was the most easily accessible—applications enabling the recognition of plant diseases—was the most commonly used, the very fact of interest in these applications suggests that small farms operating in agrarian fragmentation conditions may be a target for initiatives promoting specific digital solutions. In terms of assessing the need for using decision support systems in the studied area, the most important were those that could lead to the optimisation of resource consumption (the usefulness of the resource consumption estimation function was indicated by 62% of respondents), faster and more accurate responses to plant disease risks, as well as a more rational use of plant protection products (76% of respondents indicated the usefulness of the possibility of receiving information on the risk of plant infection), and to increasing the farm's resistance to the increasing variability of weather phenomena (62% of respondents indicated the usefulness of access to an accurate weather forecast for individual agricultural plots). The functionalities of agricultural decision support systems were more often assessed as applicable in larger farms, where, for example, the percentage indicating the usefulness of receiving information on the risk of plant disease reached 90%. It should be noted, however, that the average size of the farms studied was slightly over 8 hectares. These results suggest that there is potential for using at least some of the functions of decision support systems in fragmented agriculture. Each of the types of systems mentioned includes functions that allow communication with other users, which gives them the role of a tool supporting the exchange of agricultural knowledge. The possibility of remote exchange of information with other farmers was appreciated particularly by farm owners with an agricultural profile, related education and respondents who have experience using at least one type of decision

support technology. In the study group, nearly 50% of farm owners recognised the importance of such a function. The most significant barrier to using decision support systems was financial constraints. Problems related to technology features were also revealed, and about 16% of respondents assessed them as not fully adapted to the operating conditions of their farms. Another significant barrier was the lack of IT skills and limited trust, which was revealed mainly in respondents who did not feel the need to reach for decision support systems and respondents over 50. Many authors advocate launching programmes that support decision-support technologies through co-financing. Because of the opportunities their use may bring—optimizing farm management or achieving environmental goals—such a solution seems justified. However, the possibility of intensifying the knowledge exchange process seems particularly important. This aspect requires further research.

The research focused on a specific area with unique characteristics that should be taken into account when interpreting the results and acknowledging their limitations. Owners of small farms from the research area often declared work on the farm and outside it. The inability to focus exclusively on work on the farm may hinder progress in these areas. On the other hand, the use of DSS systems can be helpful not only in terms of increasing production efficiency but also in significantly promoting the growth of farmers' awareness. This includes important topics such as health and safety regulations, agricultural insurance, and the necessity of monitoring environmental impacts, all of which facilitate informed decisions regarding the farm's future. The role of larger farms operating in such areas also seems significant. They can be a reference point for small farms in recognizing technologies and a source of agricultural services. Additionally, they can take the lead in implementing decision support systems in this area (in the studied area, the problem of fragmentation of agricultural plots also affects farms with relatively large areas).

Further research should refer more broadly to the aspects of adapting decision support systems depending on regional conditions and assessing the degree of their impact on the functioning of the farm. The presented results can be verified and supplemented by extending the study to the entire country or selected regions of Europe and referring to small farms operating in conditions characteristic of other regions. The ability to compare research results from different areas will facilitate the development of strategies for overcoming barriers to decision

support systems implementation. However, there is a need to improve the digital skills of farmers and take steps to adapt decision-support systems to regional characteristics.

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