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Small Farms as "Data Producers" for the Needs of Agricultural Management Information System

Abstract: In the face of current global threats, including the COVID-19 Pandemic, new technological solutions are needed. Globalization, progressing urbanization, the decreasing availability of cultivable land for food production, water contamination, flood risk and climate change, can all be viewed as potential threats to food safety. According to forecasts and trends, the future of both agricultural policy and agricultural innovation will be based on big data, data analytics and machine learning. Therefore, it is and will continue to be important to develop information systems dedicated to agricultural innovation and the management of food security challenges. The main aim of the study is a classification of data for a uniform AMIS from data from IREIS, GC and AIIS based on survey and expert interview data obtained. We propose to expand the range of data produced by small farmers while keeping in mind the protection of farmers and their rights and the possible benefits of the data provided. The literature recognizes the value of such data but it has not yet been legally regulated, protected, managed and, above all, properly used for agricultural and food security policy purposes. Therefore, we develop the idea of extended farmers' participation in the production of agricultural activity data. The research used a survey questionnaire and expert interviews. A viable AIIS needs current data that farmers already produce as well as additional data needs which we identify in our research. We propose an architecture of databases and describe their flow in the Agriculture Management Information System (AMIS).

Keywords: Agriculture Management Information System, agriculture, information technology, big data, precision agriculture

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1. Introduction

A new challenge for the world in 2022 was in fight the COVID-19 pandemic. It spread quickly across all continents [1] and the scale of the disease caused people to start buying food products in bulk to secure a supply [2]. This raises the question of how to ensure food security in a world which governments have failed to anticipate.

The world of the 21st century is also one with a growing urban population [3–5]. An urban lifestyle is typically associated with greater consumption of processed, prepared and convenience foods. People are more time constrained, less centered on the family household and hence much more oriented toward convenience. Many popular packaged foods contain too much fat, sugar, and salt. In the coming decades, this will likely contribute to a high prevalence of chronic diseases such as obesity, heart disease, stroke, cancer, and diabetes [6]. On the basis of [7], in high-income countries, growing awareness of health and sustainability issues is increasingly shaping consumer decisions.

Much better co-ordination of policy responses for food safety and security is needed. Food security policy requires reliable information on the likely trends of global demand, supply, trade and prices and the factors driving them [8]. An Agricultural Information and Innovation System (AIIS) can help meet the expectations society places on public and private decision makers regarding agriculture.

AIIS may also be an effective tool for creating a medium-term baseline scenario [9]. Scenarios can help decision making with regard to agricultural commodity markets at national, regional and global levels and can help policy makers better anticipate and manage risks of such events as plant and animal diseases and extreme climatic events. Studies show that agriculture is primarily responsible for climate and environmental change [10]. Climate change [11] induces biological, physical and chemical processes [12] that increase the levels of atmospheric CO_2 [13] and speed up soil erosion. Ensuring the safety of agricultural production in the context presented above is extremely important [14]. Thus, promotion of a sustainable development policy that would ensure food security with the least possible exploitation of natural resources has become a necessity [14]. Such a policy was promoted by international norms of the Millennium Development Goals [15] and Sustainable Development Goals [16, 17]. EU Member States have also advocated their Common Agricultural Policy [18], which identifies sustainable rural development which can be achieved by focusing on a number of key priorities relating to the transfer of knowledge and innovation in agriculture at the EU level. The introduction of innovations in agriculture to guarantee food security on a global scale is mentioned as a major driver of further technological development [19, 20]. It has also been observed that recent decades have seen increased digitization and technological improvements in agriculture, resulting in the production of a huge amount of data at the lowest level – namely farms. Farms have entered a new stage of data production. What is new is the quality of real-time information obtained at farm level and the technology used to collect this data, to store, use, manage, share, process and communicate it. FAO focuses on a system-wide approach to agricultural innovation (Fig. 1).

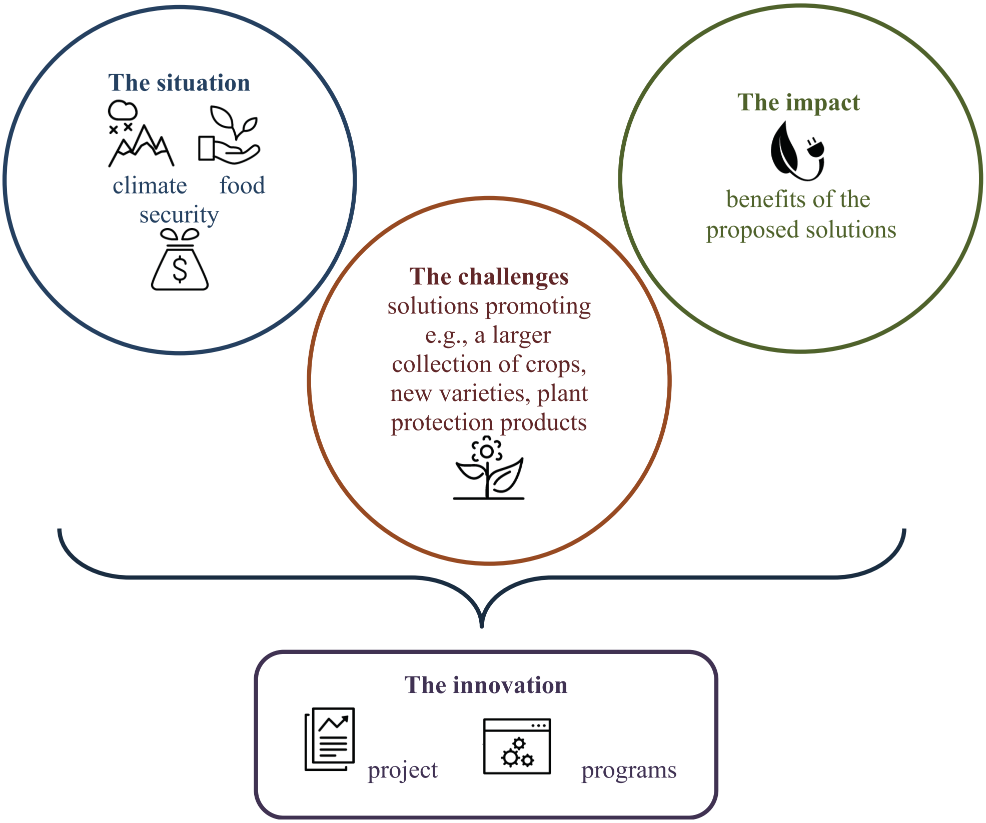


Fig. 1. Agricultural innovation (determinants)
Source: own study based on [17]

Agricultural innovation typically arises through dynamic interaction among the multitude of actors involved in growing, processing, packaging, distributing, and consuming or otherwise using agricultural products [21].

Agricultural Information and Innovation Systems (AIIS) should be composed of the following main components: research and education, business and enterprises, bridging institutions, and the enabling environment [22]. Furthermore, these large and complex series of data demand novel and better ways of exchanging data. The smarter the ways in which we exchange data, the less disruptive this will be to current business models and organizations. By layering sets of data from a wide range of sources, complex decisions can be made at different levels, such as the farm, cooperative, input suppliers, public administration authorities, banks, the scientific community, etc. [23]. An AIIS based on the scope thus indicated can achieve its objectives if all actors, and above all farmers, are involved in the process. This link is crucial for the whole system and the transfer is essential to promote bottom-up, cost-effective technological solutions that can be successfully applied – especially in the case of small and medium-sized farms.

Data currently produced by farmers are not used properly [24], are of poor quality [25, 26] and there are problems concerning their integration.

In fact, a lot of data is not compatible and does not work between systems. The indicated scope of the Big Data to be made available from farmers, complementing AIIS, would be the next step in achieving the goals (Fig. 2).

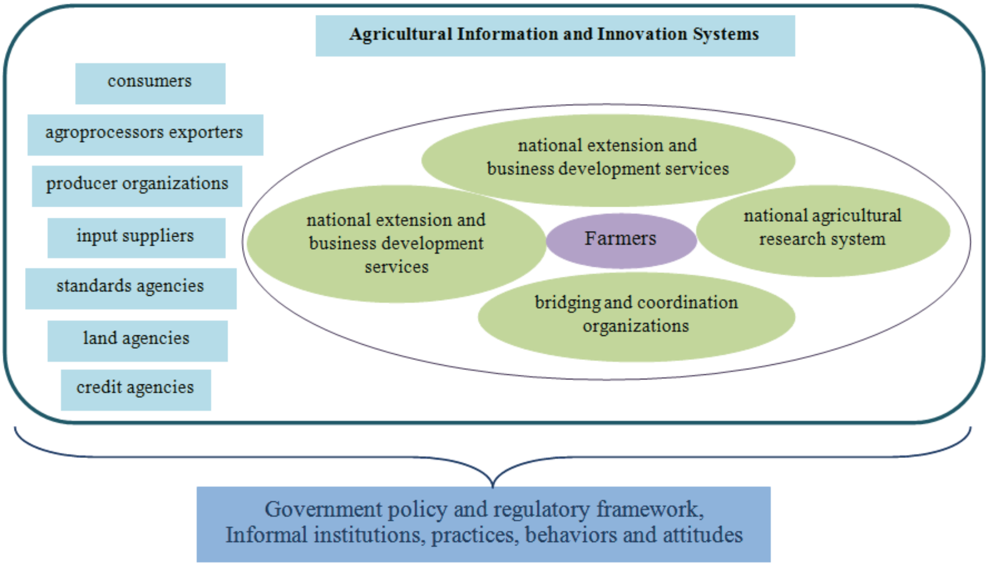


Fig. 2. Idea of Agricultural Information and Innovation System
Source: own study based on [21]

An enhanced uniform information system for agricultural production can deliver numerous benefits by facilitating the exchange of data between public registers, monitoring the actual situation in farms, controlling agricultural production, risk warning, extension of existing databases on agricultural production and farming as a whole [27, 28].

Agricultural data could be used for agricultural and non-agricultural purposes. The farms as producers of data remain at the heart of the processing of big data. Farms are responsible for the quality and credibility of data. The role of farmers is therefore crucial for agricultural systems.

Therefore, this study addresses the challenge of designing an Agricultural Information and Innovation System (AIIS) which would respond to current needs but also take into account the particular importance of farmers in the data production process.

The main objective of our research was to indicate the scope of data to be produced by farmers that could feed AIIS, while legally protecting farmers [29]. The relevant literature reports that farmers' data is valuable but is not currently being used effectively or efficiently. The data is not used from agricultural policy purposes, nor is it regulated and combined into one system [30–37].

The proposed concept is innovative for three reasons. Firstly, the system contains a complete and exhaustive database, as international recommendations, guidelines and European Union and national legislation have all been taken into account. The assumptions of previous Farm Management Information Systems (FMIS) implementations around the world were also taken into account. Secondly, there seems to be no system so far that combines the interests of governments and individual farmers. There are various information systems that are not universal and are designed to support specific functions and activities [27, 38–40]. A comprehensive information system with the special composition of databases we propose is dedicated to serving both sustainable agricultural policy and smart farming directly, including food supply chains, arable farming, greenhouse horticulture, and livestock farming, and open-air horticulture including orchards. This is possible because the big data produced by farmers and the use of the internet of things as an AIIS submodule would be included. This solution develops and fits into the technological perspective on the evolution of SDIs (Spatial Data Infrastructures), which involves combining big data produced by society with institutional data.

Thirdly, our system structure solution is designed to be effective and cost-efficient, without duplicating efforts in data production. Therefore, it is proposed that the system should use already existing reference information systems, i.e. the land administration system. This approach has not been considered in science and until now has not been applied in practice.

2. Methods and the Organization of the Study

The initial methodological assumptions are that the Agriculture Information and Innovation System (AIIS) should primarily consist of big data produced by farmers. AIIS, as a submodule, should be integrated with public registers to create a uniform Agriculture Management Information System (AMIS), according to the principle that comprehensive systems are the basis for sustainable decision making. The basic methodological principles are: to eliminate redundancy, save time, and minimize costs. AMIS should consist of existing public registers and information systems in Poland but should be complemented by data from farmers. This would mean that

AMIS, being a part of the National Spatial Data Infrastructure (NSDI), would be consistent and up to date, especially in terms of reference data, i.e., cadastral data) on a national scale. An important assumption is also the use of current technology of land administration system, referred to as the Integrated Real Estate Information System (IREIS), which functionally integrates many public registers for sustainable land administration [40]. In this respect, the system would use international standards ISO 19152 for Land Administration Domain Model (LADM) [41, 42], which closely contributes to the following Sustainable Development Goals [16]: (1) No Poverty, (2) Zero Hunger, (11) Sustainable Cities and Communities, (14) Life Below Water, (15) Life on Land.

As a result, it was initially assumed that AIIS would consist of a base part of the land administration system (IREIS), a submodule "green cadaster" and a component of big data: the AIIS based on farmers' participation. The most important element of the concept is therefore to define the scope of farmers' participation in the creation of AIIS. This logical approach can benefit SDI development through the participation of farmers. This is an innovative approach, as it involves private data for the development of SDIs, as a technological perspective on the evolution of SDIs [43]. Figure 3 presents a diagram of the organization of our study.

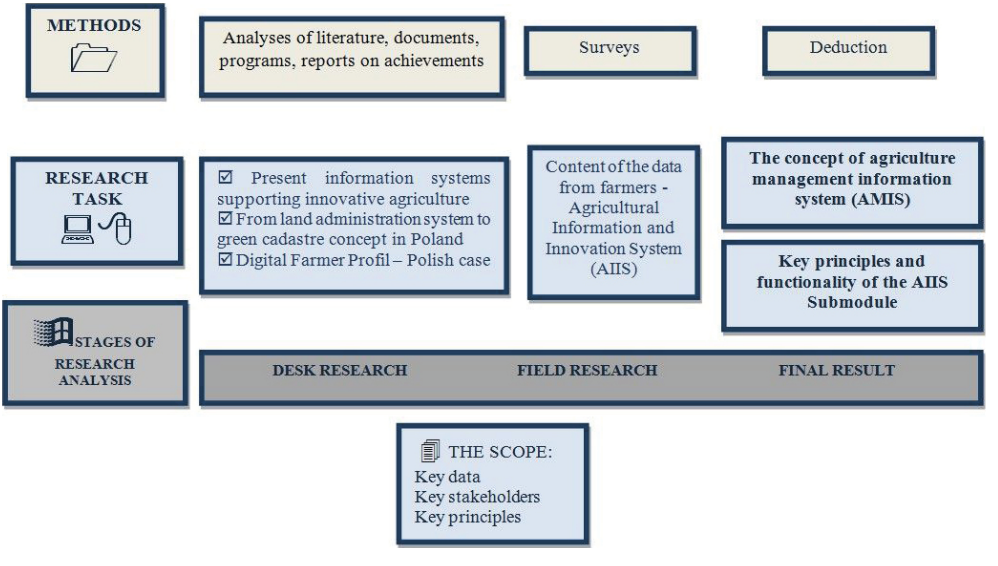


Fig. 3. Diagram of the organization of the study

In order to develop the range of data to be produced by farmers for AIIS – that can feed the AMIS – a detailed review of the baseline situation was required. The collected material is based on: strategy papers, international recommendations and legal acts concerning farms, various directives and national legislation. Political, social and economic information were gathered in the first step to prepare the background for subsequent detailed analyses (Tab. 1).

Table 1. General political and socio-economic data for Poland (2018)

Area [mln ha]	31.3	
Division into sub-units (federal state)	voivodeships district level – counties local level – municipalities	16 380 2 478
Population [thous.] of which: in rural areas	38 411 15 344	
Land [thous. ha] of which: agricultural land forest land as well as woody and bushy land lands under waters minerals areas transport residential wasteland	31 269.6 18 776.5 9 534.2 652.0 29.1 938.7 747.5 465.0	
Farms by areas groups of agricultural land [%] ≤1 ha 1.01–1.99 ha 2.00–4.99 ha 5.00–9.99 ha 10.00–14.99 ha 15.00–19.99 ha 20.00–49.99 ha ≥50.00 ha	 1.5 18.7 32.0 22.5 10.1 5.0 7.7 2.5	

Source: own elaboration based on [44]

In Poland, five typological classes of agricultural development were identified [45], which take the following criteria into account:

- share of agricultural land (AL) in the voivodeship's area [%],
- share of fallow land [%],
- share of land with reduced land use [%],
- persons working in agriculture per 100 ha of AL,
- investment outlays in agriculture and hunting per 100 ha of AL [thous. PLN],
- the gross value of fixed assets in agriculture and hunting per 100 ha of AL [thous. PLN],
- consumption of mineral or chemical fertilizers per 1 ha of AL [kg],
- global agricultural production per 1 ha of AL [thous. PLN].

The topology division is presented in the following ranking of voivodeships (Fig. 4):

- class I (very high potential of agriculture) – Opolskie, Śląskie and Wielkopolskie,
- class II (high potential of agriculture) – Dolnośląskie, Kujawsko-Pomorskie and Łódzkie,
- class III (average agricultural potential) – Lubelskie, Mazowieckie and Pomorskie,
- class IV (low agricultural potential) – Małopolskie, Świętokrzyskie and Zachodniopomorskie,
- class V (very low agricultural potential) – Lubuskie, Podkarpackie, Podlaskie and Warmińsko-Mazurskie.

Fig. 4. Agricultural potential map of Poland

A digital farmer profile (DFP) was prepared on the basis of the above data and statistical data collected by state institutions as well as thematic studies on agriculture and modern technologies and the report [46].

The content of the data from the farmers to the Agricultural Information and Innovation System (AIIS) were developed on the basis of the author's own research and was obtained in Poland by means of a questionnaire. Three voivodeships (regions): Opolskie, Śląskie and Wielkopolskie (the typological classes of agricultural development in Poland were selected and we collected questionnaires from 155 farmers. The survey was conducted using the direct interview method. The questionnaire was drawn up on the basis on [14, 46] and on the basis of information from preliminary analyses and the digital farmer profile. Respondents answered 25 questions, with most being closed-ended, single-choice questions.

The developed AMIS concept has three main components: key data, key stakeholders and key principles. The concept at this stage does not include detailed technological solutions, but only localizes the new solution in an already existing system structure or in one in the concept stage. The development of the technological architecture will be done in the next research phase.

3. Present Information Systems Supporting Innovative Agriculture

Big data is a term that describes large volumes of high velocity, complex and variable data that require advanced techniques and technologies to enable the capture, storage, distribution, management, and analysis of the information [47]. Big data has been the object of many analyses in the field of agricultural studies including: government decisions [36], smart agriculture [32], agricultural tools [37], precision farming business [48], challenging agribusiness giants [34], change of agriculture systems [35], framework [49], and technological innovation [33].

One of the key elements of innovative agriculture are information systems that support the automation of data acquisition and processing, monitoring, planning, decision making, documentation and management of farm activities [49]. In the literature review, many synonyms were found in the terminology of information systems for agriculture, for example farm management information system (FMIS), farm software (FS) decision support systems for agriculture, and information management in agriculture, or combinations of these. Hence, all these keywords were included in the review of these systems.

It has been observed that more and more different systems for farm management are being developed worldwide. These include autonomous precision farming software [40, 50, 51] and web-based technologies [52–57]. There are many terms for innovative agriculture such as smart farming, precision agriculture, site-specific farming, site-specific crop management, prescription farming, and satellite farming, where the use of modern information and communication technologies (ICT) to increase production volumes and economic profits is mentioned as key [58, 59]. In addition, innovative agriculture relies on advanced technologies such as cloud computing, remote sensing, data-driven farming, big data analytics and internet of things (IoT) [49].

Fountas et al. [56] have been successfully reviewing the information systems supporting innovative agriculture by researching various farm software offered by IT companies from United Kingdom, United States, Canada, Australia, as well as from other global software houses which provide their applications in English and have an English-based website. In addition, farm software from Germany, France and Italy were used for comparison. All of these countries are classified as highly developed countries. The European countries selected for the analysis were rated highly in the European Innovation Scoreboard Country Ranking by the European Commission [6], as strong innovators. The cited authors have observed that most of the farm software developers collect different data for different needs, i.e., for production planning, production process integration, performance management, quality and environmental resource management, as well as sale orders and contract management, but there is no one that is comprehensive, combining all these functionalities. When analyzing the internationally available farm management software, the authors [56] selected 11 main data layers which, if combined in one information system, would enable innovation agriculture:

1) field operations management (recording of farm activities),
2) reporting (creation of farming reports, work progress, work sheets and instructions).
3) finance (cost estimation of every farm activity),
4) site specific (mapping of the features of the fields),
5) inventory (inventory of all production materials, equipment, chemicals, fertilizers, and seeding and planting materials),
6) machinery management (details of equipment usage),
7) human resource management (employee management, the availability of employees in time and space),
8) traceability (data on crop recall, records related to the use of materials, employees, and equipment),
9) quality assurance (process monitoring and the production),
10) sales (management of orders, packing management and accounting systems, and the transfer of expenses between enterprises, charges for services, and the costing system for labor, supplies),
11) best practices (yield estimation).

The order of this list results from the frequency of these functions in the various software applications, which occur in the following proportions: field operations management (63%), reporting (57%), finance (45%), site-specific management (40%), inventory management (38%), machinery management (28%), human resource management (25%), traceability (19%), quality assurance (19%), sales (18%), and best practices (16%). Considering the above, it was assumed that the 11 data groups compiled should be included in a comprehensive system supporting farm management.

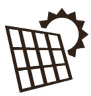
When reviewing the literature on agriculture innovation systems, to date no country has developed a multi-purpose and universal information system for agriculture that would integrate the land administration system, green cadastre and agriculture innovation system. In this sense, our proposal is unique and innovative.

4. Results and Discussion

4.1. Digital Farmer Profile – Polish Case (Tab. 2)

A digital farmer profile (DFP) is a profile that can capture comprehensive data about a farmer and the farm [46], which can be developed over time.

Table 2. Polish DFP

Criterion	Characteristics
Digital holders 	Bigholders are willing to apply innovative solutions. The larger the area of the farm, the greater the willingness to invest in technological solutions, facilitating work and saving time and allowing to maximize profit. Small farm holders (61%**)** and large farm holders **(**39%**)** participants in surveys the report [46]
Innovative solutions 	Farmers willing to apply innovative solutions in fields of: – crop production – 39% (optimization of the use of crop protection products / antibiotics), – animal production – 23%, – in other areas – 24% (sales, distribution, storage, packaging, processing)
Internet 	54% of farmers use the Internet as a source of information useful in farm management The scope of data used from the Internet is: – 81% of the search of information is on the means of production, – 79% of the search is for product sales opportunities, – 77% of the search of information is on plant and animal varieties, – 77.3% of the search of information is on plant varieties and animal breeds, – 67.3% of the search of information is on hazards (e.g. droughts, diseases), – 58.3% of the search of information is on the repair of agricultural machinery, – 56.3% of the search of information is on agricultural support (CAP funds and national budget), – 25.0% participation in discussion forums
Use of apps 	36% of farmers use various farm support applications: – record keeping, including on-farm accounting – 24.6%, – optimization of the use of crop protection products/antibiotics – 19.7%, – optimization of fertilization – 18.8%, – occurrence of diseases, pests in crops – 15.5%, – detection of heat in animals, control of animal nutrition – 7.4%, – in other areas – 0.1%

Source: own study based on [44]

The identification of DFP is important in order to discover the extent of technological innovation used by a statistical farmer, with a division into small farm holders and large farm holders. Such information is necessary to list and classify the data that a farmer currently produces and data that could potentially be produced using technology currently in use. DFP was elaborated on the basis of literature, legal regulations, statistical data collected by state institutions as well as thematic studies on agriculture and modern technologies. The report *Polska wieś i rolnictwo 2019* [46] turned out to be a particularly important document in the preparation of the DFP. In a study ordered by the Minister of Agriculture and Rural Development 1550 interviews were conducted with large and small farm holders (large farm holders – over 30 ha (39%) and small farm holders – under 30 ha (61%). The survey was conducted from July to August 2019. The survey covered all voivodeships (regions) in Poland based on the selection of respondents by the "random route" method, i.e., the interviewer selected every third unit (house/apartment), taking into account the appropriate selection of respondents for the research sample. Table 2 presents a digital farmer profile divided into four key aspects: classification and trends of digital holders, innovative solutions in farms, use of Internet, use of applications and software.

The above farmer profile, based on the cited government survey of 2019, shows that the Internet is an important source of information for Polish farmers and application tools support information management and processing. Information obtained in this way is used primarily for rational and optimal management of an agricultural holding, including the use of technological innovations [46].

4.2. Content of the Data from Farmers

International standards on the determinants of sustainable agriculture, EU guidelines, national spatial data infrastructure and implemented land administration system technologies, created the basis for the field survey of farmers' data inputs – thus creating the Polish farmer digital profile. The survey was key to determining the scope of the data that farms produce and its results can be an important component feeding into AIIS and thus providing additional information support for IREIS. These determinants were the basis for our own research where we collected data from framers analused and systematized them.

At the same time, advice and inputs from agricultural experts at key institutions were used: marshals' offices, Agency for Restructuring and Modernization of Agriculture (ARMA) and National Support Centre for Agriculture (NSCA). In the previously cited document [46] 60% of farmers consider ARMA employees as agricultural experts and 80% of NSCA employees as positive helpers. In the document [46], 60% of farmers consider ARMA employees as agricultural experts and 80% of NSCA employees as positive helpers. It should be stressed that the entity responsible for the implementation of innovations in rural areas are marshals' offices in Poland.

In order to test the methodology, a series of surveys were conducted in Poland. Three voivodeships (regions) with first class agricultural potential [45]: Opolskie, Śląskie and Wielkopolskie were selected. This survey in the area we conducted among 155 farmers. The number of respondents was the result of direct access to farmers. It is in line with standards in international literature, e.g., in Germany [59]. Cluster analysis of the considered 180 farms was conducted with IBM SPSS to address the issues of farm business situations, prospects, and successions [59].

The survey was conducted using the direct interview method. The field research was carried out in stages. The first consisted of preparing survey questionnaires and collecting farmer opinions. In the second stage, the answers received from the survey were consulted with experts implementing agricultural policy, who knew the specificity of farms in the selected area.

The questionnaire was drawn up on the basis on [14, 45] and information from preliminary analyses and the digital farmer profile. Respondents answered 25 questions. Most were closed-ended, single-choice questions. The first three concerned gender and age, size of the agricultural holding. Other questions concerned the type of data relevant to farm management, especially the data they already have at their disposal and would like to use, and questions about implemented technologies, machines and information systems that improve agricultural activity. The questions were aggregated into thematic blocks referred to the data layers envisaged in the system regarding: land-use types, infrastructure data, soil and water conditions, climate, environmental pollution and threats, agricultural production, roads, ecosystem services, economic and management data, technology / machines, staff, market, cooperation and support.

The thematic areas of our questions only referred to data which are not currently collected by state institutions but relate directly to agricultural holdings. The groups of respondents were categorized according to the digital farmer profile into the following: small (up to 30 ha area farms) and large farm holders (over 30 ha area farms). The survey was conducted at the respondents' residences from 15 January to 31 January 2021. The study covered many aspects of farmers' activities. The data characterizing innovation in agricultural holdings were separated out for this analysis.

One of the parameters was to survey a scalable static average number of small holders (56%) and large farm holders (44%), (respondents) proportional to the overall national shares. The age structure and percentage breakdown were as follows: 18–34 years – 16% of the respondents, 35–54 years – 36%, over 55 years – 48%. The respondents who managed the area of holdings up to 2.9 ha were 10%, 3–4.9 ha – 15%, 5–9.9 ha – 12%, 10–30 ha – 24%, >30 ha – 39%.

The results of the survey confirmed the information contained in the report [46] that there is a relationship between the size of the holding and the quantity of data produced. The larger the agricultural holding, the wider the scope and greater the amount of data held by farmers. Some of the surveyed farmers confirmed the use of digital farming machinery, buildings featuring robotics and digital technologies and artificial intelligence, devices connected to the internet ("internet of things" – IoT). On the basis of our research the respondents' answers, a list of tools most frequently used by Polish farmers to produce and collect data was prepared (Tab. 3). The tools have been systematized by types of data, indicating their usefulness in production planning and control.

Table 3. Type of tools to produce data for AIIS

Type of data		Tools	Planning	Control
	financial	Excel	monitoring	precision farming
	metrological	Word, Excel	monitoring	precision control
	environmental	robotics and sensors (temperature, humidity, CO_2, etc.), greenhouse computers	monitoring	climate control, precision control
	machine	GPS tracking	monitoring	precision farming
	staff	Excel	monitoring	precision control
	types of fertilizers and pesticides being used	robotics and sensors	monitoring	precision farming

Table 3. cont.

	the types of crops being grown	robotics and sensors, smartphone mapping	seeding, planting, soil typing, crop health, yield modelling	precision farming
	crop yield	robotics and sensors, smartphone mapping	lighting, energy management	precision farming
	livestock numbers and locations	biometric sensing, GPS tracking	breeding, monitoring	milk robots
	weather	weather stations, observations	monitoring	climate control, precision control

An example of innovative control for precision farming is advanced spraying technology. The HORSCH LEEB LT series trailed sprayers are a benchmark for maximum spraying precision, with the highest possible surface area efficiency. Nozzle spacing on the boom every 25 cm, allows guiding the boom at the level of 30–40 cm above the crop, which allows the spray liquid to reach the surface of the plants quickly, but also practically halves the flight time of drops adjusting its size to the speed of travel and wind strength.

Smaller droplets generally provide better coverage of the target, but they are easily carried away on a breeze and are more subject to turbulence caused by high forward speed. The system makes the gyroscope constantly gives practically information to the pneumatic cylinders, BoomSight – intelligent identification system – BoomControl Pro sensors, record the distance to the target area about one metre in front of the boom and then adapt the boom height to the terrain (Fig. 5).

In the second step of the interview, survey responses were compared to information gathered in interviews with ten experts at specialized institutions (marshal's office, ARMA and NSCA). They confirmed the fact that most of the data produced by the farmers are of good quality and can be included in the SDI. The challenge at this level of development is to design an Agriculture Management Information System (AMIS) that takes into account data from AIIS and integrates it with institutional data, especially the cadastre.

Fig. 5. Advanced spraying technology – HORSCH LEEB LT
Sources: photos 1 and 2 (from left) by M. Lemański, other photos [60]

Aggregation of information obtained from farmers' surveys, interviews with experts and analysis of the Green Cadastre concept [61] made it possible for us to construct a classification of data for a uniform AMIS based on data from IREIS, GC and AIIS (Tab. 3).

The AIIS was developed to classify data:

– A text in black bold indicates the source of data in Poland which are public registers maintained by the administration or various institutions in Poland.
– A black color indicates the scope of data that is currently being collected in public registers or by individual farmers.

In the next step of the system's development, the data layer regarding the market, cooperation and support should be extended to include logistics providers, wholesalers, retailers and consumers.

The data that are required by farmers in AIIS could be provided by agricultural business clusters, which have more technological capabilities and an elaborate policy aimed at continuous development of farms or Agricultural Advisory Centre supporting local activation of farmers and farms.

At the same time, any data submitted by farmers should be legally protected with a clause that it can only be used for the purpose for which it was submitted. Furthermore, data collected by local clusters could support small farms. Farmers, as data producers, could in return receive additional benefits by accessing the collected data in the form of a direct phone application. The protection of farmers as well as the opportunity to use the data could be the determinant that will drive farmers to share data and collaborate.

Table 4. AMIS scope of data and main source

No.	Data group	Integrated Real Estate Information System (IREIS) (reference system)	Green Cadastre Submodule (other public registers)	Agriculture Information and Innovation System Submodule (AIIS)	
				data from farmers	data from clusters and IoT
1	Address data	**Cadastre** Number of cadastral plot **Register of places, streets and addresses** Street name and number, building number **National Official Register of the Territorial Division of the Country** Statistical numbers and unique identifiers of spatial objects in the country: number of cadastral district, number of municipality, type of municipality	–	–	–
2	Physical properties of land plot	**Cadastre** Area, boundaries	**Basic map/ Situation-height map** Slope	–	Specific growing conditions due to the topography
3	Ownership / Rights, responsibilities, restrictions	**Land Register** Owner, tenant/administrator, documents granting legal title, restrictions in rights **Cadastre** Distribution of plots **National Register of Agricultural Producers, Farms and Applications for Payment Entitlements, IACS** Area and boundaries of the agricultural holding **Population Register** Personal identification number	–	–	Possibilities of using and increasing the area (purchase, lease)

Table 4. cont.

No.	Data group	Integrated Real Estate Information System (IREIS) (reference system)	Green Cadastre Submodule (other public registers)	Agriculture Information and Innovation System Submodule (AIIS)	
				data from farmers	data from clusters and IoT
4	Land-use types	**Cadastre** Agricultural land, forests, developed and urbanized land, protected ecosystems, water bodies, miscellaneous	–	The use of owned AL (possible change of use for other purposes, e.g., construction). Temporal changes in land use. Distance to the farthest field	Location of land in areas with natural or other specific constraints
5	Local policy / Restrictions	**Land Use Plans** Permissible types of land use and management, site functions, restrictions on use	**Decisions on the Conditions of Development and Land Use** In the absence of a land use plans, the decisions issued shall specify the conditions of land use and permits	–	–
6	Infrastructure data	**Cadastre** Buildings **Land Use Plans** Planned infrastructure and public utilities	**Geodetic Register of Utilities Networks** Existing infrastructure and public utilities, location of infrastructure networks	Technical data concerning farm buildings, buildings for agricultural production. Type of fencing, hardened paths, small garden and agricultural architecture	Condition of buildings, extensions or alternative uses, animal stands available or obtainable
7	Soil and water conditions	–	**Water Cadastre** Water table, watercourses and water bodies, hydrographic classification of Poland, indirect protected zones, protected water intake zones **Geology Cadastre** Soil and agricultural maps, soil type, geology	Soil nutrient supply, soil pH (repeated). Fertilizer type, irrigation type	Proposed pesticide usage list for the crop: how to use, price and availability with local source of fertilisers, pesticides, weedicides, fuel, soil temperature (repeated), soil humidity (repeated), PHI, NHI, safety and withdrawal period etc. of pesticide, weedicide etc. before harvest, weather forecasts

Table 4. cont.

8	Nature protection types	**Central Register of Nature Conservation Sites** Nature reserve, protected ecosystem, Nature 2000 area, nature and landscape conservation site	–	–	–
9	Climate	–	**Institute of Meteorology and Water Management – National Research Institute (IMWM) – climate maps** Average annual temperature, average annual precipitation, humidity, insolation (agricultural climate model – application), extreme weather events (drought, floods, hurricanes) **Solar atlas** Sunshine time per day **European Severe Weather Database**	Information on unfavorable weather conditions, atmospheric anomalies: droughts, hailstorms, air trumpets	Agro-meteorological local factors. Length of vegetation period. Sum of annual precipitation and distribution
10	Environmental pollution and threats	–	**State Environmental Monitoring – pollution maps** Air pollution (e.g., CO_2); soil pollution (e.g., nitrates and nitrate vulnerable zones), radioactive and microbiological threats, artificial water deficit, landscape degradation, air, underground water, surface water and sea water pollution, water cycle disruptions, changes in land relief, soil erosion, degradation of flora, industrial and municipal waste, noise pollution, pests	Waste management	Pests and diseases, approximate stage of crop when a particular pest/disease/ weed attacks the crop

Table 4. cont.

No.	Data group	Integrated Real Estate Information System (IREIS) (reference system)	Green Cadastre Submodule (other public registers)	Agriculture Information and Innovation System Submodule (AIIS)	
				data from farmers	data from clusters and IoT
11	Agricultural production	**National Register of Agricultural Producers, Farms and Applications for Payment Entitlements in the IACS** Area of cultivation, crop, crop and livestock production, aquaculture	–	Planned changes in agricultural production, seeds, pre-planting, planting, cultivation, harvesting, storage, processing, food safety and quality	Desired characteristics of crop and variety sown such as characteristic of product, resistance to drought, disease, pests etc., seeding rate per hectare, optimum plant density per hectare, recommended date for sowing, potential yield [kg] for full crop, recommended soil type, recommended soil humidity [%] at planting, recommended soil temperature at planting, recommended soil pH at planting, recommended soil N [kg/ha], recommended soil P [kg/ha], recommended soil K [kg/ha], required micronutrients [kg/ha], recommended quantity of farm yard manure, recommended vermicompost, time [days] of different crop maturity, seeding/transplantation method, time needed to seed/transplant per hectare [M/D], interculture date (repeated)
12	Roads	**Cadastre, Land Use Plans** Location of motorways and national roads	**Road Register** Traffic intensity, condition of roads, road traffic accidents	Communication by your own means	Optimal transport solutions

Table 4. cont.

13	Ecosystem services	–	**Polish Energy Data Exchange System** Energy benefis (photovoltaic panels, renewable energy, location of windfarms on agricultural land) **Forestry cadastre** value of trees, oxygen production **Water cadastre** catchments and ecological irrigation, flood prevention	Usefulness of drainage ditches. Use of renewable energy sources and ecosystem services	Savings with ecosystem services
14	Economic and management data	**Tax register** Tax rates and tax reliefs **Register of Real Estate Prices and Values** Prices and values of real estate, transactional data **National Official Business Register** Business registration number **National Register of Agricultural Producers, Farms and Applications for Payment Entitlements in the IACS** Findings from the EU	**Farm Accountancy Data Network (FADN)** Estimated production costs, value of animals at the beginning and end of the fiscal year, subsidies and compensatory payments, revenue from the sale of crops and livestock in the fiscal year, allocated production quotas	Planned investments, consumption, inputs, profits; average yield of the crop per hectare realised by farmer; postharvest processing	Average time to prepare 1 hectare for sowing, days to harvest the crop from date of sowing, seed availability in locality (interview). Approximate cost of seed per kilogram, storage for grain. Postharvest packaging. Feed requirements [tons]. Loans and leasing
15	Technology / machines	–	–	Equipment with fixed assets (all available machines for crop automation, year of purchase and production, value, consumption, fuel type, computer programs, applications	Stages recommended machinery, farm machinery needed for inter-cultivation and their availability, machinery for harvest, method of harvest (single/multiple picking as in castor/cotton)

Table 4. cont.

No.	Data group	Integrated Real Estate Information System (IREIS) (reference system)	Green Cadastre Submodule (other public registers)	Agriculture Information and Innovation System Submodule (AIIS)	
				data from farmers	data from clusters and IoT
16	Staff	–	**Social Insurance Institution** Number of staff employed in the enterprise and type of employed **Agricultural Social Insurance Fund** Number of staff employed on the holding and type of employment	Actual number of employees on the farm. Plans for changes in employment	Approximate labour required for pre-planting preparation, planting, weeding, spraying, etc. Estimated labor required for harvesting [days/ha]. Calculation of the necessary working time, labour intensity of the field and animal production with the production technology of the holding, etc. Labour resources of the holding. Possibility of hiring people to work and costs of paid labour
17	Market	–	CSO, data (stay and supply sale)	–	Wholesale marketing, retail marketing. Assessment of the market situation, trends, forecasts, etc. Possibilities of securing sales (contracts, agreements)
18	Cooperation and support	**National Register of Agricultural Producers, Farms and Applications for Payment Entitlements, IACS** Information on open financial and material support programs for specific types of production	marshal's office	–	Presence of entrepreneurship clusters, agricultural producer groups. Opportunities for cooperation – joint use of machines. Possibilities of using machinery from outside the holding, as well as proposals for using machinery for work outside the holding

4.3. Key Principles and Functionality of the AIIS Submodule

Considering the IREIS technology implemented in Poland and the conceptual assumptions of the Green Cadastre (GC) Submodule [61], it is possible to combine the Agriculture Management Information System (AMIS) with the AIIS Submodule using similar principles.

The architecture and semantics of the AIIS Submodule should take into account the following system functionalities:

- The AIIS should deliver the following options: data processing and analysis, data visualization, data exchange, generation of reports, generation of information materials, predictions, warnings, and alerts [54, 62].
- The AIIS databases should consist of the following layers: land-use types, infrastructure data, soil and water conditions, climate, environmental pollution and threats, agricultural production, roads, ecosystem services, economic and management data, technology/machines, staff, market, cooperation and support [48, 52].
- The AIIS should be an integral part of the national SDI, as submodule of the IREIS, which will form part of a comprehensive agricultural management information system (AMIS) [40].
- The abridged AIIS version should be made available to the public to support social participation and promote the development of a spatially enabled society [63].
- Users should be able to report invalid or missing data in accordance with their competence and license [64].
- The registered users should be able to provide access to a mobile application conforming to Open Geospatial Consortium (OGS) standards, which should be developed based on a Web GIS interface with standard GIS tools for spatial analyses [62].
- Farmers should have access to a single web application with different authorization profiles and should be able to update the existing resources from the office or from different locations in the country with the use of a tablet or a smartphone [49].
- Data should be visualized in layers with a clear legend to generate maps with content for different purposes [43].

The challenge for the authorities responsible will be to sanction the production of data, its access under license, affordability of data; control of data quality and usability including applicability and appropriation and effective use of data. Therefore, the next stage of research should be the development of an AMIS technological architecture and identification of the group of recipients and license solutions for data security (Fig. 6).

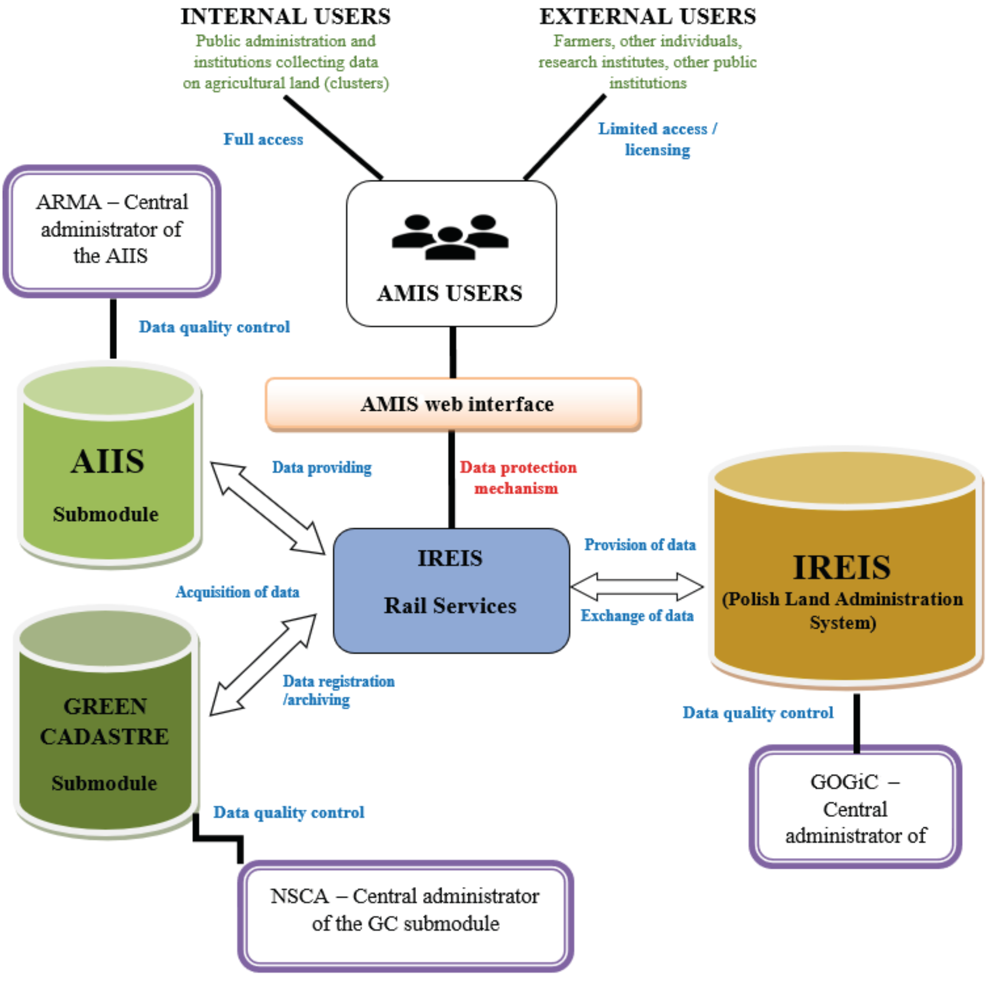


Fig. 6. Data flow in the Agriculture Management Information System. Explanations: AIIS – Agriculture Information and Innovation System; AMIS – Agriculture Management Information System; ARMA – Agency for Restructuring and Modernization of Agriculture; IREIS – Integrated Real Estate Information System; NSCA – National Support Centre for Agriculture; GOGiC – General Office of Geodesy and Cartography

5. Conclusions

The current global situation, including efforts being taken to tackle the COVID-19 pandemic, shows that in a life-threatening situation, people and nations will increasingly be taking actions to protect themselves to ensure health and food security. In order to rationally manage and make the right decisions, it is necessary to have databases of appropriate, systematic and compatible data.

Effective optimization and food production efficiency depends on farmers successively implementing ever more intelligent technologies for ecological precision farming. Farmers collect data and set up their own information systems to improve their knowledge. They provide some of this data to institutions responsible for agricultural policy. One key conclusion of this paper would be that farmers are an important part of the economy, not only as food producers, but also as data producers. That premise was the basis for the development of the Agriculture Information and Innovation System (AIIS) concept proposed here. AIIS is to be developed by farmers for precision agriculture and included as a submodule in the national Spatial Data Infrastructure in the form of an integrated Agriculture Management Information System (AMIS).

The future lies in big data as a basic element of machine learning. Processing such an amount of data requires that it be collected, systematized, and made available to the relevant actors. This can only be achieved through a properly designed information system. In the context of food security, we believe that this can be done with an appropriately developed AIIS.

Our research has proven that the Integrated Real Estate Information System (IREIS) technology implemented in Poland, first as a reference core, can be used to further develop a uniform system across the country. Integration can take place through a relational database based on the spatial reference unit – the cadastral parcel. The proposed scope of AMIS data responds to the real needs of farmers and institutions responsible for agricultural policy in Poland and is consistent with Polish and EU law. The AIIS Submodule will fill a database gap for unlimited sustainable agricultural land development activities (which require a huge amount of data).

International reports have highlighted the myriad benefits the data revolution can bring to precision agriculture and food security. The data revolution will provide an opportunity for farmers to get closer to the consumer, which is very important in terms of preserving the supply chain of goods to the market. The COVID-19 pandemic will show how important this chain is at the time of crisis. Big data in agriculture is often seen as the solution to the world's food security and crisis prevention. The results of this study have shown that such a system is very much needed in Poland. The proposed AIIS as a submodule of AMIS is a strategic and modern solution that provides users with access to comprehensive data in one place.

At the same time, AMIS, thanks to the structure based on the IREIS core and Green Cadastre (GC) and AIIS submodules will not overload the system with big data. This flexible structure will be easier to administer, as it can be easily adapted to different administrative and user requirements. The proposed scope of AIIS data is universal, as it takes into account not only the needs of farmers but it is also based on the needs of institutions resulting from legal regulations and international guidelines. Therefore, the concept can be used by other countries – especially those that are at the beginning of the development of agricultural information systems. The implementation of the proposed technology in individual countries would enable the exchange of standard data not only at national but also at international level, which is important in the context of globalization and technology transfer.

To conclude, our proposed system would allow farmers to provide crucial input for the planning, management and governance of modern agricultural production.

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Conflicts of Interest

The authors declare no conflict of interest.

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