Comprehensive Management of Agroecosystem Productivity on the Platform of Specialized Farm Management Information Systems

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ABSTRACT

The paper examines the methodological aspects of a comprehensive approach to effective management of crop production agrocenoses and resource utilization on the platform of specialized farm management information systems (FMIS). The conceptual advantages and technological foundations of precision agriculture in the context of the formation of Agriculture 4.0 are analyzed, highlighting the significance of progress in the autonomy of agricultural production at various levels of physical and digital technologies. Based on the experience of modern agricultural enterprises in Ukraine, the capabilities of well-known agroprocess management systems, such as Cropio and Soft.Farm, are analyzed. The ways to improve the algorithms and architecture of FMIS software complexes for effective management of interactions between factors in agrocenoses are demonstrated. Prospective directions include mathematical and scenario-based methods for modeling climatic indicators and crop yields.

Keywords: FMIS, Agroecosystem, Agriculture 4.0, precision agriculture, yield prediction, agrocenoses modeling

1. INTRODUCTION

Global agro-food systems are under immense pressure. In the coming decades, global agriculture will need to undergo a major transformation to meet the future demands of a growing population. It is expected that by 2050, the world's population will grow to nearly 10 billion people, and feeding them will require an increase in the production of available food by 59-98% [1]. In the context of global challenges to provide food for the planet's growing population, the search for and application of effective resource management tools for agricultural enterprises, crop productivity, and yield forecasting in changing climatic conditions have been and remain at the forefront of the scientific community, practitioners, and international organizations.

In 2018, a global government summit took place, resulting in the publication of the report "Agriculture 4.0 – the future of farming technology" [2]. This report, in particular, states that "…farms and agricultural operations will have to be managed very differently, primarily due to advancements in technologies such as sensors, devices, machines, and information technology." Future agriculture will widely utilize complex technologies such as robots, temperature, chemical, and moisture sensors, aerial imagery, and GPS (Global Positioning System) technologies. These advanced devices, precision farming, and robotic systems will enable farms to be more profitable, efficient, safe, and environmentally friendly [3].

Agriculture 4.0, which is part of the fourth wave of the industrial revolution, offers the ideal state of fully autonomous and optimized production in farming. Nowadays, customers demand transparency and traceability of the supply chains of the food products they purchase.

In addition to efficiency, Industry 4.0 provides a foundation for proactive tracking in the agro-food chain through digital technologies to achieve Agriculture 4.0 [4]. The principles of Industry 4.0 parameter visibility, transparency for understanding why events occur, predictability for proactive modeling, and autonomy for operation without human intervention - are widely applied to Agriculture 4.0 as well.

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Since 2018, precision farming systems have been announced as part of the Agriculture 4.0 framework at the global forum. In this context, precision farming is increasingly associated not only with new approaches to managing production processes but also with the application of modern information systems and digital platforms for processing the streams of big data generated and collected by various devices, which require specialized algorithms and tools for processing and storage.

The technologies of precision farming, which emerged at the end of the 20th century and began to be widely developed and implemented at the beginning of the 21st century, have provided opportunities to significantly increase the productivity of the crop production sector through diversified (precise) management of resources, robotics, and technological operations.

Modern achievements in telecommunications, digital technologies, and methods of information collection and processing objectively contribute to the creation of fundamentally new software complexes that can integrate the expertise of many specialists in agronomy, biology, economics, and other related fields [5].

The authors of this work have systematically studied and developed the concept of managing production processes in crop production using precision farming in previous works, justifying the modular composition of specialized information management systems for production processes in agricultural production [6].

In this work, the main focus is on the necessity of forming a comprehensive approach to managing data of agroecosystems of key crops using the expanded capabilities of specialized FMIS systems designed for agricultural producers. A significant number of users utilize such platforms only for accounting and managing material resources, and for managing tasks during technological operations. However, the capabilities of managing such components of the agroecosystems as natural conditions and resources, as well as yield forecasting, often remain overlooked by agricultural producers and software system developers.

2. DIRECTIONS OF CHANGES IN AGRI-FOOD SYSTEMS USING DIGITAL TECHNOLOGIES

Today, the agricultural production sector is much more than just the traditional view of food production. Agro-food systems are a complex interaction between people, technologies, and natural resources that ensure the production, processing, transportation, storage, and consumption of food. These systems are complex and depend on many factors, such as climate, soils, water resources, technologies, economics, politics, and culture [7].

Recent data shows that approximately 3.1 billion people -or 40% of the entire human population -could not afford a healthy diet in 2022, and this number is expected to grow due to the ongoing trend of rapid increases in global food prices and rising inequality. These issues have been further exacerbated by the growing imbalance of power among food system actors, as well as the impact of the COVID-19 pandemic, climate change, and armed conflicts around the world, including in Ukraine.

Food systems contribute to and are influenced by these interconnected issues of inequality, hunger and malnutrition, climate change, biodiversity loss, zoonotic diseases, and conflicts.

The Food and Agriculture Organization of the United Nations implements the "Sustainable Food Systems" (SFS) program—a multi-stakeholder partnership aimed at accelerating the urgent transformation to sustainable food systems as a critical strategy for achieving sustainable development goals [8]. The SFS program promotes the transition to sustainable food systems, as called for by the UN Secretary-General's Food Systems Summit in 2021, by building synergies and fostering cooperation among a wide range of participants and initiatives.

Open-source software, architectures, frameworks, and APIs support accessible digital technologies. Swarm intelligence will play a key role in autonomous farming in a decentralized self-learning mode.

Technologies can help balance productivity, employment, and sustainability (Figure 1). They offer accessible and innovative solutions to enhance productivity while reducing economic and environmental risks [9].

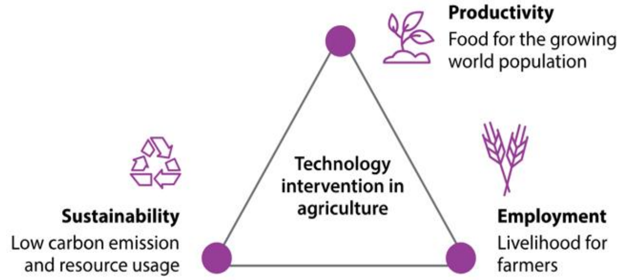

Figure 1. Technologies balance productivity, employment, and sustainability [9]

In the convergence of the digital and physical worlds in agriculture, there is an integration of information technology (IT) and operational technology (OT) into Industry 4.0, known as IT-OT integration. IT pertains to enterprise-level data, while OT refers to shop-floor-level data. Similarly, agricultural field data (e.g., soil nutrient content) must be integrated with external parameters (e.g., weather conditions, commodity prices, and equipment condition). Agriculture 4.0 combines science and technology by reengineering the entire value creation chain of demand and supply.

It is expected that autonomous farming will provide cost-effective solutions throughout the value creation chain through continuous real-time monitoring of fields, crops, machinery, and weather. Potential use cases include path optimization; coverage area; machinery time used for plowing, cultivating, and harvesting; reduction of operating costs; connection of processes for real-time crop monitoring; and logistical support for agricultural production [10].

The goal of implementing precision farming systems is to accurately direct the necessary (correct) amount of resources to the required areas of production to achieve financial benefits and enhance human expertise. The scientific basis of the precision farming concept acknowledges the existence of certain heterogeneities within each cultivated field and its specific characteristics. Modern technologies such as GPS (Global Positioning System), various sensors, aerial photography, satellite imagery, and specialized programs based on Geographic Information Systems (GIS) are already being used for data collection, evaluation, and monitoring [11-12]. Thus, precision farming as a complex high-tech management system includes:

1) Global Positioning Technologies (GPS);
2) Geographic Information Systems (GIS);
3) Yield Monitor Technologies;
4) Variable Rate Technology;
5) Remote Sensing Technologies (RST);
6) Internet of Things (IoT) solutions (a network of internet-connected objects capable of collecting and exchanging data from embedded services).

Applications of precision farming include:

1) Agronomic: enhancing agricultural production by considering the real needs of crops for fertilizers and plant protection products (PPP);
2) Technical: improving farm-level time management (including better planning of agricultural operations);
3) Environmental: reducing the negative impact of agricultural production on the environment (more precise assessment of crop needs for fertilizers and PPP leads to limited application and input of fertilizers and PPP);
4) Economic: increasing productivity and/or reducing costs to improve agribusiness efficiency (including reduced costs for nitrogen fertilizer application).

In other words, precision farming is the combination of human expertise and skills with modern technologies. Methodology for implementing PFS:

1) Correct identification of the location and causes of problems that lead to yield losses and increased production costs.
2) Documentation of the problem, field operations, and prediction of potential outcomes.
3) Determining the financial aspect of solving or not solving the problem.
4) Prioritization of problems.
5) Implementation of technological solutions.
6) Evaluation of results.

Various sources indicate that the advancement of information technologies in agricultural production demonstrates that the transition from precision farming to the level of Agriculture 4.0 is not a leap but involves the application of many different technologies and systems [13-14]. Ultimately, the transition cannot be accomplished without the use of a management information system that allows calculations for all types of work and necessary decision-making.

It should be noted that the agricultural sector is quite resistant to innovations. The analysis of the main limiting (slowing) factors often encountered when implementing digital technologies and systems in agricultural production has been conducted in separate scientific studies [6]. These factors include technical phenomena, in particular: inconsistency in the division into management zones (field arrays) [12]; lack of readiness to process large volumes of data obtained from numerous sensors, satellites, drones, etc., in a single system; incompatibility of individual systems servicing one enterprise due to different standards; and low-quality internet access in rural areas. In this context, the readiness level of personnel for innovations and the level of digital knowledge play a special role. Researchers in many countries pay special attention to this factor and consider that the main obstacle is not technology, equipment, or even finances. The main obstacle worldwide is organizational culture and personnel readiness [15].

At Poltava State Agrarian University (PSAU), systematic work is being carried out to train agronomists with modern digital skills [5]. For eight years, a direction of interaction between IT companies – developers of systems for agronomists, agricultural producers, and scientists in the fields of IT and agronomy has been developing. This allows for obtaining operational information about the needs of the agro-complex, adjusting the content of university education, and preparing specialists for the modern needs of the agricultural sector [16].

3. JUSTIFICATION FOR THE CHOICE OF ARCHITECTURE AND FUNCTIONAL CHARACTERISTICS OF FMIS

The purpose of implementing FMIS in the management of agrocenoses is to increase the efficiency and competitiveness of agricultural production. Through information systems and technologies, agronomists can optimize the selection of crop varieties, planting planning, application of fertilizers, plant protection products, harvesting, and other aspects of agrotechnologies. This collectively contributes to improving product quality, reducing costs, and preserving resources and the environment.

The plan for implementing information systems in the management of agrocenoses should include goals, objectives, resources, stages, and expected results from using modern technologies to enhance the efficiency and competitiveness of the agricultural sector. Table 1 presents the components of the information system that ensure the automation of key aspects of agricultural production and their management.

Table 1. Key Components of Effective Agriculture and Automation Methods in FMIS Environment

Component	Subject of Management Automation	Expected Result
Land Bank: - Fields - Land plots - Lease agreements	Automation of Land Bank Management: - GIS - CRM - Agro-drones	- Land consolidation - Risk reduction - Increased company capitalization
Technical and Material Values: - Seed material - fertilizers - Plant protection products Fuel	Automation of Accounting, Working Time, Write-offs: - Mobile agronomist - Automation of fuel stations and scales - GPS monitoring of equipment and operations	- Cost reduction - Prompt decision-making - Asset control
Equipment: - Movement geometry across the field - Operation standards - Operation monitoring	Implementation of Precision Agriculture: - Parallel driving - Monitoring of tillage, sowing, and spraying - Management of operation norms	- Operational efficiency - Technology adherence control - Improved EBITDA (Earnings Before Interest, Taxes, Depreciation, and Amortization)
Information: - Land bank data - Soil data - Weather data - Data on completed operations - Data on crops and yield	Software Products and Services: - Satellite monitoring - Weather services - Precision agriculture systems - Farm Management Systems	- Knowledge transfer - Unified information field - Company capitalization

However, in practice, agricultural enterprises do not utilize the full functionality of FMIS. For example, in the work [], hundreds of publications related to the description of FMIS functions and usage were analyzed. Statistical analysis showed that the more popular functions remain resource and financial accounting (present in 17 out of 38 reviewed FMIS) compared to yield forecasting, weather services (7 out of 38).
Based on Table 1, information systems in agronomy should encompass all production and technological links by including components such as remote monitoring systems, weather forecasting, crop cultivation optimization, water resource management, data analysis, and more. Typically, most core functions are implemented in specialized modules of Farm Management Systems (FMIS) with identical names. The justification for the set of modules and functions of FMIS as a unified data management platform for production processes in crop production was presented in the work [17].
The functionality of the most well-known comprehensive solutions for agricultural producers, such as FieldView™ by Bayer [18], Soft.Farm [19], and Cropwise Operations by Syngenta [20], features a similar set of production modules. Figure 2 shows a fragment of the main page of the Soft.Farm system, displaying the full set of system modules.

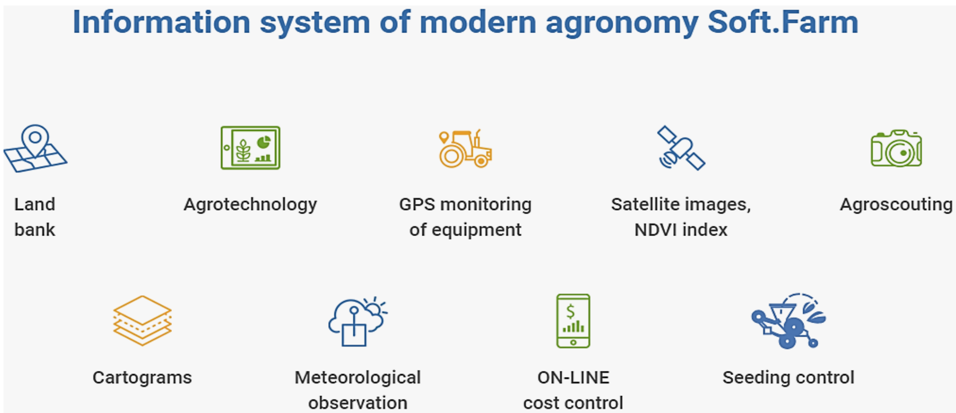

Figure 2. Set of Main Modules in the Soft.Farm Information System in the "Crop Production" Section [19]

All modules can be grouped into the following main categories: Land data processing modules and field inspection modules based on satellite imagery, as well as planning and work control modules. In the context of performing all functions, it can be stated that the most optimal, cost-effective, and geographically accessible (not tied to a specific workstation) systems are those based on cloud services. The advantage of using cloud computing is the ability to manage costs for software and hardware efficiently, such as with Software as a Service (SaaS). Successful cloud solutions should be used as a replacement or expansion of traditional software solutions for technical and fundamental reorganization of the business model. They enable the storage of large volumes of data, which can be accessed from mobile and personal computers.
The architecture of modern information systems based on cloud computing is an upgraded version of the more familiar client-server architecture. Cloud computing is known to involve software and hardware for web interface or remote access. In this setup, the terminal becomes the user's network-connected workstation, and the servers are part of the computing cloud [21].
In general, implementing information systems in agronomy must consider regional specifics, farmer needs, infrastructure availability, and funding, as well as potential risks and challenges. To understand the composition of technologies and select the necessary functionality of information systems for automating production management in a specific agricultural enterprise, a significant amount of preparatory work is required. A structured description of the stages of implementation and use of FMIS is provided in the following sections of the work. Examples are implemented in the Soft.Farm environment, which has thousands of users both in Ukraine and abroad, and includes all necessary modules and flexible pricing plans. The system developers collaborate with Poltava State Agrarian University (PSAU). The authors also gathered and analyzed information on the capabilities of other systems, implementation experience in agricultural enterprises, and summarized areas for their improvement and necessary tasks for expanding functionality and removing limitations.

4. FEATURES OF DATA ARRAYS PROCESSING IN AGROECOSYSTEMS BASED ON FMIS

First and foremost, all interested parties need to clearly understand the essence and interrelationship of technological operations, for example in the field of crop production, the categories of processed information, as well as the list and form of incoming and reporting documents that are created and processed in all accounting and technological processes.
Modern agricultural technologies are characterized as resource-saving and soil-preserving, and are part of the so-called industrial technology. The essence lies in the fact that throughout the period from sowing to harvesting, biologists, agronomists, and other biological science specialists monitor plant development, analyze and, upon detecting signs of developmental disruptions (e.g., pests, diseases, etc.), treat crops with wide-coverage machinery and apply adjusted doses of fertilizers, herbicides, or pesticides. For rational organization of production of specific types of crops and accounting in agricultural enterprises, technological maps for growing agricultural crops must be compiled. The main indicators of agroecosystem efficiency are crop yield and production profitability.
Crop yield is an integrated parameter determined by plant density in the field and their average productivity. The value of the latter parameter depends on both the genetic characteristics of the plants and the level of availability of several environmental factors, primarily water, heat, and essential nutrients.

The main factors affecting plant potential realization include: weather, soil, seed selection, equipment choice, soil preparation, sowing, water distribution, nutrient management, observations during the growing season, pest, disease, and weed control, and harvesting. Essential elements of precision farming in this context are: maps, remote monitoring, technological solutions, weather stations, risk modeling, financial decisions, and management decisions.

The process of implementing and using FMIS begins with creating databases and, first of all, collecting information about the field. Remote sensing methods are used for data collection, including aerial photography, satellite imagery, harvesting equipment equipped with yield monitoring systems, automatic soil samplers combined with GPS receivers. Data are usually formatted into lists. Most systems provide for linking them with other operations, supplementing, modifying, and editing. Main aspects of data in each system must be follows.

Database development. Collecting information

For collecting information, remote sensing methods are used, including aerial photography, satellite imagery, harvesting equipment with yield monitoring systems, and automatic soil samplers with GPS receivers. Data are collected according to relevant methodologies and entered into thematic dictionaries.

To complete information about field areas, it is necessary to: conduct an inventory of fields, delineate the actual sizes and boundaries of field areas, and then create an electronic map based on the obtained data. For this purpose, processed satellite images or a mobile complex consisting of a vehicle with a GPS receiver and a PC can be used.

Creating and using productivity zones on the field

A productivity zone is an area in the field with significant differences in soil type, permeability, and/or history, as well as information about the agrochemical and agrophysical properties of the soil and plant development levels. The best results for forming productivity zones were achieved in fields with varying soil types, relief features, and drainage conditions. Sources of data for forming productivity zones in the field within the FMIS environment include:

1) Remote monitoring data (UAV/satellite), on the basis of which the Vegetation Index (NDVI) is calculated and a vegetation map is constructed.
2) Variability map (soil electrical conductivity).
3) Terrain data.
4) Yield maps, constructed based on yield monitoring systems.
5) Soil analysis results.

Management of each productivity zone in the field may vary depending on the planned yield and production profitability. Information from productivity zones in the field is used for calculating seeding rates, fertilizer application rates, plant protection systems, and determining profitability levels. Currently, attempts at full automation of productivity zone determination are imperfect if the management system and software on the primary equipment are incompatible. That is why large holdings often create platforms for the supply of fertilizers, equipment, and seeds (e.g., Bayer, Syngenta, and others). Other software solutions consider similar factors, creating flexible systems with corresponding APIs, such as Soft.Farm.

Electronic Field Maps

For working with multi-layer electronic maps, there are specialized computer software packages based on Geographic Information Systems (GIS). Interactive electronic maps, which are built-in tools in FMIS (e.g., Soft.Farm [19]), allow for the creation and use of various types of layers, including: vegetation; variability; scouting; NDVI; grain moisture; field treatment; overlap; application; efficiency zones; profitability; expenses; yield; height; speed; productivity; fuel; and output.

Weather Conditions

The use of meteorological stations with advanced digital forecasting tools for predicting weather trends in the region is essential for planning field work.

From the above, it is clear that modern agriculture involves processing a large amount of intra-farm information. Throughout the year, a producer makes at least 50 key decisions. Each decision affects the next one and ultimately impacts the yield. An error in one decision can lead to significant losses per hectare. This is when the role of data is particularly valuable in the production process. Decisions should be based on facts, not assumptions, and should be made based on data analysis.

Each decision is the result of analyzing reliable and correctly integrated data. Based on data management, it is possible to control not only operational and planning activities in agricultural enterprises. A higher level of FMIS effectiveness is modeling the management of agroecosystem productivity and forecasting, for example, yield under different weather conditions. The use of modern technologies, agro-technical systems, and modeling for forecasting and optimizing the impact of climatic factors on crop cultivation can help increase agroecosystem productivity and reduce the risk of crop loss.

According to surveys of leading agricultural specialists who have used FMIS for more than 10 years, it has been confirmed that mathematical modeling of crop growth can include various aspects that help determine optimal cultivation strategies and make informed management decisions. The directions for the effectiveness of such models are listed below.

1) Physiological growth models: consideration of different plant development phases, such as growth, flowering, and fruiting.
2) Agrotechnical models: determining the impact of different soil treatment methods, irrigation, and fertilization on crop cultivation; modeling optimal timings and methods for applying agro-technical practices.
3) Meteorological models: modeling the impact of weather conditions on phonological processes of crops.
4) Optimization of cultivation: considering various parameters, such as seed varieties, planting density, row spacing, etc., for optimizing cultivation.
5) Yield forecasting models: using machine learning algorithms to forecast yield based on historical data.
6) Spatial and geo-information models: using GIS to model the spatial distribution of crops, considering different soil and landscape characteristics.
7) Resource cost models: mathematical modeling of water, fertilizer, and energy costs during crop cultivation.

Using such mathematical models in online planning systems allows farmers and agronomists to more accurately forecast, plan, and optimize crop cultivation processes to enhance agroecosystem productivity.

Scenario modeling of crop cultivation in online planning systems allows farmers and agronomists to study different scenarios and their impact on crop cultivation to make informed management decisions. Online systems with scenario modeling may include the following elements.

1) Crops: defining the types of crops to be cultivated. Choosing different soil treatment, irrigation, fertilization methods, etc.
2) Distribution parameters: determining the optimal planting density for each crop type. Choosing optimal row placement for maximizing space utilization.
3) Climatic and weather conditions: temperature, humidity, considering different weather scenarios and their impact on crop cultivation, modeling the negative effects of anomalous weather conditions.
4) Resource (weather, fertilizers) dosage: planning optimal irrigation based on weather conditions and crop needs, determining optimal fertilizer doses for growth stages.
5) Pest and disease control measures: modeling scenarios for managing pests and diseases, choice of protection methods.
6) Economic aspects: modeling resource costs and forecasting cultivation expenses.
7) Monitoring and analyzing results: ability to view scenario cultivation results in real-time.

The main value of data lies not in the volumes of raw information but in the well-reasoned actions supported by analytical and forecasting tools, meaning that it is about a digital platform for managing intra-farm data. The digital platform automatically integrates data from various sources, performs analysis, and provides timely, accurate information for assessing the situation and making decisions. Results of production data analysis: reduction in labor costs, increased efficiency, management of production profitability.

Programs for analyzing the obtained information should address issues related to management, accounting, and tax accounting in agriculture and be capable of providing informational support for precision farming technology.

5. ELEMENTS OF A PRACTICAL CASE FOR MANAGING PRODUCTION PROCESSES IN CROP PRODUCTION WITHIN FMIS

To illustrate the described capabilities of FMIS, examples of performing specific management operations and utilizing interconnected data for analytics and decision-making by specialists in agricultural enterprises are provided. Screenshots provided by agricultural enterprises and examples of process modeling within educational cases at PSAU are used.

When implementing the Information System (IS), it is noted that most agricultural enterprises in Ukraine manage several thousand hectares of land and are located in multiple settlements (so-called branches) that belong to one of the natural-climatic zones with characteristic soil types, water balance, etc. General agronomic information is entered into the system during the development and adaptation stages in specific conditions. Information about the enterprise is entered at the beginning of the system implementation. When conducting accounting and planning various agricultural activities, the objects of the IS are certain characteristics of the enterprise's branches, fields, and plots, from which the fields themselves are formed.

The "Fields" directory is one of the key components for further work and is filled after entering data about the branches, as well as based on the directories "Natural Zone", "Soil Types", and "Land Types" along with primary data (area, number, plot type). The directory data are interrelated by specific relationships. For example, when selecting the natural zone of land placement, a list of soil characteristic of that zone is automatically generated.

The Soft.Farm FMIS, like most similar systems, allows for the creation of crop rotation schemes in the enterprise, taking into account modern scientific research in this area. The principle of creating the "Crop Rotation" directory is similar to creating the "Fields" directory, except for the data entry into the "Crop Rotation Steps" column. When forming each crop rotation, the "Crops" directory is used, listing the crops in the rotation scheme and selecting their application period through the built-in Calendar. The formation of crop planting in the electronic environment is shown in Figure 3.

In addition to reference directories, the system includes a more effective toolkit in the form of electronic maps of fields, with the capability to load, process, and manage geodata. The program allows users to create an electronic map of their own farm. Geozone boundaries can be drawn manually or imported from existing GPS measurements [22]. Using all available tools in the program, users can sequentially outline the boundaries of all plots across all fields in all sections.

This figure can be saved in the KLM format for geodata and used in another geosystem or archived. The final saved field will contain all information displayed from the filled directories in a single window (Figure 4).

After completing the aforementioned operations, you can perform various managerial and accounting tasks related to crop cultivation.

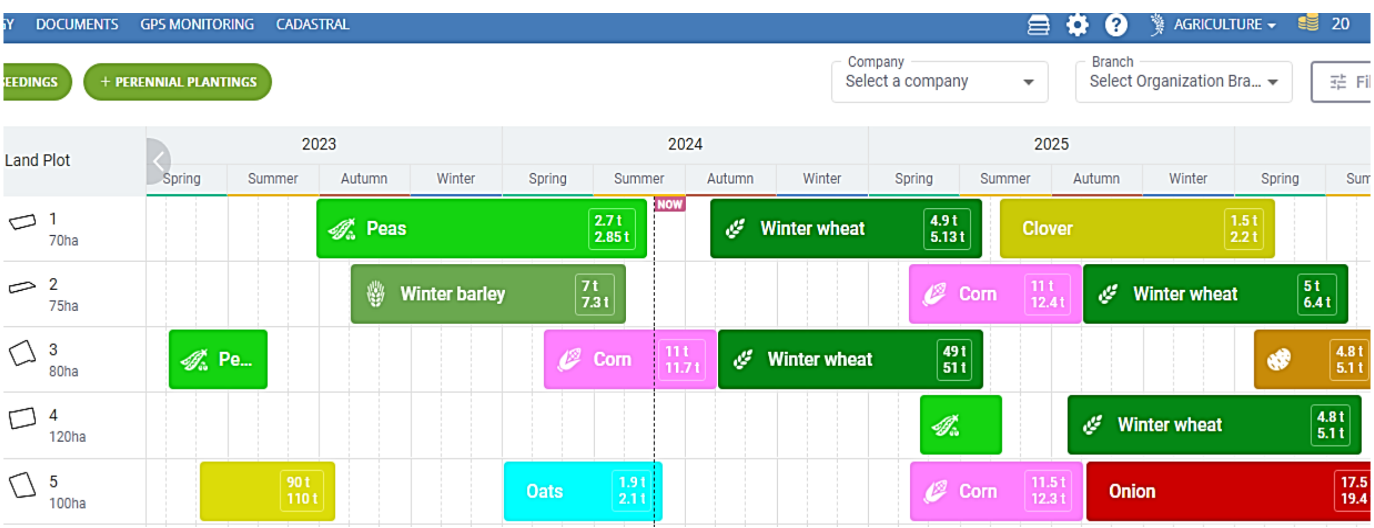

Figure 3. Visualization of the crop planting plan across different fields and plots within the crop rotation scheme

Figure 4. Display of the selected field on the map as a geozone and field passport (farm's example)

A powerful tool is conducting a comprehensive analysis of seeding operations within the "Seeding Control" module. Figure 5 illustrates, as an example, the calculation of the optimal trajectory for a machine with attached equipment during the seeding operation for sunflower cultivation.

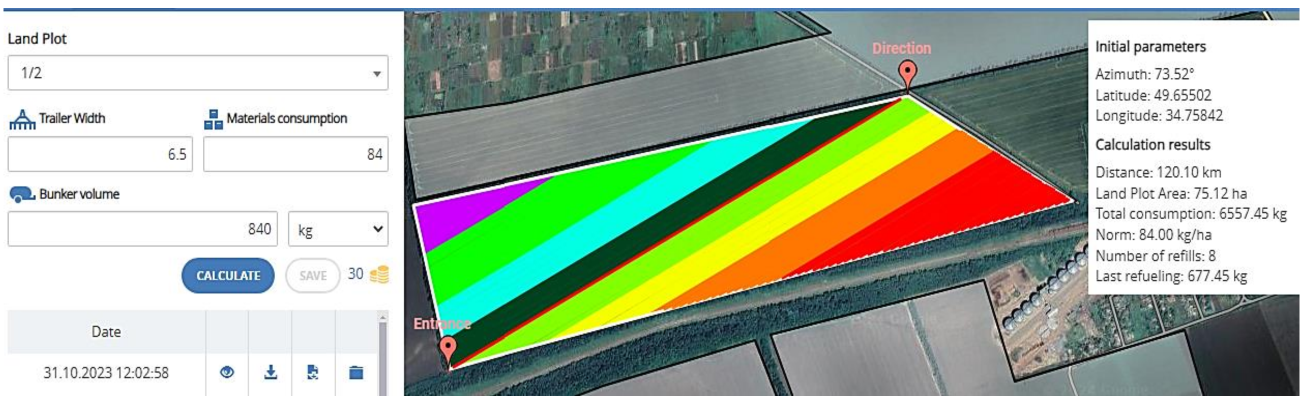

Figure 5. Calculation of the number of passes required by the equipment for performing a specified technological operation in the field

The system automatically calculates the sown area in the field, seed usage, and fertilizer application, as well as the total working time. The result is a planting map that allows for yield planning, differentiated fertilizer application, and an overall assessment of work quality. The planting map displays equipment brands, work quality indicators, daily time expenditures, start/end work times, etc. The "Seeding Control" module supports real-time monitoring of seeding operations during the planting season, including equipment movement, trajectory and others.

The module functions both independently and in conjunction with other subsystems: technological maps, field work planning and closure, material write-off, thus closing accounting indicators and exporting data to accounting systems. Such comprehensive analysis enables the handling of reliable information and the generation of operational reports on work quality

Through the provided examples, it has been demonstrated that the Soft.Farm system, with its modular structure, includes a significant set of tools, directories, and mathematical support, capable of ensuring completeness and flexibility in managing the enterprise's production processes within the system.

An important factor is the ability to exchange documents and data with other systems in standard formats, such as XML, XLS, and others. This enables the future creation of a unified data bank for the enterprise and the expansion and coordination of automation processes on a single platform.

Evaluations of resource savings using various methods (e.g., [20]) have shown significant savings in fuel, labor time, planting material, herbicides, and pesticides due to the use of GPS equipment control and parallel driving technologies, which reduce overlap or gaps in technological operations. According to data released by "Kvart Soft LLC," the official developer and supplier of the Soft.Farm system, significant economic benefits are observed with the use of each module.

Future directions for the system involve the development of yield prediction models based on large volumes of data with the potential application of artificial intelligence, as well as the development of mechanisms for integrating in ERP.

6. CONCLUTIONS

Agriculture, due to objective natural, global technical, and economic processes, is gradually transforming into one of the most science-intensive fields in the context of Agriculture 4.0. It is implementing digital technologies, precision farming systems, and requires modern software, data collection, and monitoring systems based on robust and reliable communications.

The gradual increase in the flow of large data volumes during numerous production operations can only be integrated and efficiently processed on platforms of specialized information management systems.

Evaluating the effectiveness of implementing and using FMIS in agricultural enterprises has shown that the main source of economic effect is improving the accuracy of resource usage accounting (land, fertilizers, plant protection products, seeds, working time, fuel, etc.) and making optimal decisions in managing all processes.
The practical significance of the work lies in conducting a critical analysis of a sufficient volume of scientific and practical material regarding the functional capabilities of information systems intended for implementation and use in managing production processes in the crop sector on a single platform.

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