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Enhancing Agricultural Efficiency and Land Resource Management through Information Systems

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ABSTRACT: Many issues related to the use of land resources have been considered in the context of the possible application of modern information systems to improve the efficiency of agricultural management and ensure food security. The article aims at facilitating the introduction of information systems into the management of land resources in the Republic of Kazakhstan and improving the efficiency of managing its agricultural territories. Based on the analysis of documents and the results of an expert survey, the authors determine the implementation of land management information systems, its main stages and reasons for failures which require solutions through joint efforts of both the state and business. It is concluded that the information support for land management gives a comprehensive idea about the organization of land resources in a particular area, streamlines agricultural land and crop rotations, and helps make informed decisions in the process of land management, provides an opportunity for each participant in the agricultural market of Kazakhstan to quickly obtain accurate, reliable and sufficient information at minimum cost. The obtained results will to understand Kazakhstan's experience in the field of land resource management and apply it to the development of national management information systems.

Keywords: Agriculture; Agricultural enterprise; Food security; Management information systems; Sustainability.

I. INTRODUCTION

The expediency of introducing information support for land management is determined by scientific and technological progress in the field of agriculture [1,2], geodesy and cartography [3], irrigation [4,5], the development of GIS technologies [6], energy industry [7] and the need to improve the efficiency of land management [8,9]. The informatization of land use can be represented as a set of organizational, economic, scientific, and technical processes aimed at creating conditions that satisfy the information needs of this process based on the development and implementation of information technologies [10,11].

The issues of building and implementing management information systems with the development of modern technologies increase scientific interest from the viewpoint of management [12] and from the perspective of improving technical means. The latter is the subject of research by specialists in the high-technology industry [13]. Considering the above, it is relevant to study the conditions and features of implementing the management information system in the processes of managing agricultural land at the level of consumers of modern software to identify problem areas and find ways to overcome them. Our research primarily aims to understand how to improve the information system for land resource management. The necessity, or rather the evident need, for the development of information systems is recognized by researchers as an objective situation. However, developing such systems in practice, based on the experience of countries like Russia, Kazakhstan, and Belarus, is challenging due to the lack of coordination, incomplete data, limited access to information, and dependence on "manual management," where decisions are made by the territory's leader based on personal judgment. These issues hinder effective land information management, leading to delays in obtaining land rights, project rejections, and an increased risk of errors in data collection and maintenance.

In this context, special attention must be given to monitoring issues, specifically the need for constant updates considering social changes, which presents a significant challenge for maintaining data relevance and accuracy. Addressing these issues requires optimizing data dissemination processes, establishing institutional agreements, and implementing digital cadasters to improve access to cadastral information and enhance overall land resource management. Efforts to develop Land Information Management Systems (LIMS) are aimed at overcoming these challenges by providing standardized methods for the efficient collection, recording, and dissemination of land-related data.

II. LITERATURE OVERVIEW

The concept of management information system is extremely flexible since this category is interpreted in the general theory of systems as a means of ensuring effective communications between the object and the subject of management activity [14,15]. In recent years, there has been a significant increase in scientific and practical interest focused on finding ways to effectively manage land resources. The situation is gradually changing, as research efforts have been directed toward developing scientifically based policies aimed at promoting the efficient use of land resources worldwide and achieving sustainable development [16]. However, the adoption of effective management decisions requires compliance between the procedures for analyzing, evaluating, and forecasting the processes of managing and using land resources and the results of the financial and economic activities of enterprises [17-19]. In this regard, the main task of this information system is as follows: to collect information from various internal and external sources [20]; to register, process, and provide information characterizing the state of production and its management [21,22]; to distribute information between specialists and managers, departments and performers in accordance with their participation in the production and management processes [23]. In the context of our research, we considered it important to highlight the areas of agricultural and land resource management that are actively developing in Kazakhstan and Russia. The formalization of the land inventory process aims to increase the efficiency of land inventory by reducing the volume of surveying through the use of an information model and GIS [24]. This helps make timely and reasonable decisions at various levels of management both territorial and economic [25,26].

Another important area of information support for the efficient use of agricultural land [27] is directly related to the improvement of agricultural operations and processes. According to O.S. Lazareva and A.A. Artemyev [28], the introduction of management information systems by agricultural land resources is associated with the identification of sown areas and the costs of their maintenance since sown areas change their properties over time under the influence of some factors (natural, economic, and political) [29,30]. The processes of regulation and management depend on the availability of objective, reliable, and updated information on durable means of agricultural production [31]. The main resource of agricultural production is biological assets that emerge and decline, have their own terms of use and renewal [32], biochemical and geographical characteristics [33,34], etc. Therefore, information certainty depends on the technical characteristics introduced into the technical projects of information systems [35].

Information about the state of land plots and plants obtained from ground sources is subjective [36], i.e. in many cases it does not reflect reality and changing climatic conditions affecting the receipt of data on the volume of land resources (sown areas) and the establishment of land use regimes [37], the data obtained with the help of satellites improve the monitoring of agricultural lands. Therefore, various researchers highlight the importance of implementing an information system to ensure land monitoring. This means of control checks the biological state of crops, the cartography of the terrestrial part of plants, and the development of geoinformation technologies in the cartographic analysis of irrigated lands [38].

The informatization of agricultural land management and use provides for the introduction of the management information system [39,40]. The latter is based on software that best meets the requirements for effective document management and information exchange on a given agricultural land. As stated in [41], the management information system can be a software package that consists of modules covering all areas of agricultural land use and their interaction in real time. In this mode, the monitoring of this process is significantly improved and it becomes possible to fix the corresponding indicators of the system for further evaluation [42,43]. For example, the Digital Agricultural Knowledge and Information System (DAKIS) employs digital technologies to support decision-making towards diversified and sustainable agriculture by integrating remote sensors and on-site sensors, artificial intelligence, modeling, and sustainability impact assessment through broad participation [44]. The PestNu architecture and OpenHub platform are examples of systems designed to facilitate knowledge sharing among subject matter experts and promote best practices [45]. Additionally, Agricultural Information Systems (AGRIS) are discussed as catalysts for achieving ESG goals in Africa, emphasizing the need for well-developed AGRIS to overcome challenges impeding agricultural development [46,47]. Finally, the effectiveness of implementing precision agriculture systems on agricultural enterprises is highlighted for their potential to enhance productivity and sustainability [48].

According to the results, the economic efficiency of the management information system being implemented is determined by cost and labor indicators. The main method of calculation is to compare both the initial and reporting data [49]. Since the implementation of management information systems is the result of a design concept, their performance is assessed through the project performance indicators that justify the ratio of invested capital and income expected from implementing the system [50]. Most scholars emphasize the following criteria: net present value (NPV) [26,51], profitability index (PI) [19], payback time (T) [22], and the internal rate of return (IRR) [22,52].

The effectiveness of the information support subsystem within the management information system (as an intellectual subsystem) is determined by the management quality improvement factor, i.e. a conditional value that characterizes the ratio of management quality compared to the previous indicator before the introduction of the new system. It is identified by the indicators of reducing the time spent on collecting information, processing and delivering it to users, as well as on analyzing and making managerial decisions. It is also necessary to fix the level of competence [53] and other factors of managerial experience at the time the system was implemented and after it [25]. The functioning of such a system at the control object creates conditions for improving the forms and methods of control.

The presented criteria and examples of the use of information systems in agriculture and land management allow us to conclude that the next stage of their development is the integration of data from government authorities, citizens, businesses, and other sources on a single platform; the creation of open databases; the multipurpose use of processed information results, and their accessibility. Information efficiency is determined by the cumulative effect of information activities and the use of information since these processes are a component of effective management decisions [15,54,55].

The conducted literature review shows that a number of applied issues remain unresolved, not only across different countries but also across different continents. The general trend is that the integration of various systems enables the application of a cross-functional approach to the use of information systems for improving methods of agricultural and land resource management. In particular, the Republic of Kazakhstan is at the stage of actively developing information systems in land management processes and cadastral planning. Researchers and practitioners are focusing their efforts on identifying bottlenecks in the development of projects to enhance their effectiveness in land management.

The research question in the article is formulated as follows: "*Is it possible to improve the efficiency of land, agriculture and territory management based on the implemented state information solutions in the Republic of Kazakhstan?*"

In this regard, the purpose of the article is to determine the ways of implementing information systems in land management in Kazakhstan and increasing the efficiency of managing its agricultural territories.

III. METHODS

To achieve the stated goal, we conducted a thematic study based on qualitative methods of information collection and utilized correlation methods for evaluating the obtained information.

At the first stage of the study, we analyzed scientific sources on using information technologies in land management from January 15 to February 15, 2023. Special attention was paid to the functioning of the automated information system of the State Land Cadastre (AIS SLC) [56].

At the second stage of the study, we considered the Internet resources of 29 district akimats of the Almaty Region, Karaganda Region and Kyzylorda Region in the period from February 16 to March 5, 2023. Subsequently, we selected akimat employees responsible for agricultural land management. The sampling consisted of 36 respondents who were sent emails indicating the objective and program of the study; 33 of them agreed to participate in the survey. Next, we selected 35 farm and peasant households and sent similar emails to their managers with relevant experience, receiving 24 completed questionnaires in response. The final group of respondents consisted of researchers and university staff in the fields of agrotechnology, land management, environmental studies, and information technology. Forty questionnaires were sent out, of which 34 completed questionnaires were returned. Thus, 91 experts participated in the study.

At the third stage of the study, we surveyed the respondents from March 6 to April 1, 2023. The questionnaires were sent by e-mail and included the following open-ended questions:

1. Are management information systems being implemented by land resources in your area?
2. What are the results of introducing management information systems controlling land resources in your area?
3. Describe the algorithm for developing and implementing the management information system by land resources.
4. 4. What are the main reasons for failures in the implementation of the management information system by land resources?

After completing the survey, we asked the experts to assign points to their answers and arrange them on a scale of order, depending on the significance of the results of implementing the management information system by land resources and the reasons for their failures. According to the calculated scores, we ranked each result of implementing the management information system and the reasons for their failures. For a more objective analysis, we measured the consistency of expert opinions using the Kendall concordance coefficient (W), which was calculated using the SPSS software. Based on the expert ranking, we determined the impacts of expert opinions.

To determine the minimum sample size for the expert survey, involving at least 91 experts, it is necessary to calculate whether this number is sufficient to confirm the non-randomness of the expert agreement using the Pearson Chi-Square test [57]. The formula (Equation 1) to calculate the actual Pearson Chi-Square statistic is:

$$Chi - Square = \frac{W \times m \times (n-1)}{1-W} \quad (1)$$

where W is the coefficient of concordance, m is the number of experts, and n is the number of items ranked.

IV. RESULTS

1. AIS SLC

At the national level, the AIS SLC is the main management information system in Kazakhstan.

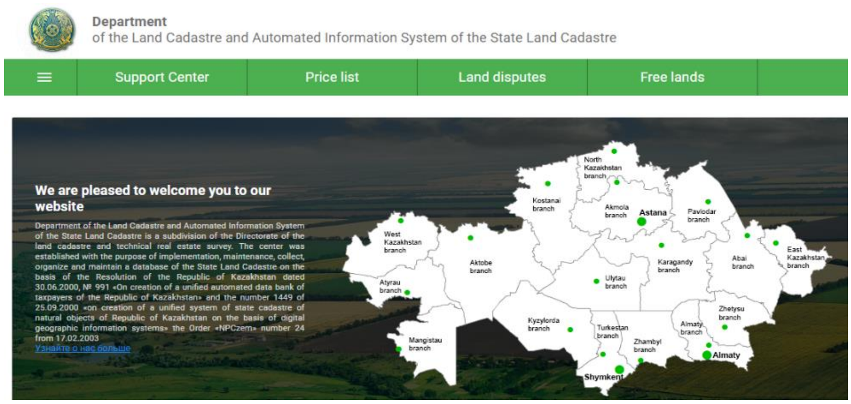

FIGURE 1. Main Page of the Website: Management of the Automated Information System of the State Land Cadastre and Technical Inspection

The management of the Automated Information System of the State Land Cadastre and Technical Inspection has been implemented to coordinate efforts in the creation, development, implementation, and maintenance of the AIS SLC, as well as in the collection of land cadastral information into the AIS SLC databases at all levels. The direct maintenance of the AIS SLC at all levels, including the district level, is carried out by the organization's structural subdivisions (Figure 2).

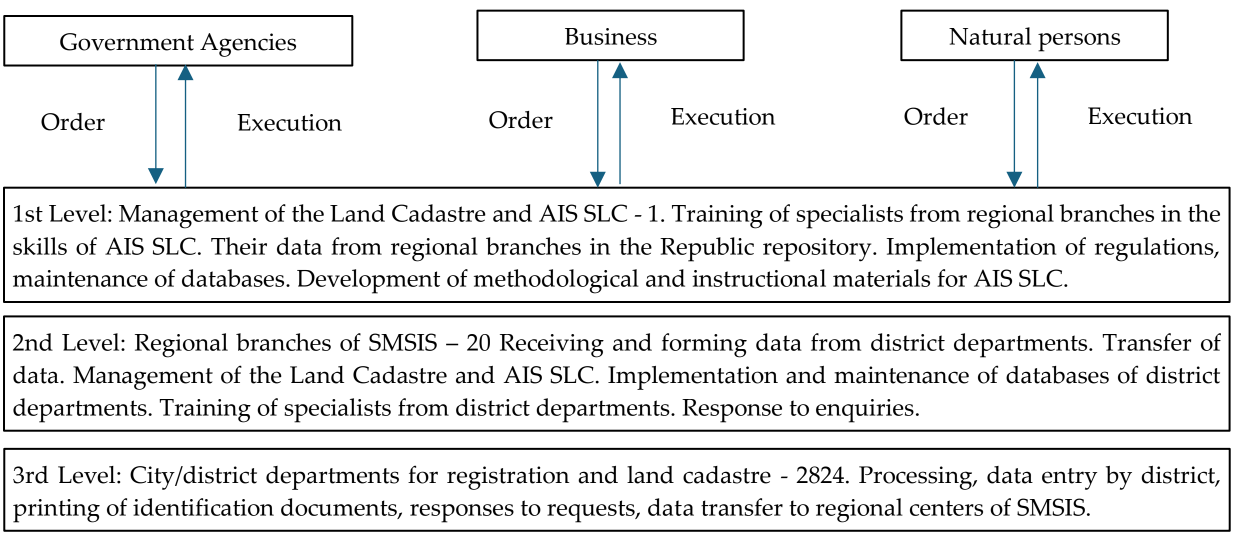

FIGURE 2. Structural and Functional Diagram of the Implementation of the Automated System for Maintaining the State Land Cadastre

Its basic tasks include:

– To fill the system with graphic information and eliminate topological errors.

– To increase the relevance and reliability of the information in the AIS SLC database. Between 2021 and 2022, the following activities were conducted: to modify the "Work with users" subsystem in terms of interaction with the "Integrated database" information system; to update integrated cooperation software for public services provided through the "e-Government" portal (launched on December 30, 2021); to improve business processes for the formation and maintenance of a land balance. As of December 1, 2021, 6.73 million attributive land plots were registered in the Republican database of the AIS SLC, including 5.18 million plots in operation and 5.12 million of them in the graphic database. 99.3% of this database consisted of attributive and graphic data. Since the main users of this information are state bodies and institutions, they can receive online data on owners (users) of land plots, as well as a group of owners throughout Kazakhstan.

2. *THE IMPLEMENTATION OF MANAGEMENT INFORMATION SYSTEMS BY LAND RESOURCES AT AGRICULTURAL ENTERPRISES IN KAZAKHSTAN (SURVEY RESULTS)*

In relation to the introduction of management information systems by land resources at the level of agricultural enterprises in Kazakhstan, such companies actively implement navigation and control technologies that are aimed at managing costs in the technological processes of growing crops and tillage [58]. Technologies of precise farming or rational land use have been introduced in 13% of agricultural enterprises in Kazakhstan (where the respondents work). According to one of the experts, the basic solution of technical projects for the implementation of such systems requires information about the location, shape, size, and other characteristics of agricultural land.

According to the expert survey, the effectiveness of a rational farming system is achieved under the condition of efficient land use, where one of the key factors is the introduction of management information systems focused on the following results (Table 1).

Table 1. The results of implementing the management information system for land resources.

No.	Results of implementing the management information system	Ranking	Impact
1	Obtaining data on the efficient use of land resources	1	0.33
2	Identifying degradation sites (uncultivated areas, waterlogged lands, excess green mass, etc.)	2	0.25
3	Support for optical and radar data from remote sensing of soils	3	0.20
4	Determining the condition and assessing the quality of plants	4	0.13
5	Accounting for external impacts	5	0.09

Note: compiled based on the expert survey; the concordance coefficient W = 0.72 ($p < 0.01$), which indicates a strong consistency of expert opinions.

To determine the minimum sample size for an a priori ranking of 5 results of implementing land management information systems with the participation of at least 91 experts, we calculated if this number of experts is sufficient to confirm the non-randomness of the expert agreement with the Pearson Chi-Square test. Given that W is 0,72, the Pearson Chi-Square test is equal to 932.57. Since 932.57 is much greater than 16.919 (the critical value for 4 degrees of freedom at a significance level of 0.05), the number of experts ($m = 91$) is sufficient to confirm the non-randomness of the expert agreement based on the Pearson criterion.

When analyzing the expert answers, we concluded that the development and implementation of a management information system for land resources at the level of an individual agricultural enterprise includes the following stages (Table 2).

Table 2. The stages of developing and implementing management information systems by land resources.

No.	Stage	Content
1	Survey and assessment of agricultural land	The preliminary survey and assessment of agricultural land (data collection and activity analysis, development of a business process model, identification of the main elements of the management system and technology, forecasting the behavior of the management information system, development of a business process model "as it should be", determination of requirements for the future behavior of the management information system)
		The preliminary preparation for implementation (a concept for developing the management information system is being made, including the stages of creating such a system, its content, ways to adapt existing automated control systems, an implementation model, identifying and agreeing on ways to reorganize the management system and ways to develop information technologies)
		When building a model, they are guided by a finished product (a fully developed system or the adaptation of a ready-made software package) or a hybrid model (a part of the system is developed to order, and the other part is realized by a ready-made package)
2	Designing a management information system	Developing terms of reference outlining all the main parameters of the project and its completion schedule is the basis for the preliminary design that describes management and information relationships within the system. After the approval, it is possible to design and implement selected subsystems (by business processes or departments) to reduce the time for obtaining a result from the implemented technologies. The terms of reference for subsystems are specified and implemented until the trial operation is completed
		Developing a technical project of the management information system, i.e. a process in which a business model of the management information system is built within specific subsystems. A technical project is a documentary description of the technical characteristics of the management information system, including technical indicators of the project. It should describe workplaces with the business operations assigned to them; database structure, data relationships, and processing algorithms; the number of users; characteristics of the required equipment and software
3	Introducing automated control systems	The formation and training of the customer's project team to support the automated control system and train other users
		Testing the automated control system, including an experiment on its operation (using bench equipment or prototype) with the technical setup of typical workplaces, trial data conversion, and operational commissioning
		Start-up work (software configuration; the creation of additional modules in accordance with the technical design; training users of workplaces; proving technical configuration at workplaces; industrial data conversion; operation)
		Drawing up an act on putting into commercial operation (according to the relevant results of trial operation, the project for the implementation of land management information systems will be completed)
		Support for the information management system (by in-house or freelance specialists, for several months until the system is fully debugged)

Thus, the expert survey proved that large- and medium-sized agricultural lands in Kazakhstan have experience in implementing management information systems of different complexity. However, the use of such software is not always effective, as evidenced by lower-than-expected indicators of economic and social efficiency. According to the experts, the main reasons for failures in the implementation of the management information system are presented in Table 3.

Table 3. Reasons for failure when implementing the management information system.

No.	Reasons for failure	Ranking	Impact
1	Shortcomings in the implementation of the management information system	1	0.36
2	The lack of a single leading center for the implementation of the management information system	2	0.27
3	The lack of interest of the top management in organizational changes and optimization of business processes for the use of land resources	3	0.22
4	Insufficient support from the top management of agricultural enterprises in implementing the management information system at different stages	4	0.15

Note: compiled based on the expert survey; the concordance coefficient $W = 0.68$ ($p < 0.01$), which indicates a strong agreement of expert opinions.

To determine the minimum sample size for an a priori ranking of 4 reasons for failure when implementing a management information system with the participation of at least 91 experts, we calculated if this number of experts is sufficient to confirm the non-randomness of the expert agreement with the Pearson Chi-Square test. After the calculation, the Pearson Chi-Square test is equal to 580.13. Since 580.13 > 7.815 (the critical value for 3 degrees of freedom at a significance level of 0.05), the number of experts ($n = 91$) is sufficient to confirm the non-randomness of the expert agreement.

V. DISCUSSION

According to the survey results, the main reasons for failures in the implementation of management information systems (Table 3) are as follows:

– Shortcomings in the implementation of management information systems, in particular in the optimal number and professional composition of project teams for each functional area of agricultural land use. According to one expert, whose opinion aligns with the research results [59], each group should include leading specialists (employees of agricultural enterprises) and specialists from the company developing the relevant software. In Kazakhstan, pilot projects have demonstrated the effectiveness of a functional approach. For example, the implementation of GPS-guided equipment and remote sensing technologies in wheat-growing areas has led to more efficient land use and resource management. According to a report by the Food and Agriculture Organization (FAO) [60], farms that adopted precision agriculture technologies reported a 25% reduction in fertilizer use and a 15% increase in water use efficiency.

– No single center for implementing the management information system, whose participants are responsible for forming a unified concept of information support for all structural divisions; preparing and coordinating contractual relations between representatives of agricultural enterprises and software developers [61]; timely delivery of hardware and technical means for the implementation of the management information system; adjusting a schedule for implementing system modules by project teams [62], as well as identifying and minimizing unforeseen financial costs at all stages of the implementation and maintenance of the management information system [13].

The obtained results enable us to draw several conclusions that help to understand the systemic issues in implementing information systems for agricultural and land resource management.

1. TECHNICAL PROBLEMS: THE COMPLEXITY OF ADAPTING BOTH READY-MADE SOLUTIONS AND DEVELOPING NEW MODULES

When discussing the reasons for failures in the implementation of management information systems by land resources, one of the experts highlighted the acquisition of finished software as an additional difficulty. In the case of implementing a ready-made management information system, it is necessary to adapt the existing management system to the finished software. Adaptation takes place if a decision is made to modify the existing system. If the existing system is abandoned and it is decided to adopt a fundamentally new one, its implementation is gradual and the previous system is preserved with step-by-step changes, as opposed to a complete transition to an uncontrolled new version.

Modern studies of management information systems also highlight that the choice of new software covers additional issues related to its compatibility and integration with existing applications: compatibility with the software and the information support system that exists in a particular enterprise [63]; the possibility of integrating the new program into its information environment; the rational choice and sufficient rating of the software developer; the compatibility of this software with the existing hardware capabilities and platforms; capacity to maintain the existing program [11].

According to one of the experts, the development of management information projects for land resources is based on system-wide approaches and technical features of the designed equipment and software. Therefore, the flexibility and openness of such software should be ensured at the stage of its design since negative consequences can occur during the operation of the management information system, in particular during the formation and preparation of reports for both top management and external organizations. In this case, the interaction of functional units in real time is achieved through the integration of modules that are carriers of information about the possible use of land resources. The effectiveness of implementing this approach will depend on the integration of accumulated experience, resources, and the administrative capabilities of government bodies. As research indicates, in Russia, a systematic and scalable approach to incorporating information obtained from various sources enables the development of land monitoring to address land management tasks and to forecast various aspects of territorial development, thereby reducing the environmental impact.

2. *STRUCTURAL PROBLEMS: UNEVEN REGIONAL DEVELOPMENT AND A SHORTAGE OF SKILLED PERSONNEL*

One of the primary issues is the underdeveloped information and communication infrastructure in rural areas of Kazakhstan, which hinders the effective implementation and use of digital technologies in agriculture [64]. As our research has shown, this problem is exacerbated by a lack of qualified personnel necessary for the implementation and maintenance of these digital systems, as well as a general disinterest among enterprises in training targeted personnel for digital agriculture. The agricultural sector also suffers from the use of outdated equipment and technologies, both physically and morally, which further complicates the transition to modern information systems [65]. The situation is worsened by the improper use of data analysis methods and the lack of engagement in intelligent data analysis, which is crucial for competitive and efficient agricultural practices [66]. Efforts to overcome these challenges are further impeded by the slow adoption of innovations and advanced technological developments, attributable to various factors including the slow pace of reforms and insufficient implementation of government programs aimed at supporting science, technology, and innovation [67].

Despite the potential economic benefits of digital devices in the agro-industrial complex, these technological and structural problems must be addressed to fully develop modern trends in digital agriculture in Kazakhstan. In particular, the integration of artificial intelligence (AI) and the Internet of Things (IoT) into agricultural practices in Kazakhstan could significantly transform agricultural and land resource management. The introduction of AI in Kazakhstan's agricultural sector is actively being incorporated into production processes, including the development of unmanned vehicles and agricultural machinery, indicating a significant shift towards technologically advanced farming methods [68]. The digitalization of the energy and agro-industrial complex in Kazakhstan, including the implementation of digital farms, contributes to economic growth, highlighting the importance of econometric modeling in understanding the impact of energy production and digital technologies on agricultural production [69]. Collectively, these developments signify a transformative phase in Kazakhstan's agricultural sector, driven by artificial intelligence and the Internet of Things, leading to increased productivity, sustainability, and economic growth.

VI. CONCLUSION

Information support for land management gives a comprehensive idea about the organization of land resources in a particular area, streamlines agricultural land and crop rotations, and helps make informed decisions in the process of land management. The management information system for land resources aims at providing an opportunity for each participant in the agricultural market of Kazakhstan to quickly obtain accurate, reliable, and sufficient information at a minimum cost. The lack or insufficiency of high-quality information on the current state of affairs in the agricultural sector leads to the fact that the labor and resource costs invested in agriculture over a long period can result in direct losses and aggravate the management of these territories.

In this connection, the research results will optimize cost and time resources for the implementation of the management information system by the processes of land use, free up management personnel to solve current problems, and, ultimately, contribute to economic and social effects from the implementation. It is particularly important to note that the development of information systems in agriculture, particularly through precision farming, provides significant sustainability and environmental benefits for the Republic of Kazakhstan. Continuous investment and the expansion of these technologies, coupled with careful management of their implementation and operation, will be crucial for maximizing their positive impact on sustainability.

The limitations of the study, which must be considered when interpreting the results in the following: we used information that was collected from open sources and on its basis the analysis of the work of the AIS SLC was carried out, therefore, if additional data were available, the existing results section could have been presented more deeply. Depending on the structural features of the functioning of a particular information system, the results obtained will differ. In addition, from the point of view of the method of collecting information, we didn’t use data from mass surveys of users of this system but focused on the opinion of developers and experts in this field. On the one hand, this is a disadvantage, but on the other hand, we wanted to get an expert opinion in the field of development of this system, first of all, those people who influence its development and have a certain status. Further research should focus on the possibilities of using application programs to control the implementation of management information systems of different complexity by Kazakh agricultural enterprises.

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Author Contributions

All authors have contributed equally

Conflict of Interests

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