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ECONOMIC EFFICIENCY OF DIGITAL MANAGEMENT SYSTEMS IN CROP PRODUCTION IN KAZAKHSTAN

The article discusses the issues of economic efficiency of the introduction of precision farming elements and production management systems in the crop-growing sub-sector of the agro-industrial complex of Kazakhstan. Modern approaches to the digitalization of production process management are analyzed and the results of the application of information and management technologies in farms in the northern regions of the country are summarized. The scale of the introduction of precision farming elements in Akmola, North Kazakhstan and Kostanay regions is considered, which made it possible to identify regional features and uneven distribution of digital solutions. The study analyzed the economic effects of the introduction of key elements of precision agriculture, including automatic and parallel driving systems, differentiated application of fertilizers and plant protection products, as well as fuel consumption control systems. It is shown that the use of these technologies reduces production costs and increases the resource efficiency of crop production. Based on economic modeling, the effectiveness of the implementation of integrated production management systems in farms with different levels of technical equipment has been determined. It has been revealed that digitalization of management helps to reduce costs regardless of the scale and technical level of farms, with an acceptable payback period for investments. The methodological basis of the research includes methods of comparative, economic and system analysis, as well as generalization of statistical and analytical data. The results obtained confirm the importance of digital management solutions for increasing the sustainability and competitiveness of the crop-growing sub-sector of the agro-industrial complex. The practical significance of the study lies in the possibility of using the conclusions obtained by agricultural producers and management bodies in substantiating investment decisions in the field of digitalization of agricultural production.

Keywords: crop production, agro-industrial complex, production management, precision agriculture, digitalization, economic efficiency, regions of Kazakhstan.

Кілт сөздер: өсімдік шаруашылығы, агроөнеркәсіптік кешен, өндірісті басқару, нақты егіншілік, цифрландыру, экономикалық тиімділік, Қазақстан өңірлері.

Ключевые слова: растениеводство, агропромышленный комплекс, управление производством, точное земледелие, цифровизация, экономическая эффективность, регионы Казахстана.

Introduction. The modern development of Kazakhstan's agro-industrial complex is taking place in the context of increased global competition, rising production costs, climate instability and increasing demands on the sustainability of food systems. Under these conditions, improving the efficiency of production process management in crop production is becoming one of the key scientific and practical tasks directly related to ensuring food security, competitiveness of the agricultural sector and sustainable rural development.

Traditional approaches to production management, based primarily on intuition and accumulated experience, increasingly meet modern challenges and require transformation based on digital and information technologies.

Of particular importance in this context is the introduction of precision farming elements and integrated production management systems that ensure a differentiated approach to resource use, increased transparency of production processes and the validity of management decisions. At the same time, despite the active development of digital solutions in the agricultural sector, the level of their implementation in Kazakhstan's crop production remains uneven, and issues of economic efficiency and payback of management systems require additional scientific justification. This determines the relevance of the

research aimed at analyzing and evaluating the effectiveness of digital production management tools in the crop-growing sub-sector of the agro-industrial complex.

The purpose of this study is to substantiate the economic efficiency of using precision farming elements and production management systems in crop production based on an analysis of their impact on reducing costs and improving the manageability of production processes.

To achieve this goal, the following tasks have been solved:

- the scale of the introduction of digital technologies in crop production in the northern regions of Kazakhstan is analyzed;
- the main directions of the economic effect from the use of precision farming elements have been identified;
- an assessment of the effectiveness of production management systems is given, taking into account the level of technical equipment of farms.

The methodological basis of the research consists of methods of comparative and economic analysis, generalization and systematization of scientific data, as well as economic modeling. The materials of regional agricultural management bodies, data from demonstration farms and the results of previous scientific research were used as an information base. The use of these methods made it possible to ensure reproducibility of the results and to form reasonable conclusions about the expediency of digitalization of production management in crop production.

Literature review. The issues of digitalization of the agro-industrial complex and increasing the efficiency of production management in crop production are widely represented in modern scientific research, but remain highly relevant in the context of economic transformation and increasing demands on the sustainability of the agricultural sector. A number of works emphasize that digital technologies are considered as a key factor in modernizing agricultural production and increasing its competitiveness. For example, in a study by Smagulova et al. It is shown that the digitalization of agro- and energy complexes in Kazakhstan creates new opportunities for optimizing resources and increasing production efficiency, but its development is hindered by institutional and technological constraints [1]

In the works of Kabdullina et al. The agricultural sector is analyzed in the context of food security, which emphasizes the role of production efficiency and regional differences in ensuring sustainable agricultural development [2,3]. These studies confirm that without the introduction of modern management and technological solutions, cost reduction and productivity growth remain limited. The economic aspects of the impact of production conditions on grain yields are discussed in detail in the work of Kussainov et al., where the high sensitivity of crop production results to managerial and technological factors is proved [4].

A separate area of research is related to the relationship between digitalization, sustainable development and resource efficiency. In the works of Kurmanov et al. it is shown that technological innovations and rational resource management are an important prerequisite for sustainable economic growth and food security [5]. At the same time, Tsapova et al. they point to the industry specifics and systemic problems of digitalization of the agro-industrial complex of Kazakhstan, including the uneven introduction of technologies and the lack of managerial competencies [6]. The institutional aspects of the functioning of the agro-industrial complex are also considered as a significant factor in the effectiveness of management [7].

At the same time, despite the existence of a significant body of research, the issue of a comprehensive assessment of the economic efficiency of production management systems in crop production based on the integration of precision farming elements remains insufficiently developed. This necessitates further research aimed at substantiating the economic effects of digital management decisions, taking into account regional and industrial specifics, which determines the choice of the topic of this study.

Main part. The modern development of the crop-growing sub-sector of the agro-industrial complex of Kazakhstan is increasingly determined by the introduction of digital and information technologies aimed at improving the efficiency of production process management. In conditions of high dependence of agricultural production on natural and climatic factors, fluctuations in yields and resource constraints, the use of precision farming elements that provide a differentiated approach to managing agrotechnological operations is of particular importance.

Digitalization of production management in crop production is aimed at optimizing the use of material, labor and energy resources, increasing the transparency of production processes and the validity of management decisions. At the same time, the level of implementation of modern technologies in

agricultural farms remains heterogeneous and varies significantly by region, which requires an analysis of the scale and specifics of their application in key grain-producing regions of the country.

In this regard, the study examined the northern regions of Kazakhstan - Akmola, North Kazakhstan and Kostanay regions, which account for the bulk of grain production. The analysis of regional data makes it possible to identify current trends in the introduction of precision farming elements and assess their impact on production management efficiency.

A comparative description of the spread of precision farming elements in the northern regions of Kazakhstan is presented in Table 1. The data reflect the number of farms using digital solutions, as well as the area of agricultural land covered by the relevant technologies.

Table – 1

Indicators of the introduction of precision farming elements in the northern regions of Kazakhstan*

Region	Number of farms, units	Share of farms, %	Coverage area, thousand hectares	Share of the sown area, %
Akmola	106	2.4	1 469.3	27.7
North Kazakhstan	198	–	2 407.9	55.2
Kostanay	78	1.5	935.4	17.8

**compiled by the authors on the basis of data from regional departments of agriculture*

An analysis of the data in Table 1 shows a significant differentiation in the levels of implementation of precision farming elements between regions. The highest degree of coverage of acreage was recorded in the North Kazakhstan region, where the use of digital technologies covers more than half of the region's acreage (55.2%). This indicates a higher technological readiness of farms and the scale of agricultural production, which make it possible to compensate for investment costs due to economies of scale.

In the Akmola region, the share of farms using precision farming elements remains relatively low (2.4%), but the coverage area reaches 27.7% of the total sown area, which indicates the concentration of digital technologies mainly in medium and large farms. A similar situation is observed in Kostanay region, where, with a share of farms of less than 2%, digital technologies cover 17.8% of the acreage.

Thus, the regional analysis confirms that the introduction of precision farming elements in Kazakhstan is of a focal nature and is primarily related to the scale of farms, the level of their technical equipment and investment opportunities. This creates the prerequisites for a subsequent analysis of the economic feasibility of using individual digital solutions in crop production management.

The economic feasibility of using precision farming elements in crop production management is manifested primarily in reducing current production costs through more rational use of resources. Table 2 summarizes the results of the assessment of the economic impact of the introduction of key digital solutions used in the farms of the northern regions of Kazakhstan.

Table – 2

Cost savings from the introduction of precision farming elements

The element of precision farming	The main saving item	Economic effect
Parallel driving system	Labor, fuel, materials	170.7 tg/ha
Automatic driving system	Labor, fuel, materials	1,041.4 tg/ha
Differentiated fertilization	Material resources	1,079.3 tg/ha
Fuel consumption monitoring system	Fuel and lubricants	up to 3,460 tg/ha (≈4% of costs)
Differentiated application of plant protection products	Plant protection products	up to 3,500 tg/ha

** calculations are based on data from demonstration farms*

An analysis of the data in table 2 shows that the greatest economic effect is achieved through the introduction of technologies that directly affect the reduction of consumption of material and energy resources. Thus, the use of automatic driving systems provides savings of over 1,000 tenge per hectare by reducing overlaps during agrotechnical operations, optimizing vehicle routes and reducing labor costs. A

similar effect is demonstrated by differentiated fertilization, which makes it possible to adapt the standards of use of agrochemicals to the actual state of the soil and the needs of plants.

A significant contribution to cost reduction is made by the introduction of fuel consumption control systems, which reduce fuel costs by up to 30%, which in terms of KZT 3,460 per hectare and reaches about 4% of total production costs. The economic effect of the differentiated application of plant protection products is also significant and is formed by reducing the volume of drugs used while maintaining the technological efficiency of crop treatment.

Taken together, the results obtained indicate that the elements of precision farming form a stable direct economic effect, expressed in reducing the cost of crop production. However, the degree of manifestation of this effect depends on the level of technical equipment of farms and the complexity of the implementation of digital solutions, which necessitates the transition from analyzing individual elements to evaluating the effectiveness of production management systems as a whole.

To assess the integral effect of digitalization of production process management in crop production, the study examines management systems adapted to farms with different levels of technical equipment. The generalized results of economic modeling are presented in Table 3.

Table – 3

The effectiveness of the introduction of production management systems in crop production

The level of technical equipment of the farm	Lower production costs, %	Economy, tg/ha	Payback period, years
Low	5.2	3 747.9	3.0
Average	4.9	3 565.6	3.1
High	4.7	3 417.0	3.0

** compiled by the authors based on the results of economic modeling*

The data in Table 3 show that the introduction of production management systems based on the use of digital and information technologies leads to a reduction in production costs in all groups of farms, regardless of the initial level of their technical equipment. The largest relative cost reduction is observed in farms with a low level of technical equipment (5.2%), which is explained by the "low base" effect and the high sensitivity of such farms to the introduction of even basic digital solutions.

In farms with medium and high levels of technical equipment, the cost reduction is 4.9% and 4.7%, respectively, while the absolute savings per hectare remains comparable and exceeds 3,400 tenge. This indicates that as the production process becomes saturated with digital technologies, the additional effect persists, but becomes more stable and systemic.

The payback period for investments in production management systems in all groups of farms is about three years, which confirms their investment attractiveness and practical feasibility in modern agribusiness. The results obtained allow us to conclude that integrated production management systems not only reduce costs, but also form the basis for increasing the sustainability and competitiveness of crop farms.

Thus, the results of the analysis confirm that the introduction of precision farming elements and integrated production management systems has a comprehensive positive impact on the efficiency of the crop-growing sub-sector of the agro-industrial complex of Kazakhstan. The economic effect is manifested both at the level of individual technological operations and on the scale of the entire production cycle, ensuring cost reduction, increased process manageability and the validity of decisions.

The revealed patterns indicate the expediency of phased and differentiated implementation of digital solutions, taking into account the scale of farms, their resource capabilities and the level of technical equipment, which creates prerequisites for the further development of digital management in crop production.

Conclusion. The article discusses the issues of economic efficiency of the introduction of precision farming elements and production management systems in the crop-growing sub-sector of the agro-industrial complex of Kazakhstan. The analysis showed that digitalization of production process management helps to reduce production costs, make more rational use of resources and increase the resilience of farms to external and internal risks. It has been established that the economic effect of the introduction of digital solutions is manifested both at the level of individual technological operations and within the framework of integrated management systems, regardless of the level of technical equipment of farms. The scientific novelty of the study lies in a comprehensive assessment of the direct economic effect and systemic effectiveness of production management in crop production. The results obtained can be used by

agricultural producers and agricultural authorities to justify investment decisions in the field of digitalization. Promising areas for further research are the development of regionally adapted digital governance models and the assessment of the long-term socio-economic effects of digital technologies in agriculture.

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ҚАЗАҚСТАННЫҢ ӨСІМДІК ШАРУАШЫЛЫҒЫНДАҒЫ ЦИФРЛЫҚ БАСҚАРУ ЖҮЙЕЛЕРІНІҢ ЭКОНОМИКАЛЫҚ ТИІМДІЛІГІ

Андатпа

Мақалада Қазақстанның агроөнеркәсіптік кешенінің өсімдік шаруашылығы кіші саласына нақты егіншілік элементтерін және өндірісті басқару жүйелерін енгізудің экономикалық тиімділігі мәселелері қарастырылған. Өндірістік процестерді басқаруды цифрландырудың заманауи тәсілдері талданды және елдің солтүстік өңірлерінің шаруашылықтарында ақпараттық және басқару технологияларын қолдану нәтижелері жинақталды. Ақмола, Солтүстік Қазақстан және Қостанай облыстарында нақты егіншілік элементтерін енгізу ауқымы қарастырылды, бұл цифрлық шешімдердің аймақтық ерекшеліктері мен біркелкі емес таралуын анықтауға мүмкіндік берді. Зерттеу дәл егіншіліктің негізгі элементтерін, соның ішінде автоматты және параллельді жүргізу жүйелерін, тыңайтқыштар мен өсімдіктерді қорғау құралдарын сараланған қолдануды және отын шығынын бақылау жүйелерін енгізудің экономикалық әсерін талдады. Бұл технологияларды пайдалану өндіріс шығындарының төмендеуін және өсімдік шаруашылығының ресурстық тиімділігін арттыруды қамтамасыз ететіні көрсетілген. Экономикалық модельдеу негізінде техникалық жарақтандырудың әртүрлі деңгейлері бар шаруашылықтарда өндірісті басқарудың интеграцияланған жүйелерін енгізудің тиімділігі анықталды. Басқаруды цифрландыру инвестицияларды өтеудің қолайлы мерзімдері кезінде шаруашылықтардың ауқымы мен техникалық деңгейіне қарамастан шығындарды азайтуға ықпал ететіні анықталды. Зерттеудің әдіснамалық негізі салыстырмалы, экономикалық және жүйелік талдау әдістері, сондай-ақ статистикалық және аналитикалық деректерді жалпылау болды. Алынған нәтижелер АӨК өсімдік шаруашылығы кіші саласының тұрақтылығы мен бәсекеге қабілеттілігін арттыру үшін цифрлық басқару шешімдерінің маңыздылығын растайды. Зерттеудің практикалық маңыздылығы аграрлық өндірісті цифрландыру саласындағы инвестициялық шешімдерді негіздеу кезінде алынған қорытындыларды ауыл шаруашылығы тауарын өндірушілер мен басқару органдарының пайдалану мүмкіндігі болып табылады.

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ЭКОНОМИЧЕСКАЯ ЭФФЕКТИВНОСТЬ ЦИФРОВЫХ СИСТЕМ УПРАВЛЕНИЯ В РАСТЕНИЕВОДСТВЕ КАЗАХСТАНА

Аннотация

В статье рассмотрены вопросы экономической эффективности внедрения элементов точного земледелия и систем управления производством в растениеводческой подотрасли агропромышленного комплекса Казахстана. Проанализированы современные подходы к цифровизации управления производственными процессами и обобщены результаты применения информационных и управленческих технологий в хозяйствах северных регионов страны. Рассмотрены масштабы внедрения элементов точного земледелия в Акмолинской, Северо-Казахстанской и Костанайской областях, что позволило выявить региональные особенности и неравномерность распространения цифровых решений.

В ходе исследования проанализированы экономические эффекты от внедрения ключевых элементов точного земледелия, включая системы автоматического и параллельного вождения, дифференцированное внесение удобрений и средств защиты растений, а также системы контроля расхода топлива. Показано, что использование данных технологий обеспечивает снижение производственных затрат и повышение ресурсной эффективности растениеводства. На основе экономического моделирования определена эффективность внедрения интегрированных систем управления производством в хозяйствах с различным уровнем технической оснащенности. Выявлено, что цифровизация управления способствует снижению издержек независимо от масштаба и технического уровня хозяйств, при приемлемых сроках окупаемости инвестиций.

Методологическую основу исследования составили методы сравнительного, экономического и системного анализа, а также обобщение статистических и аналитических данных. Полученные результаты подтверждают значимость цифровых управленческих решений для повышения устойчивости и конкурентоспособности растениеводческой подотрасли АПК. Практическая значимость исследования заключается в возможности использования полученных выводов сельхозтоваропроизводителями и органами управления при обосновании инвестиционных решений в сфере цифровизации аграрного производства.