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TRADITIONAL METHODS AND IT SOLUTIONS IN THE FIELD OF CROP PRODUCTION: COMPARATIVE ASSESSMENT

ӨСІМДІК ШАРУАШЫЛЫҒЫ САЛАСЫНДАҒЫ ДӘСТҮРЛІ ӘДІСТЕРІ МЕН IT-ШЕШІМДЕР: САЛЫСТЫРМАЛЫ БАҒАЛАУ

ТРАДИЦИОННЫЕ МЕТОДЫ И IT-РЕШЕНИЯ В ОТРАСЛИ РАСТЕНИЕВОДСТВА: СРАВНИТЕЛЬНАЯ ОЦЕНКА

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Abstract. The article is devoted to the study of the effectiveness of traditional methods and modern solutions in crop production through the prism of cost, productivity, efficiency and ecology. The *goal* is to identify the advantages and disadvantages of basic principles and quantitative tools in the field of crop production, to determine their role in increasing the intensity and production return of field agricultural technologies. *Methods* - assessment of the effectiveness of classical and innovative approaches to agronomic activity, comparison of scientific literature, system-structural, content-analysis to justify the need for integration of information technologies, taking into account the specifics of the agricultural sector. *Results* - the preservation of the demand for generally accepted strategies in agriculture in the context of regulated access to infrastructure based on analytical work and productivity calculations, optimization of resource use, reduction of the environmental

burden is shown. It was found that their potential is limited by low labor intensity and high labor intensity, and the latest automated systems provide long-term reduction in costs, increasing fertility, crop yields, but require significant investments and training of highly qualified personnel. The introduction of digital services in the Republic is at an early stage, which justifies the need to create an integrated model that combines elements of existing practices with digital platforms, provided that technological innovations are adapted to local conditions. *Conclusions* - within the framework of the interrelated concepts of Real Farming and "smart" agriculture, attention should be paid to the integrated use of various methods, which will lead to constant monitoring of crops, timely introduction of medicines and fertilizers, diagnosis of diseases, planting seeds, a stable increase in the production of crop production. It is important to provide state support for subsidies and benefits to farmers, as well as expand programs for their training and acquisition of new skills.

Аңдатпа. Мақала шығын, өнімділік, тиімділік және экология призмасы арқылы өсімдік шаруашылығындағы дәстүрлі әдістері мен заманауи шешімдерінің тиімділігін зерттеуге арналған. *Мақсаты* - өсімдік шаруашылығы саласындағы негізгі принциптер мен сандық құралдардың артықшылықтары мен кемшіліктерін анықтау, олардың далалық агротехнологиялардың қарқындылығы мен өндірістік қайтарымын арттырудағы рөлін анықтау. *Әдістер* - агрономиялық қызметке классикалық және инновациялық тәсілдердің нәтижелілігін бағалау, аграрлық сектордың ерекшелігін ескере отырып, ақпараттық технологияларды интеграциялау қажеттілігін негіздеу үшін ғылыми әдебиеттерді салыстыру, жүйелік-құрылымдық, контент-талдау. *Нәтижелер* - аналитикалық жұмыс пен өнімділікті есептеу, ресурстарды пайдалануды оңтайландыру, экологиялық жүктемені азайту негізінде инфрақұрылымға регламенттелген қол жетімділік жағдайында егіншілікте жалпы қабылданған стратегияларға сұраныстың сақталуы көрсетілген. Олардың әлеуеті төмен еңбек қарқындылығымен және жоғары еңбек сыйымдылығымен шектелетіні анықталды, ал соңғы автоматтандырылған жүйелер шығындарды ұзақ мерзімді қысқартуды, құнарлылықты, дақылдардың өнімділігін арттыруды қамтамасыз етеді, бірақ айтарлықтай инвестициялар мен жоғары білікті кадрларды даярлауды қажет етеді. Республикада сандық сервистерді енгізу бастапқы кезеңде тұр, бұл технологиялық инновацияларды жергілікті жағдайларға бейімдеу шартымен қалыптасқан тәжірибелердің элементтерін сандық платформалармен үйлестіретін интеграцияланған үлгі құру қажеттілігін негіздейді. *Қорытындылар* - нақты егіншілік пен "ақылды" ауыл шаруашылығының өзара байланысты тұжырымдамалары шеңберінде әртүрлі әдістерді кешенді қолдануға назар аудару керек, бұл дақылдарды үнемі бақылауға, дәрі-дәрмектер мен тыңайтқыштарды уақтылы енгізуге, ауруларды диагностикалауға, тұқым отырғызуға, өсімдік шаруашылығы өнімдерін өндірудің тұрақты өсуіне әкеледі. Фермерлерге субсидиялар мен жеңілдіктерді мемлекеттік қолдау, сондай-ақ оларды оқыту және жаңа дағдыларды игеру бойынша бағдарламаларды кеңейту маңызды.

Аннотация. Статья посвящена исследованию эффективности традиционных методов и современных IT-решений в растениеводстве через призму издержек, производительности, рентабельности и экологии. *Цель* – определить преимущества и недостатки базовых принципов и цифровых инструментов в растениеводческой отрасли, выявить их роль в повышении интенсивности и производственной отдачи полевых агротехнологий. *Методы* – сравнения, системно-структурный, контент-анализ научной литературы для оценки результативности классических и инновационных подходов к агрономической деятельности, обоснования необходимости интеграции информационных технологий с учетом специфики аграрного сектора. *Результаты* – на основе аналитической работы и расчетов урожайности, оптимизации использования ресурсов, снижения экологической нагрузки показана сохраняющаяся востребованность общепринятых стратегий в земледелии в условиях регламентированного доступа к инфраструктуре. Установлено, что их потенциал ограничен низкой интенсивностью труда и высокой трудоемкости, а новейшие автоматизированные системы обеспечивают долгосрочное сокращение затрат, увеличение плодородия, продуктивности сельскохозяйственных культур, однако требуют значительных инвестиций и подготовки высококвалифицированных кадров. Отмечается, что в республике внедрение цифровых сервисов находится на начальном этапе, что обосновывает необходимость построения интегрированной модели, сочетающей элементы устоявшихся практик с цифровыми платформами при условии адаптации технологических новшеств к местным условиям. *Выводы* – следует акцентировать внимание на комплексном применении разнообразных методов в рамках взаимосвязанных концепций точного земледелия и «умного» сельского хозяйства, что обуславливает постоянное наблюдение за посевами, своевременное внесение препаратов и удобрений, диагностику болезней, посадку семян, стабильный рост производства продукции растениеводства. Важное значение имеет государственная поддержка субсидий и льгот фермерам, а также расширения программ по их обучению и приобретению новых навыков.

Key words: agriculture, crop production, traditional methods, IT solutions, modernization, efficiency, productivity, resource optimization, reducing the environmental burden.

Түйінді сөздер: ауыл шаруашылығы, өсімдік шаруашылығы, дәстүрлі әдістері, IT шешімдері, модернизация, тиімділік, өнімділік, ресурстарды оңтайландыру, экологиялық жүктемені азайту.

Ключевые слова: сельское хозяйство, растениеводство, традиционные методы, IT-решения, модернизация, эффективность, производительность, урожайность, оптимизация ресурсов, снижение экологической нагрузки.

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Introduction

Crop production plays a crucial role in ensuring food security, economic growth, and the sustainable development of a country's agricultural sector. In the face of growing global challenges such as climate change, demographic processes, soil degradation, and increasing food security concerns, the importance of introducing innovative and adaptive technologies in crop production is steadily increasing. Traditional methods, based primarily on experience and empirical approaches, remain widely used in many regions; however, their effectiveness is often limited by rapidly changing environmental conditions, technological demands, and the growing expectations of the modern agricultural market.

Modern IT solutions, such as precision agriculture systems, the use of drones, geographic information systems (GIS), and advanced analytical platforms, offer new and promising opportunities for optimizing various processes in crop production. These technologies make it possible to significantly improve productivity, reduce operational and input costs, and minimize environmental impact by enabling precise, data-driven monitoring of soil conditions, crop health, and local weather patterns. However, the implementation of such innovative solutions comes with several challenges, including high initial investment costs, the need for comprehensive technical staff training, limited digital infrastructure in rural areas, and the adaptation of technologies to specific local agricultural and climatic conditions.

This study aims to conduct a comparative analysis of the effectiveness of traditional methods and modern IT solutions in crop production. Accordingly, the main tasks of the study are to identify the advantages and disadvantages of traditional methods and modern IT-based approaches in crop production, develop a set of performance indicators, and propose practical measures for their optimal and complementary use in the industry through the lens of costs, productivity, profitability, scalability, and environmental impact. The object of the study is traditional and modern technological methods applied in crop production systems. The subject of the study is a comparative analysis of the efficiency and practical viability of traditional methods and modern IT solutions in Kazakhstan's crop production sector, aimed at assessing their impact on key economic, production, technological, and environmental performance indicators.

This study makes it possible to uncover not only the strengths, practical applications, and development prospects of using traditional and/or modern IT solutions in crop production but also to identify their existing limitations and constraints. Furthermore, it seeks to find a balanced and context-specific economic calculation between the use of traditional and modern methods. This is particularly important for ensuring sustainable and competitive crop production, improving its long-term resilience, and facilitating its transformation into a high-income and innovation-driven sector amid growing global and local challenges.

Literature Review

Xiong L., Liu Z., Wang P. et al. [1] are devoted to traditional methods based on years of experience and empirical knowledge, which continue to be widely used in various regions of the world. These approaches, such as crop rotation, the use of organic fertilizers, and manual labor, contribute to maintaining agrobiodiversity and ecosystem stability. However, Hasan K., Tanaka S.T.T., Alam M. et al. [2] presented the traditional methods are often characterized by low productivity and high labor intensity, which limit their effectiveness in modern agricultural conditions, making them less competitive compared to modern methods.

Canicattì M., Vallone M. [3] identified to development of digital technologies in crop production, there has been an increase in the application of IT solutions aimed at optimizing production processes. Precision agriculture systems, including the use of drones, sensors, and geographic information systems (GIS), enable the collection and analysis of data on soil conditions, moisture levels, and plant health.

At the same time, Harish P., Peddinti P.R.T., Tamvada J.P. et al. [4] note that high initial costs and the need for technical staff training are significant barriers to the widespread adoption of these technologies, especially in developing countries.

Tavan M., Wee B., Brodie G. et al. [5] have attempted to directly compare the efficiency of traditional methods and modern IT solutions. Research shows that the use of modern digital technologies in farming increases wheat yields by 11.5%. However, Khiyat Z. [6] emphasized that the effectiveness of IT solutions strongly depends on context, including climatic conditions, infrastructure levels, and access to technical support (Stringer L.C., Fraser E.D.G., Harris D. et.al.) [7]. In turn, Shamshiri R., Sturm B., Weltzein C. et al. [8] highlighted that in contexts with limited access to technologies and capital resources, traditional methods may be more sustainable and economically justified.

Despite the clear advantages of modern IT solutions, their implementation comes with several challenges. Abiri A., Rizan N., Balasundram S.K. et.al. [9] pointed to the need for the development of tailored solutions for smallholder farms that take into account their specific needs and constraints. Additionally, emphasizes the importance of an interdisciplinary approach that combines agronomic knowledge with information technologies to successfully integrate digital tools into agricultural practices.

Content analysis of scientific literature and a systematic-structural approach to comparative analysis led to conclusions about the feasibility of integrating IT solutions into traditional crop production methods. The study also identified key directions for further research and practical implementation, as traditional methods, despite their limitations, continue to play an important role, particularly in contexts with limited access to modern technologies. Future research should focus on developing integrated approaches that combine the strengths of both methods to ensure sustainable agricultural development.

Materials and methods

The research materials include a wide range of statistical data from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, as well as internationally recognized sources such as the World Bank. This datasets provide the empirical foundation for a detailed examination of the current state and dynamics of crop production methods. Using a combination of statistical, economic, and multifactor analysis methods, the study identifies and evaluates the efficiency indicators of traditional and modern methods employed in crop production. These indicators include, but are not limited to, cost structures, levels of profitability, labor productivity, water resource optimization, and the environmental impact associated with each approach. This allows for a nuanced comparison between conventional agricultural practices and emerging technological solutions.

The study uses observational research, comparative analysis, induction, deduction, and system-structural analysis to examine technological and socio-economic links in crop production. A content analysis was conducted on a broad corpus of international research literature, analytical reports by international organizations, strategic policy documents adopted at the national level, and credible open-access online sources. This methodological framework identified the key strengths and limitations of traditional and modern IT-based crop production methods, supporting evidence-based recommendations for Kazakhstan's agriculture.

Results

Traditional methods used in crop production, such as manual labor, simple mechanized tools, traditional irrigation systems, and organic fertilizers, remain the backbone of agriculture in regions with limited access to modern technologies. Modern IT solutions, including drones, unmanned aerial vehicles, geographic information systems (GIS), the Internet of Things (IoT), artificial intelligence (AI), and robotics, play a crucial role in transforming the agricultural sector by offering innovative approaches to managing production processes and improving the efficiency of crop production.

The choice and application of a particular method in crop production directly affect the efficiency of the sector, as they determine resource utilization, the quality of production process management, the volume and stability of yields, and environmental impact. Thus, understanding the advantages and disadvantages of the methods used in crop production enables informed decision-making aimed at maximizing production efficiency, minimizing risks, and enhancing the long-term sustainability of the industry (table 1).

The efficiency of traditional and modern methods in crop production is determined by their ability to provide stable and high yields while enhancing the profitability of agricultural production.

Table 1 – Advantages and disadvantages of traditional methods and modern it solutions used in crop production in Kazakhstan

Traditional methods		Modern IT solutions	
• Manual labor and mechanization tools • Organic fertilizers • Traditional irrigation systems • Experience-based approach to soil cultivation and planting		• Precision agriculture systems • Use of drones for crop monitoring • Geographic Information Systems (GIS) for soil and climate analysis • Internet of Things (IoT) and sensors for plant condition monitoring	
Advantages	Low implementation cost	Advantages	Optimization of resources (water, fertilizers, energy)
	Ease of use		Increased yield and product quality
	Minimal dependence on technical equipment		Reduced environmental impact
Disadvantages	Low labor productivity	Disadvantages	High initial costs
	High dependence on climatic conditions		Requirement for technical staff training
	Limited capability for precise process management		Dependence on infrastructure (internet, power supply)
	Labor intensity and time consumption		
	Environmental impact		
Note: developed by the authors			

Using a comprehensive approach, the comparative assessment of both methods involves the consideration of the following key criteria: yield; economic efficiency, expressed in terms of net profit and profitability; labor productivity; resource optimization, reflected through water savings and reduced fertilizer usage; environmental impact, calculated through reductions in CO_2 emissions (table 2).

Table 2 – Indicators for evaluating the efficiency of traditional and modern methods in crop production in Kazakhstan

Criteria, indicators		Values, formulas
Yield		Based on data from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan and/or reporting statistical data from companies engaged in crop production.
Economic efficiency	Net profit (NP)	$\text{NP} = \text{Income} - \text{Cost Price}$
	Profitability (P)	$\text{P} = \text{NP}/\text{Cost Price} * 100\%$
Labor productivity (LP)		$\text{LP} = \text{Yield}/\text{person} - \text{hours}$
Resource optimization	Water savings (WS)	$\text{WS} = \frac{(\text{W tradit.} - \text{W modern.})}{\text{W tradit.}} * 100\%$
	Reduced fertilizer usage (FU)	$\text{FU} = \frac{(\text{F tradit.} - \text{F modern.})}{\text{F tradit.}} * 100\%$
Environmental impact	Reductions in CO_2 emissions (EC)	$\text{EC} = \frac{(\text{F tradit.} - \text{F modern.})}{\text{F tradit.}} * 100\%$
Note: compiled and developed by the authors based on (On approval of the Concept…; Rada A., Fedulova E.A., Kosinsky P.D.) [10, 11]		

Calculations for each criterion and indicator can be performed separately for each crop production method, followed by a comparative analysis of the results obtained.

To gain a deeper understanding of the applied approaches, the authors of the article conducted relevant calculations based on a comparison of traditional methods and IT solutions. This was done using the example of a farming enterprise in the Kostanay region - PF «ALGA», which employs traditional crop production methods, and an agroholding in the Akmola region – LLC «Enbek», which integrates modern technologies into its operations.

The calculations were conducted using wheat cultivation as a case study. To assess economic efficiency, initial parameters were taken, including a set of indicators for both agricultural enterprises (table 3).

Table 3 – Calculation of the efficiency of traditional and modern methods in crop production in Kazakhstan using the example of agricultural enterprises

Indicators	Initial Parameters			Indicators	Efficiency Calculation			Change
	unit	traditional	IT solutions		unit	traditional	IT solutions	
				Economic Efficiency Calculation				
Cultivated Area	hectare	100	100	Revenue	million KZT	18	37.5	+2.1 times
Wheat Yield	tons / hectare	1.2	2.5	Production Cost (labor + fertilizers + water)	million KZT	33	10.7	↓3.1 times
Wheat Price	thousands KZT / tons	150	150	Net Profit	million KZT	-15	+26.8	>11.8
Labor Costs	person-days / hectare	60	15	Profitability	%	-45.5	250.5	>5.5
Wages	thousands KZT / day	5	5	Optimization of Resource Use Calculation				
Fertilizer Cost	thousands KZT / hectare	20	15	Water Savings (WS)	thousand	10	7	↓30%
Water Cost	thousands KZT / hectare	10	7	Reduced Fertilizer Usage (FU)	thousand	20	15	↓25%
Capital Expenditure	thousands KZT	0	5 000 (drones, software, sensors)	Labor Costs	days/ hectare	60	15	↓75%
IT Depreciation Period	years	-	5	Environmental Impact Calculation				
				CO_2 Emissions (EC)	kilograms/ hectare	50	30	↓ 40%
				IT Investment Payback Period	years	-	2.2	
Note: compiled and calculated by the authors								

As seen from the data in table 3, the farming enterprise in the Kostanay region did not generate any net profit from using traditional crop production methods. In contrast, the agroholding in the Akmola region achieved a net profit of 26.8 million KZT by implementing modern IT solutions. Consequently, the profitability of traditional methods was -45.5%, whereas modern methods yielded a profitability of 250.5%.

The calculations demonstrated that resource optimization in modern crop production methods resulted in 30% water savings, 25% fertilizer savings, and a 75% reduction in labor costs, highlighting the distinct advantages associated primarily with modern IT solutions.

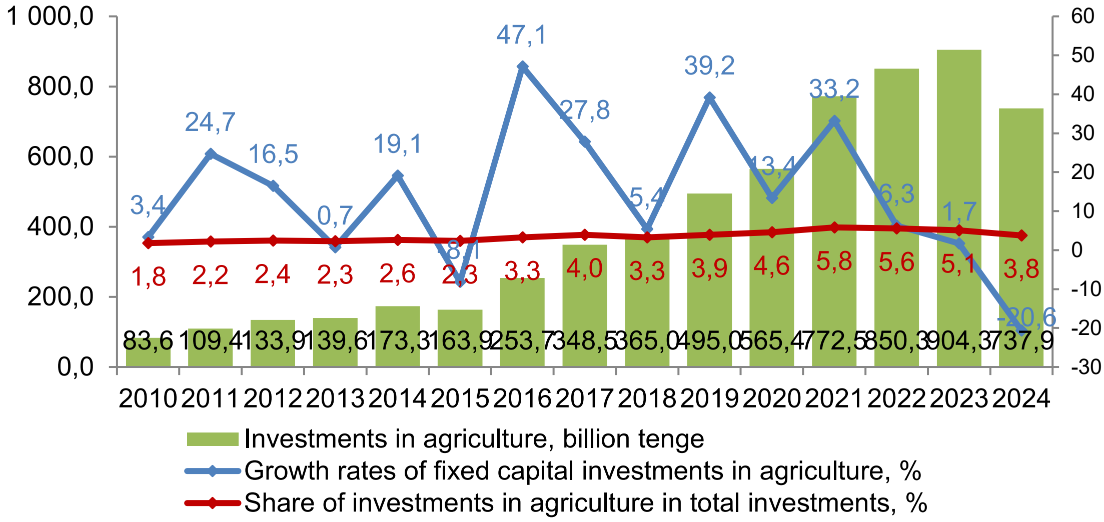
Regarding CO_2 emissions, traditional methods, due to excessive use of fertilizers and transportation, pollute the environment 40% more than modern methods. This reduction is achieved through optimized logistics and precise fertilizer application.

As a result, the agroholding in the Akmola region, which implemented IT solutions, not only recouped its equipment investment in 2.2 years with a profitability of 250.5% but also significantly minimized its environmental footprint.

Thus, the widespread adoption of "smart" crop production leads to a reduction in agriculture's environmental impact, the active use of big data analytics, and the development of digital platforms for supply chain logistics (World Bank. Climate. Smart Agriculture…; World Bank Group. Bringing the Concept…) [12, 13].

In Kazakhstan, however, the application of modern IT solutions in crop production is still in its early stages, which limits productivity growth and cost reduction in the sector. Modern methods in the country's crop production are mainly implemented through precision farming mechanisms in pilot projects, positively affecting cost reduction for farmers and yield increases (On approval of the Concept…) [10].

The development of modern IT solutions in crop production requires active government support aimed at increasing investment in the sector. Between 2010 and 2024, investments in agriculture in Kazakhstan grew nearly elevenfold in nominal terms, with its share in total investment flows grew from 1.8% in 2010 to 5.1% in 2024, with a gradual decline starting from 2021. The growth rate of agricultural investments decreased from 3.4% in 2010 to (-20.6%) in 2024, reflecting uneven distribution of investment volumes across the years, largely dependent on the implementation of government strategic programs (figure).



Note: based on data from (Investment statistics. Dynamic series…) [14]

Figure – Dynamics of investments in agriculture and their share in total investments from 2010 to 2024, billion tenge / %

The predominance of traditional methods in crop production can be explained by the high cost of modern technologies, which small-scale farms often cannot afford, thereby widening the gap between large and small producers (Dhillon R., Moncur Q.) [15]. Modern technologies are frequently designed for universal application, and their adaptation to specific climatic or soil conditions may be challenging. Nevertheless, it is important to note that, despite their limitations, traditional methods remain a vital part of crop production in Kazakhstan. Their adaptation and modernization can enhance production efficiency and serve as a bridge for transitioning to modern technologies.

Discussion

The research highlights the trade-offs between traditional and modern crop production methods in Kazakhstan, focusing on economic efficiency, sustainability, and environmental impact.

Traditional methods are characterized by low implementation costs, minimal need for training, and suitability for remote regions. These approaches are accessible for small-scale farms with limited resources and infrastructure.

However, they suffer from low labor productivity, lack of precision in resource use, and high dependency on weather conditions

(Karymsakova Zh., Kerimova U., Deliana Y.) [16]. Inefficient irrigation and fertilization can lead to soil degradation and reduced long-term fertility.

Modern IT solutions offer enhanced precision, enabling data-driven decisions in irrigation, fertilization, and crop protection. Technologies such as drones, sensors, and GIS systems improve productivity, reduce environmental impact, and optimize resource use, based on digitalization (Kurmanova G.K., Wendland A., Omarov M.B.) [17].

At the same time, these methods entail high initial costs, demand skilled personnel, and require stable internet, electricity, and technical support. Without these, the risk of technical failures increases.

Traditional methods remain relevant for low-tech farms, but they limit yield growth potential. Modern solutions ensure long-term efficiency and sustainability, but their adoption depends on access to finance and infrastructure.

Digitalization is key to boosting Kazakhstan's agricultural competitiveness. The experience of successful farms, such as the Akmola agro holding, should be scaled up. At the same time, traditional practices should be adapted and modernized, not discarded.

Efforts should focus on bridging infrastructural and cultural gaps and integrating Kazakhstan into global sustainable agriculture value chains.

Conclusions

1. The comparison of traditional methods and IT solutions demonstrates that both approaches have their advantages and limitations. IT solutions are more productive, environmentally sustainable, and economically efficient in the long term, particularly for medium and large-scale farms. However, their application is constrained by infrastructure and financial factors. Traditional methods, while less efficient, remain crucial for farmers with limited resources and in regions lacking developed infrastructure.

2. To improve the efficiency of crop production and ensure the sustainable development of the agricultural sector, an integrated approach is necessary. This approach should combine elements of traditional methods with modern IT solutions. The gradual digitization of agriculture will allow time-tested practices to be adapted to new technological conditions, facilitating a smooth transition to innovative practices.

3. Government support plays a key role in this process. Subsidy programs are needed to reduce the financial burden on farmers when adopting IT solutions. Additionally, it is essential to build appropriate infrastructure, including access to high-speed internet, modern equipment, and energy resources. This will form the foundation for the successful application of technologies across various regions of the country.

4. Farmer education is another critical element of digitization. Enhancing farmers' knowledge and skills for working with modern technologies will enable them to maximize the benefits of IT solutions and incorporate them into daily operations. Developing educational programs, conducting training, and establishing learning centers are essential steps in this direction.

5. Regional characteristics must also be considered. Developing and adapting IT solutions to local climatic, soil, and economic conditions will make technologies more accessible and effective for farmers. This flexibility will accommodate the unique needs of each region.

6. The integration of traditional methods with modern technologies, supported by the government and accompanied by educational initiatives, will pave the way for the agricultural sector's transition to a sustainable and high-tech future. This approach will ensure not only increased productivity but also strengthen the competitiveness of the crop production sector and agriculture as a whole.

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