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ECONOMIC EFFICIENCY OF IMPLEMENTING INNOVATIVE TECHNOLOGIES IN AGRICULTURAL ENTERPRISES: INTERNATIONAL EXPERIENCE AND A MODEL FOR KAZAKHSTAN

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This article presents a comprehensive assessment of the economic efficiency of implementing innovative technologies in the agricultural sector, based on a systematic analysis of international practices and the development of an adaptive model for the Republic of Kazakhstan.

The study focuses on agricultural enterprises in seven countries with varying levels of innovation-namely, the United States, the Netherlands, Israel, Germany, China, India, and Brazil-during the period from 2018 to 2024. A comparative analysis revealed substantial disparities in innovation adoption rates: 75-85% in developed countries, 30-50% in developing economies, and less than 5% in Kazakhstan.

A strong positive correlation was established between the level of innovation activity and key economic performance indicators, including labor productivity, return on investment (ROI), and export competitiveness. For instance, ROI in the Netherlands reaches 300%, whereas in Kazakhstan it remains at only 80%.

The study identifies essential institutional, technological, and organizational determinants for successful innovation adoption, such as the effective integration of science, business, and government; the presence of innovation infrastructure; availability of qualified human capital; access to financing mechanisms; and export-oriented strategies.

A diagnostic analysis of Kazakhstan's agricultural sector reveals significant institutional and infrastructural constraints, including inefficient allocation of state support (with a predominance of direct subsidies), weak science-industry cooperation, and limited access to advanced agro-technologies.

In response to these challenges, a five-component innovation development model is proposed, comprising institutional, technological, financial, educational, and infrastructural modules. The model outlines a phased implementation mechanism with measurable indicators of progress and emphasizes the importance of fostering public-private partnerships.

Forecasts for the model's implementation by 2033 indicate the potential to increase the share of innovation-active enterprises to 40%, boost labor productivity by 150-200%, reduce production costs by 20-30%, and double or triple agricultural exports.

The study contributes to the literature on agricultural economics by offering a systematic framework for innovation-driven development in emerging agricultural economies.

Keywords: agricultural innovation, economic efficiency, technology adoption, productivity growth, Kazakhstan agriculture, international experience, innovation model, agricultural modernization, sustainable development, agribusiness transformation.

ЭКОНОМИЧЕСКАЯ ЭФФЕКТИВНОСТЬ ВНЕДРЕНИЯ ИННОВАЦИОННЫХ ТЕХНОЛОГИЙ В АГРАРНЫЕ ПРЕДПРИЯТИЯ: МЕЖДУНАРОДНЫЙ ОПЫТ И МОДЕЛЬ ДЛЯ КАЗАХСТАНА

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В данной статье представлен комплексный анализ экономической эффективности внедрения инновационных технологий в аграрном секторе, основанный на систематическом анализе международной практики и разработке адаптивной модели для Республики Казахстан.

Исследование охватывает сельскохозяйственные предприятия семи стран с различным уровнем инновационного развития - а именно, США, Нидерландов, Израиля, Германии, Китая, Индии и Бразилии в период с 2018 по 2024 годы.

Сравнительный анализ выявил существенные различия в уровнях внедрения инноваций: 75-85% в развитых странах, 30-50% - в развивающихся экономиках, и менее 5% - в Казахстане. Установлена прочная положительная корреляция между уровнем инновационной активности и ключевыми показателями экономической результативности, включая производительность труда, рентабельность инвестиций (ROI) и экспортную конкурентоспособность. Так, ROI в Нидерландах достигает 300%, тогда как в Казахстане он составляет лишь 80%.

В исследовании выявлены ключевые институциональные, технологические и организационные детерминанты успешного внедрения инноваций, такие как эффективная интеграция науки, бизнеса и государства; наличие инновационной инфраструктуры; доступ к квалифицированным человеческим ресурсам; наличие механизмов финансирования; а также экспортно-ориентированные стратегии.

Диагностический анализ аграрного сектора Казахстана выявил серьёзные институциональные и инфраструктурные ограничения, включая неэффективное распределение государственной поддержки (с преобладанием прямого субсидирования), слабое взаимодействие науки и промышленности, а также ограниченный доступ к передовым агротехнологиям.

В ответ на данные вызовы предложена пятикомпонентная модель инновационного развития, включающая институциональный, технологический, финансовый, образовательный и инфраструктурный модули. Модель предусматривает поэтапный механизм реализации с измеримыми индикаторами прогресса и подчёркивает важность формирования государственно-частного партнёрства.

Прогнозы по реализации модели к 2033 году указывают на возможность увеличения доли инновационно-активных предприятий до 40%, роста производительности труда на 150-200%, снижения издержек производства на 20-30%, а также удвоения или утроения объёмов аграрного экспорта.

Настоящее исследование вносит вклад в научную литературу по экономике сельского хозяйства, предлагая системный подход к инновационно-ориентированному развитию аграрных отраслей в странах с формирующейся экономикой.

Ключевые слова: аграрные инновации, экономическая эффективность, внедрение технологий, рост производительности, сельское хозяйство Казахстана, международный опыт, модель инновационного развития, модернизация сельского хозяйства, устойчивое развитие, трансформация агробизнеса.

ЭКОНОМИКАЛЫҚ ТИІМДІЛІК АУЫЛ ШАРУАШЫЛЫҒЫ КӘСІПОРЫНДАРЫНА ИННОВАЦИЯЛЫҚ ТЕХНОЛОГИЯЛАРДЫ ЕНГІЗУ: ХАЛЫҚАРАЛЫҚ ТӘЖІРИБЕ ЖӘНЕ ҚАЗАҚСТАНҒА АРНАЛҒАН МОДЕЛЬ

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Бұл мақалада аграрлық секторға инновациялық технологияларды енгізудің экономикалық тиімділігіне кешенді талдау ұсынылған. Зерттеу халықаралық тәжірибені жүйелі талдау мен Қазақстан Республикасына бейімделген үлгі әзірлеуге негізделген.

Зерттеу 2018-2024 жылдар аралығында инновациялық даму деңгейі әртүрлі жеті елдің - АҚШ, Нидерланд, Израиль, Германия, Қытай, Үндістан және Бразилияның ауыл шаруашылығы кәсіпорындарын қамтиды.

Салыстырмалы талдау нәтижесінде инновацияларды енгізу деңгейлерінде елеулі айырмашылықтар анықталды: дамыған елдерде - 75-85%, дамушы экономикада - 30-50%, ал Қазақстанда - 5%-дан төмен. Инновациялық белсенділік деңгейі мен экономикалық нәтижеліліктің негізгі көрсеткіштері - еңбек өнімділігі, инвестициялардың рентабельдігі (ROI) және экспорттық бәсекеге қабілеттілік арасында берік оң корреляция орнатылды. Мысалы, Нидерландта ROI 300%-ға жетсе, Қазақстанда ол небәрі 80%-ды құрайды.

Зерттеу барысында инновацияларды табысты енгізудің негізгі институционалдық, технологиялық және ұйымдастырушылық детерминанттары анықталды. Оларға ғылым, бизнес және мемлекеттің тиімді интеграциясы; инновациялық инфрақұрылымның болуы; білікті адами ресурстарға қол жеткізу; қаржыландыру тетіктерінің болуы; сондай-ақ экспортқа бағытталған стратегиялар жатады.

Қазақстанның аграрлық секторының диагностикалық талдауы институционалдық және инфрақұрылымдық шектеулерді көрсетті, атап айтқанда: мемлекеттік қолдаудың тиімсіз бөлінуі (тікелей субсидиялаудың басым болуы), ғылым мен өндіріс арасындағы өзара іс-қимылдың әлсіздігі, сондай-ақ озық агротехнологияларға қол жеткізудің шектеулілігі.

Аталған сын-қатерлерге жауап ретінде институционалдық, технологиялық, қаржылық, білім беру және инфрақұрылымдық модульдерді қамтитын бес компонентті инновациялық даму үлгісі ұсынылды. Үлгі кезең-кезеңімен іске асыру тетіктерін және прогресті өлшейтін индикаторларды қарастырады, сондай-ақ мемлекеттік-жекеменшік әріптестіктің маңыздылығын айқындайды.

Модельді 2033 жылға дейін іске асыру болжамдары инновациялық белсенді кәсіпорындар үлесін 40%-ға дейін арттыруға, еңбек өнімділігін 150-200%-ға өсіруге, өндіріс шығындарын 20-30%-ға қысқартуға және аграрлық экспорт көлемін екі-үш есеге ұлғайтуға мүмкіндік бар екенін көрсетеді.

Бұл зерттеу ауыл шаруашылығы экономикасы бойынша ғылыми әдебиетке үлес қосып, қалыптасып келе жатқан экономикалардағы аграрлық салаларды инновациялық бағытта дамытуға жүйелі көзқарасты ұсынады.

Түйін сөздер: аграрлық инновациялар, экономикалық тиімділік, технологияларды енгізу, еңбек өнімділігінің өсуі, Қазақстан ауыл шаруашылығы, халықаралық тәжірибе, инновациялық даму үлгісі, ауыл шаруашылығын жаңғырту, орнықты даму, агробизнестің трансформациясы.

Introduction. The contemporary stage of agro-industrial complex (AIC) development is marked by the growing role of innovative technologies that drive productivity, sustainability, and competitiveness in agriculture. In the context of global challenges including climate change, population growth, and geopolitical instability-the transition to innovation-based models of crop and livestock production becomes a key factor in ensuring food security and economic growth. This issue is especially relevant for the Republic of Kazakhstan, where agriculture remains a strategically important sector of the economy, providing rural employment, export potential, and regional sustainability.

In recent years, Kazakhstan has shown an

active commitment to modernizing its AIC through the adoption of advanced technologies. In crop production, this is reflected in the use of precision farming, satellite monitoring, automated irrigation systems, and digital platforms for enterprise management. In livestock production, key innovation areas include genomic selection technologies, automated feeding and health monitoring systems, and the development of smart farms. Government support is provided through programs such as «Digital Kazakhstan», «Agrobusiness-2025» and the «National Agro-Industrial Development Project», which include subsidies for technological upgrades, concessional lending, and the development of agricultural science.

Nevertheless, despite ongoing efforts, the level of innovation adoption within Kazakhstan's AIC remains uneven. Large agroholdings are actively investing in modern technologies and demonstrating high economic efficiency, while small and medium-sized farms face significant barriers such as high implementation costs, a shortage of qualified personnel, and insufficient infrastructural support. Moreover, a dependency on imported technologies and equipment persists, limiting the sector's sustainable development potential. In this context, a comprehensive analysis of the economic effectiveness of innovative technologies in Kazakhstan's crop and livestock sectors holds both academic and practical importance.

Amid growing challenges related to food security and climate change, the innovative development of the agro-industrial sector becomes a strategic priority for national policy and research agendas. This is especially critical for Kazakhstan, where agriculture plays a pivotal role in domestic market provision and export development but struggles with low productivity, limited access to modern technologies, and stark regional disparities.

Numerous national and international scholars have addressed various aspects of innovation in agriculture. Contributions to the methodology for analyzing AIC economic development are found in the works of Daribayeva A.K., Shulenbayeva F., and Bauer M. [1]. Recent scientific discourse, especially against the backdrop of global technological advancement, increasingly underscores the urgency of innovation-led transformation in agriculture. While modern agricultural enterprises are becoming active agents in innovation, Clancy M.S., Moschini G., and Heisey P. note that the sector largely depends on external sources of technology and knowledge due to its relatively low internal innovative capacity [2].

Similarly, Bjerke L. and Johansson S. emphasize that the geographic isolation of agricultural enterprises from urban and scientific hubs limits their access to innovation infrastructure and resources [3]. Andrade D., Pasini F., and Scarano F.R. argue that in countries prioritizing high-tech sectors (e.g., IT, biomedicine, aerospace), agriculture often falls outside the scope of national innovation policies [4].

Contemporary research emphasises the importance of socio-technical innovation packages for the transformation of agri-food systems. Barrett C.B., Benton T., Fanzo J. and colleagues argue that successful agricultural modernisation requires a comprehensive approach that combines technological, institutional and social innovations [5]. This approach is particularly relevant for developing economies, where, as Swinnen J. and Kuijpers R. note, inclusive value chains can significantly accelerate poverty reduction and increase agricultural productivity [6].

This observation is particularly relevant for Kazakhstan: despite isolated cases of innovation in crop and livestock production, the agricultural sector as a whole remains under-attractive for investors (Talymova L.A., Zhukenov B.M., Akenov S.Sh., et al.) [7]. Baudron F. and Liégeois F. warn that neglecting the innovation vector may lead to deteriorating food security, increased environmental stress, and declining international competitiveness [8].

According to Campos H. and Żak A., the need for agricultural innovation today is driven not only by the imperative to increase productivity but also by shrinking land and labor resources, especially amid rapid urbanization [9,10]. Innovations represent the

only viable mechanism for compensating these losses.

Significant attention in contemporary literature is devoted to digitalization as the primary vector of agricultural innovation. It is viewed as a strategic enabler of production transformation, management efficiency, and market integration (Abraliyev O.A., Sugirova G.S., Velesco S.; Kaldiyarov D.A., Kalymbekova Zh.K., Zhumanazarov K.B.; Shaynurov A.S., Smagulova Zh.B.) [11-13]. Digital solutions enhance farmers' capacities in planning, accounting, and resource management, as highlighted by Shogenov B.A. and Mirzoeva A.R. [14].

Moreover, the relevance of innovation is closely tied to sustainable development. Several authors emphasize that long-term competitiveness in agriculture is unattainable without environmentally responsible innovations that promote the sustainable use of natural resources (Ferreira Apal, de Oliveira L., Talamini E.; Ndaba B., Roopnarain A., Haripriya R., et al.) [15,16].

The objective of this study is to assess the economic effectiveness of innovation implementation in agricultural enterprises based on international experience and to develop an adapted model for Kazakhstan. To achieve this, the study addresses the following tasks:

-conduct a comparative analysis of innovation implementation in the agricultural sectors of seven leading countries (USA, Netherlands, Israel, Germany, China, India, Brazil) for the period 2018-2024;

- identify key success factors determining the economic efficiency of innovation adoption in agriculture;

- assess the current status and challenges of innovation diffusion in Kazakhstan's agricultural enterprises;

- develop a model for innovation implementation in Kazakhstan's agricultural sector based on international experience and national specificities;

- propose a methodology for evaluating economic efficiency and forecasting the potential outcomes of the proposed model.

The scientific novelty of the study lies in the development of a comprehensive model for innovation deployment in Kazakhstan's agricultural sector, based on a systematic analysis of international experience and adaptation of best practices to local conditions. The proposed model accounts for economic, social, environmental, and institutional dimensions of innovation, ensuring its comprehensiveness and practical applicability.

Thus, the innovative transformation of Kazakhstan's agro-industrial complex is not merely desirable but strategically imperative. Global experience confirms that only the systemic adoption of advanced agritechnologies can ensure the sustainable growth and resilience of the sector.

Methodology and Materials. The methodological basis of this study is a systematic approach, within which the process of introducing innovative technologies in the agricultural sector is viewed as a complex multi-level system comprising interrelated economic, technological, institutional and social components. This approach provides a comprehensive understanding of the phenomenon under study and helps to identify sustainable patterns that influence the effectiveness of innovations in agriculture.

The comparative analysis is based on a multi-criteria evaluation system that includes the following key indicators: the level of innovation adoption, expressed as a percentage of enterprises using innovative technologies; return on investment (ROI), calculated using a modified formula that incorporates sustainable development factors; labour productivity index with a base value of 2018 taken as 100%; investment intensity, measured as a share of gross domestic product in agriculture.

The data collection and processing procedure was carried out in accordance with a structured protocol comprising five consecutive stages. The first stage involved the selection of primary data sources from the official databases of international organisations - the Organisation for Economic Co-operation and Development (OECD), the Food and Agriculture Organisation of the United Nations (FAO) and the World Intellectual Property Organisation (WIPO). The second stage involved

validating the data obtained by cross-checking it with information from the national statistical services of the countries under study. The third stage involved analysing time series based on annual data for the period 2018-2024. The fourth stage involved the application of statistical methods, in particular Pearson' s correlation analysis, in which a correlation coefficient of r > 0.7 was interpreted as an indicator of a strong relationship. In the final fifth stage, forecast models were developed based on linear regression with a 95% confidence interval.

According to the latest report by the Asian Development Bank, digital transformation in Central Asian agriculture shows significant potential for increasing productivity, with Kazakhstan identified as the country with the greatest potential for technological breakthroughs in the region [17]. This confirms the need to intensify investment in the innovative development of the industry.

The study used both general scientific methods (analysis, synthesis, comparison, generalisation) and specialised methods of economic research, including statistical analysis, econometric modelling and graphical data visualisation. The comprehensive application of these methods ensured the scientific validity and reproducibility of the results obtained.

Results and discussion. An analysis of international experience indicates that over the past 20 years, developing economies have become the primary drivers of global agricultural market growth-a trend expected to continue into the next decade. The increase in agricultural product consumption is mainly driven by population growth and rising incomes in low- and middle-income countries.

According to the OECD-FAO Agricultural Outlook 2024-2033, China's influence on global food consumption is declining, with its share in global consumption growth projected to decrease from 28% in the previous decade to 11% in the next. In contrast, India and Southeast Asian countries are expected to account for 31% of global consumption growth by 2033.

A key trend is that the increase in crop production will primarily result from productivity gains on existing agricultural lands, rather than expansion of cultivated areas. A significant portion of growth in the livestock and fisheries sectors will also stem from increased productivity. However, despite expected productivity gains-especially in low- and middle-income countries-substantial productivity gaps will persist, posing challenges to farm incomes and food security.

From an environmental sustainability perspective, the intensity of greenhouse gas emissions in agriculture is expected to decline. Nevertheless, direct emissions from the agricultural sector are projected to rise by 5% in absolute terms. Halving food loss by 2030 could potentially reduce global agricultural emissions by 4%.

For the comparative analysis, seven countries were selected that represent various regions of the world and demonstrate successful practices in implementing innovative technologies in agriculture: The United States, Netherlands, Israel, Germany, China, India, and Brazil. These countries were chosen due to their leading positions in different aspects of agricultural innovation and their diverse approaches to innovation implementation.

An analysis of data from 2018 to 2024 reveals significant differences in the levels of innovation adoption across the agricultural sectors of the studied countries [18 - 20] (Fig.1).

As can be seen from the data presented in Figure 1, the highest level of innovation technology adoption in the agricultural sector in 2024 is recorded in developed countries. The Netherlands leads the way with 85%, followed by the United States (80%) and Israel and Germany (75% each). These figures reflect a high degree of technological maturity and a sustainable investment policy in the field of agricultural innovation.

In countries with dynamically developing economies, the level of innovation implementation varies at an average level: China demonstrates an indicator of 50%, India - 40%, and Brazil - 30%. This indicates a gradual but purposeful movement of these countries towards the technological modernisation of agriculture.

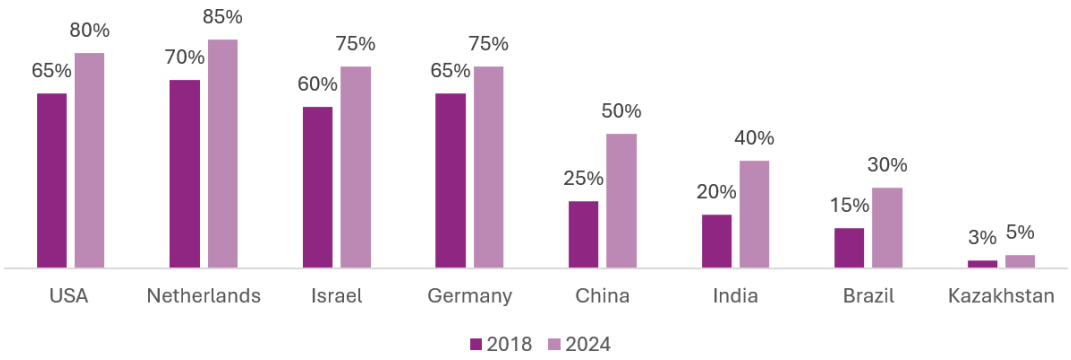


Fig.1 - Level of innovation technology adoption in the agricultural sector (2018-2024)

Kazakhstan, in turn, lags significantly behind both developed and rapidly developing countries: the level of implementation of innovative solutions in the agricultural sector was only 5% in 2024. This indicator points to a significant lag, requiring systematic measures of state support and stimulation of technological development in the industry.

Despite varying levels of involvement, all countries surveyed show positive dynamics in the period from 2018 to 2024. The most pronounced growth rates are observed in China (an increase of 25 percentage points) and India (+20%), which indicates the implementation of active government policies aimed at introducing innovative solutions into agricultural production. At the same time, growth in Kazakhstan was only 2%, which may be due to institutional, financial and human resource barriers to technological modernisation of the agro-industrial complex.

The economic efficiency of introducing innovative technologies, measured by the return on investment (ROI) indicator, also varies significantly between countries [19,21] (Fig.2).

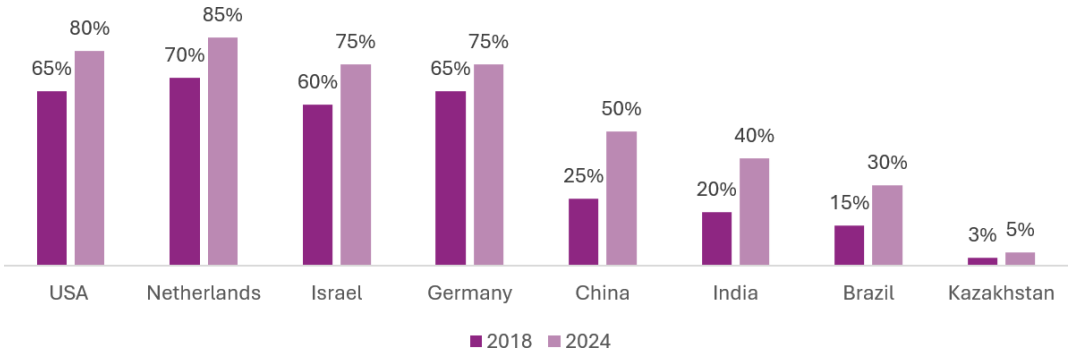


Fig.2 - Economic Efficiency of Innovations in the Agricultural Sector (2018-2024)

According to the data presented, the highest rates of return on investment in innovation in the agricultural sector in 2024 were recorded in the Netherlands (300%), the United States and Germany (280% each), and Israel (270%). These figures indicate the high effectiveness of innovation policy and a developed technology transfer system in these countries.

Countries with rapidly developing economies show moderate levels of return: China - 180%, India - 150%. These indicators reflect the positive effect of investments in technological modernisation and the introduction of advanced solutions, accompanied by an increase in agricultural productivity.

Relatively low profitability values are observed in Brazil (120%) and Kazakhstan (80%). Despite the positive dynamics, these values indicate

insufficient effectiveness in realising the innovative potential in the agricultural sector of these countries, which may be due to structural constraints, weak institutional support and limited access to advanced technologies.

During the period 2018-2024, all countries analysed demonstrated growth in the return on investment in innovation, which indicates an increase in the effectiveness of the technologies being implemented and an improvement in the conditions for their application. The most significant increase in indicators was recorded in India and China, at +60 percentage points. This is due to the active development of innovation infrastructure, growth in investment in scientific research, and improvements in the quality of the solutions being implemented. In Kazakhstan, the increase was 40 percentage points, which is undoubtedly a positive shift. Nevertheless, in absolute terms, the return on investment remains low, which requires further systematic efforts to increase the return on innovation.

The importance of government policy in stimulating innovation is confirmed by the experience of Kazakhstan, where the National Project for the Development of the Agro-Industrial Complex for 2021-2025 provides for the allocation of significant resources for the technological modernisation of the industry [22]. However, as the analysis shows, the key challenge remains the effective use of the allocated funds.

The level of investment in agricultural innovation, measured as a percentage of agricultural GDP, also varies significantly between countries [16,21] (Fig.3).

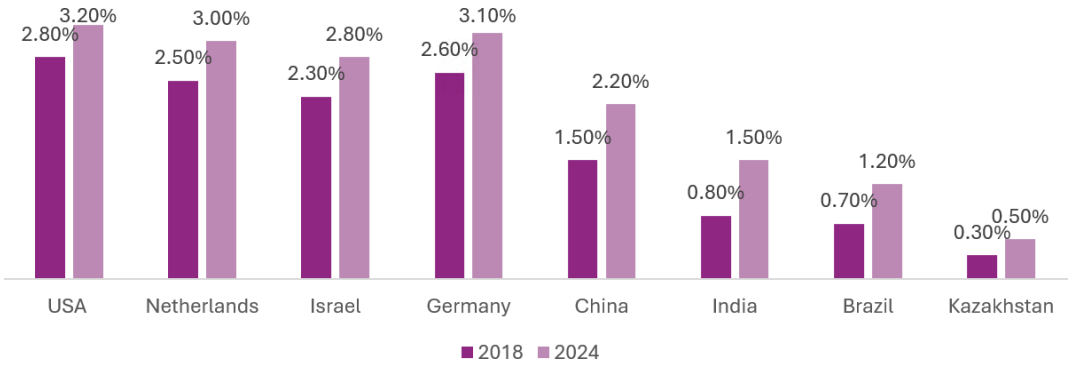


Fig.3 - Investments in agricultural innovation (2018-2024)

An analysis of the distribution of investment resources in agricultural innovation by country in 2024 allows us to identify a group of global leaders demonstrating the highest level of investment relative to gross domestic product in agriculture. Thus, in the United States, the share of investment in agricultural innovation amounted to 3.2% of agricultural GDP, in Germany - 3.1%, in the Netherlands - 3.0%, and in Israel - 2.8%. These data reflect the sustained focus of these countries on innovation-oriented development of the agro-industrial complex, as well as the existence of effective mechanisms for financing scientific and technical developments in agriculture.

China shows a moderate level of investment - 2.2%, which nevertheless indicates a growing focus on the development of agricultural technologies as one of the priorities of state agricultural policy. India, Brazil and Kazakhstan are characterised by significantly lower indicators: 1.5%, 1.2% and 0.5%, respectively. The level is particularly low in Kazakhstan, which indicates limited funding for innovation in the agricultural sector and the existence of institutional and resource barriers.

At the same time, all countries showed growth in investment in agricultural innovation between 2018 and 2024. The most pronounced positive dynamics were recorded in China and India, where growth amounted to +0.7 percentage points. This confirms the existence of a sustainable trend

towards strengthening state support and developing innovative infrastructure in the agricultural sector. In Kazakhstan, the increase was only 0.2 percentage points, which can be regarded as insufficient progress in the context of global trends and continuing technological backwardness.

One of the key indicators of the effectiveness of innovative technology implementation is the growth of labour productivity in the agricultural sector [21,23] (Fig.4).

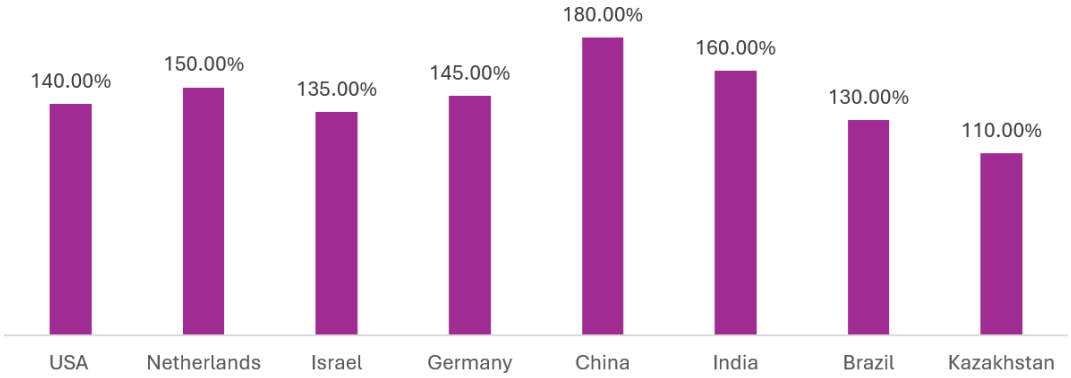


Fig.4 - Labour productivity growth in the agricultural sector (2018-2024)

The data shows that the highest growth in labour productivity for the period 2018-2024 is observed in China (180%), India (160%), the Netherlands (150%) and Germany (145%). The United States, Israel and Brazil show average figures: 140%, 135% and 130% respectively. Kazakhstan shows the lowest labour productivity growth among the countries studied - 110%.

-The base year was taken as 2018 (value = 100%).

-The labour productivity growth index for 2024 was calculated for each country.

-Labour productivity was measured as the volume of agricultural production per worker.

It is important to note that there is a direct correlation between the level of innovation technology adoption and labour productivity growth (Fig.5).

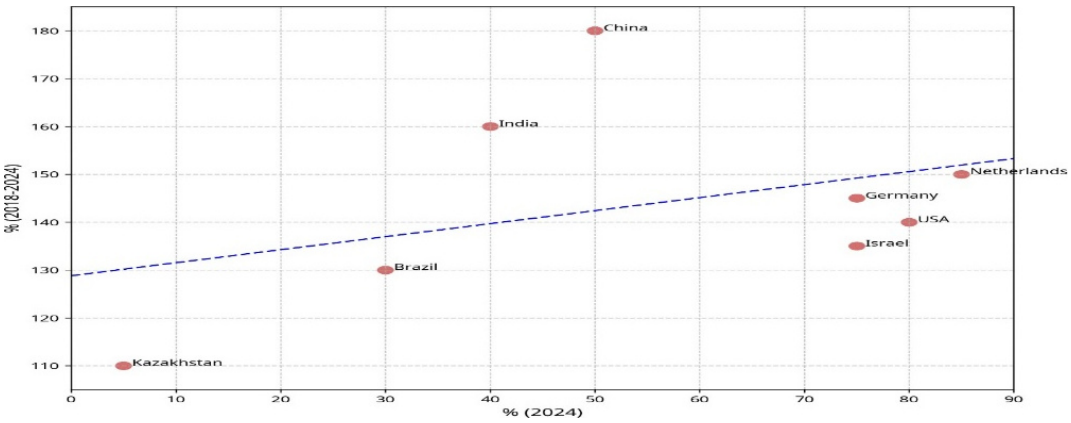


Fig.5 - Level of Innovation Implementation in 2018-2024 (%)

As can be seen in Figure 5, countries with higher levels of innovation adoption tend to demonstrate higher labour productivity growth. However, there are exceptions: China and India show higher productivity growth with average levels of innovation adoption, which may be due to

the «low base» effect and higher growth potential in these countries.

The choice of a grain-producing enterprise for testing the model is determined by the priorities of the National Project for the Development of the Agro-Industrial Complex, where grain production is identified as one of the key areas for the introduction of innovative technologies [20].

Based on an analysis of international experience, the following key factors can be identified that determine the successful implementation of innovative technologies in the agricultural sector:

Integration of science, business and government. The most successful examples of innovation implementation are observed in countries where effective interaction between scientific organisations, agricultural enterprises and government structures has been established. A striking example is the Netherlands, where Wageningen University and Research Centre closely cooperates with farmers and agribusinesses with the support of the state [18].

Developed infrastructure and innovation ecosystem. Countries that are leaders in innovation implementation (the United States, Germany, the Netherlands) are characterised by a developed innovation infrastructure, including research centres, technology parks, incubators, demonstration farms and technology transfer centres.

Targeted state support. The successful examples of China and Israel demonstrate the importance of targeted state policies to support innovation in the agricultural sector. The key factor here is not so much the amount of support as its focus on the development of infrastructure and technologies, rather than direct subsidies [20].

The technological component includes the introduction of socio-technical innovation packages, the concept of which is detailed in the study by Klerkx L and co-authors [24]. This approach involves not simply borrowing technologies, but adapting them to local conditions, taking into account social and environmental factors.

Education and training. Countries with high levels of innovation pay particular attention to training qualified personnel for the agricultural sector. For example, Germany and the Netherlands have developed a dual education system that combines theoretical training with practical training in enterprises.

Access to financing. A developed system of financing innovative projects, including government programmes, private investment, venture capital and specialised funds, is an important factor for success. The United States leads the way in the development of venture financing in the agricultural sector [24].

Focus on exports and international competitiveness. Countries focused on agricultural exports (the Netherlands, the United States, Brazil) demonstrate a higher level of innovation, as international competition stimulates increased efficiency and product quality.

Kazakhstan’ s agricultural sector has significant potential for development thanks to its vast land resources (more than 272 million hectares of agricultural land) and favourable climatic conditions for growing various crops. However, despite this potential, the level of innovation in agriculture remains extremely low. According to a study conducted in 2024, the share of innovative technologies in Kazakhstan’ s agricultural production does not exceed 5% [18]. This is significantly lower than in developed countries (75-85%) and even in middle-income countries such as China (50%) and India (40%).

Investment in agricultural innovation in Kazakhstan accounts for only 0.5% of agricultural GDP, which is 6-7 times lower than in developed countries. At the same time, most of the state support for the agricultural sector is directed towards direct subsidies rather than infrastructure and technology development [25].

Labour productivity growth in Kazakhstan’ s agricultural sector for the period 2018-2024 was 110%, which is the lowest among the countries studied. This indicates the low efficiency of the technologies and production methods used.

The return on investment in innovation in Kazakhstan' s agricultural sector is 80%, which is significantly lower than in other countries. This is due to the inefficient use of investments, insufficient infrastructure development and low staff qualifications.

Based on an analysis of the current situation, the following main problems and barriers to the introduction of innovative technologies in Kazakhstan' s agricultural sector can be identified:

Inefficient use of state support. Most state support is directed towards direct subsidies rather than infrastructure and technology development. According to a study conducted in 2024, about 70% of state support for Kazakhstan' s agricultural sector goes to direct subsidies [25].

Kazakhstan lacks adequate infrastructure for the storage, processing and transportation of agricultural products, which leads to significant losses and reduced production efficiency.

Weak integration of science and business. The lack of effective mechanisms for interaction between scientific organisations and agricultural enterprises hinders technology transfer and innovation implementation.

The proposed model for introducing innovative technologies in Kazakhstan' s agricultural sector is based on an analysis of international experience and the adaptation of best practices, taking into account national characteristics. The model is an integrated ecosystem that combines the key elements of successful innovation implementation identified in the analysis of the experience of leading countries.

The key principles of the model are:

- systematic and comprehensive approach - interconnected development of all elements of the innovation ecosystem

- results-oriented approach - priority of economic efficiency and sustainability

- adaptability - taking into account regional characteristics and different types of farms

- phased implementation - consistent implementation with measurable results

- public-private partnership - joint efforts of the state and business

Structural components of the model.

The institutional component of the model is based on the experience of the Netherlands (integration of science, business and the state) and Israel (targeted state support). Proposed measures include:

- creation of a National Centre for Agricultural Innovation based on the model of Wageningen University (Netherlands);

- formation of regional innovation clusters with the participation of universities, research centres and agribusiness;

- reorientation of state support from direct subsidies to infrastructure and technology development;

- developing a long-term strategy for innovative development of the agro-industrial complex with clear KPIs.

The technological component of the model is based on the experience of Israel (water-saving technologies), the United States (digitalisation and automation) and Germany (precision farming). The proposed measures include:

- introduction of a precision farming system adapted to the conditions of Kazakhstan;

- development of water-saving technologies (drip irrigation, soil moisture monitoring);

- creation of a digital platform for the agricultural sector with the integration of IoT, big data and AI;

- development of automation and robotics in large farms;

- introduction of smart livestock farming technologies.

The financial component of the model is based on the experience of the United States (venture capital financing) and China (government investment in innovation). The proposed measures include:

- creation of a specialised agricultural innovation fund with public and private capital;

- development of a preferential lending system for the introduction of innovative technologies;

- introduction of mechanisms for insuring

innovative risks;

- tax incentives for investments in agricultural innovation;

- development of leasing for innovative equipment and machinery.

The financial component is based on international experience in creating inclusive financial mechanisms. As demonstrated by Swinnen J. and Kuijpers R., access to finance is a critical factor for involving small and medium-sized farms in innovation processes [23].

The educational component of the model is based on the experience of the Netherlands (integration of education and practice) and Germany (dual education). The proposed measures include:

- modernisation of agricultural education with a focus on innovative technologies;

- creation of demonstration farms at agricultural universities;

- development of exchange programmes with leading agricultural universities around the worl;

- introduction of a system of continuing education for farmers and agribusiness specialists;

- creation of an online platform for training in modern agricultural technologies.

The infrastructure component of the model is based on the experience of the Netherlands (logistics infrastructure) and Brazil (export infrastructure). The proposed measures include:

- development of digital infrastructure in rural areas (broadband Internet, mobile communications);

- creation of modern logistics centres for storage and processing of products;

- modernisation of irrigation systems with the introduction of smart technologies;

- development of transport infrastructure for product exports;

- creation of a network of innovation centres for demonstrating and testing new technologies.

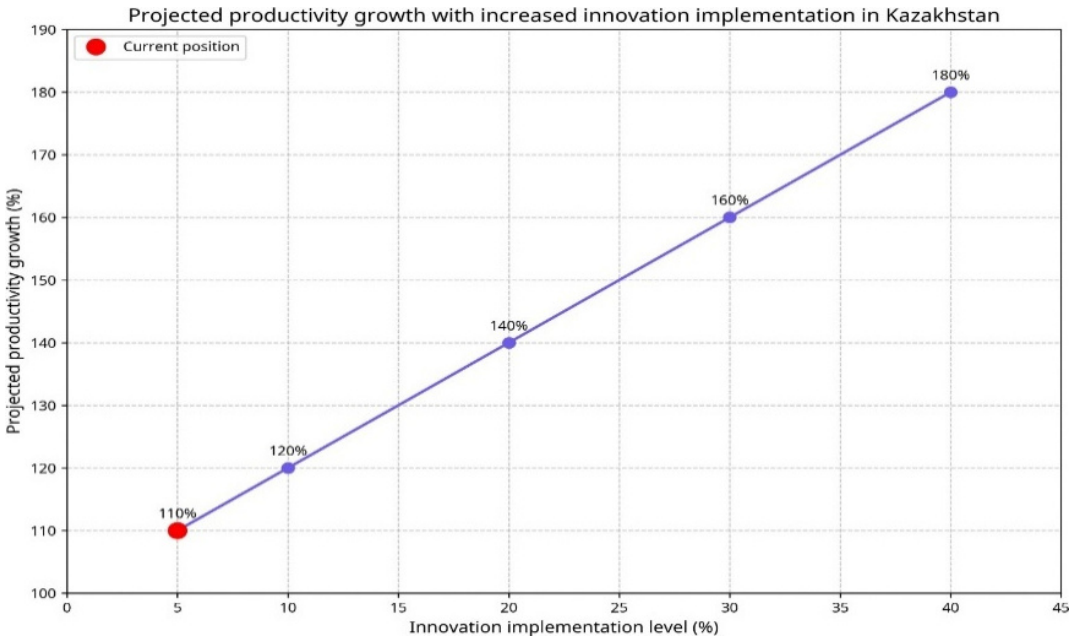


Fig. 6 - Level of innovation implementation %

Based on an analysis of international experience and the current state of Kazakhstan' s agricultural sector, the following results of the proposed model' s implementation can be predicted by 2033:

- increase in the share of enterprises implementing innovations from 5% to 40%;

- growth in labour productivity in the agricultural sector by 150-200%;

- reduction in production costs by 20-30%;

- increase in agricultural exports by 2-3 times;

- reduction in water consumption per unit of production by 30-40%;

- reduction of losses during storage and transportation by 50%;

- creation of 50-70 thousand new jobs in the high-tech agricultural sector.

The projected indicators are consistent with regional trends identified by the Asian Development Bank, according to which Central Asian countries could increase agricultural productivity by 40-60% by 2030, provided that they successfully undergo digital transformation [15].

The forecast for productivity growth with an increase in the level of innovation implementation in Kazakhstan is presented in Fig.6.

As can be seen from Fig.6, increasing the level of innovation adoption from the current 5% to 40% could lead to a 180% increase in labour productivity by 2033. This would significantly improve the competitiveness of Kazakhstani agricultural products on international markets and ensure the sustainable development of the agricultural sector.

To assess the economic efficiency of introducing innovative technologies in Kazakhstan' s agricultural sector, we propose using the following formula (1). The proposed formula for assessing return on investment is a modified approach to the traditional ROI calculation, adapted to the specifics of Kazakhstan' s agricultural sector:

$$ROI = \frac{\Delta R - \Delta C}{I} * (1 + S * E) \qquad (1)$$

where:

ΔR - revenue increment determined by the functional dependence on the technological and infrastructural components of the model;

ΔC - change in operating costs determined by the synergistic effect of the financial and educational components;

I - total investment accumulated across all five components of the model;

S is the sensitivity coefficient, set at 0.3 for Kazakhstan based on an analysis of the volatility of the agricultural sector for the period 2018-2024;

E is the external effect coefficient, estimated at 0.2 and reflecting the potential for export orientation.

The mechanism of interaction between the model components and the ROI formula parameters is characterised by the following functional dependencies:

The institutional component has a modulating effect on the sensitivity coefficient S by ensuring the stability of agricultural policy, which can change its value in the range of ±0.1. The technological component demonstrates a direct positive correlation with revenue growth ΔR, providing potential growth in the range of 20-30% with full-scale implementation. The financial component determines not only the volume of investment I, but also the weighted average cost of capital, affecting the discounting of future cash flows. The educational component contributes to a 15-20% reduction in operating costs ΔC by improving staff qualifications and optimising production processes. The infrastructure component increases the external effect coefficient E in the range of 0.1-0.3 by improving access to domestic and international markets.

To demonstrate the practical applicability of the developed model, we will calculate the economic efficiency of introducing innovative technologies using the example of a typical grain-producing farm in the Akmola region with a land bank of 5,000 hectares, specialising in wheat production.

The initial parameters of the farm at the beginning of 2024 are characterised by the following indicators: annual revenue from sales is 500 million tenge with production costs of 350 million tenge, which provides an operating profit of 150 million tenge. The planned investment in innovative technologies, including precision farming systems, satellite crop monitoring and automated equipment control, is 100 million tenge.

The projected results of the introduction of innovative technologies by 2026, based on an

analysis of international experience and adapted to the conditions of northern Kazakhstan, suggest the following dynamics: revenue growth (ΔR) will amount to 125 million tenge, which is equivalent to a 25% increase from the baseline due to higher yields and product quality; reduction in production costs (ΔC) will reach 70 million tenge, or 20% of the baseline, thanks to optimised resource use; the sensitivity coefficient (S) is assumed to be 0.3, reflecting moderate volatility in the grain market; the external effect coefficient (E) is estimated at 0.2, taking into account the potential for entering export markets.

Applying formula (1) to calculate the return on investment gives the following result:

$$ROI = \frac{125 - (-70)}{100} * (1 + 0,3 * 0,2) = \frac{195}{100} * 1,06 = 2,067$$

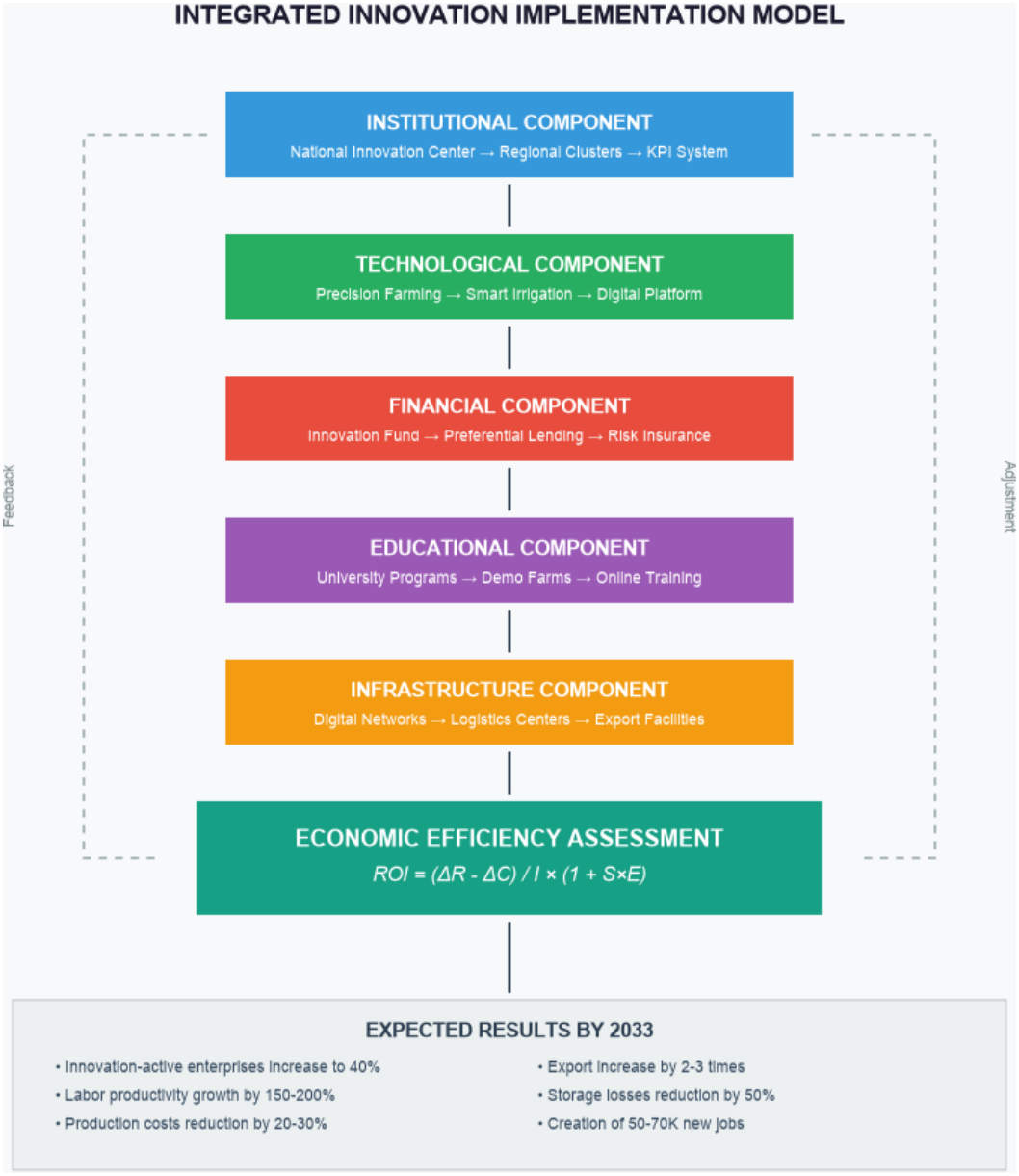


Fig.7 - Integrated model for introducing innovations in Kazakhstan' s agricultural sector

The ROI value of 206.7% indicates the high economic efficiency of introducing innovative technologies with a payback period of less than two years, confirming the feasibility of the proposed model for Kazakhstan.

The architecture of the proposed model for introducing innovative technologies in Kazakhstan' s agricultural sector is a hierarchically organized system of interconnected components (Fig 7), where each element performs a specific function in the overall mechanism of industry transformation.

The structure presented demonstrates the cascading nature of component interaction, where the institutional component forms the regulatory and legal framework through the creation of a National Innovation Centre, the development of regional clusters, and the introduction of a system of key performance indicators. The technological component ensures the direct modernisation of production processes through the introduction of precision farming, smart irrigation systems and a unified digital management platform. The financial component creates the necessary economic conditions through the formation of a specialised innovation fund, preferential lending mechanisms and an innovation risk insurance system. The educational component guarantees staffing through the modernisation of university programmes, the creation of demonstration farms and the development of online learning platforms. The infrastructure component forms the material and technical base through the development of digital networks, the construction of modern logistics centres and the creation of export infrastructure.

The financial component of the model is based on international experience in creating inclusive financial mechanisms. As demonstrated by Swinnen J. and Kuijpers R., access to finance is a critical factor for involving small and medium-sized farms in innovation processes [6].

Conclusion. The study demonstrated that the introduction of innovative technologies in the agricultural sector is a key factor in increasing its economic efficiency and competitiveness. International experience shows that there is a direct correlation between the level of innovation activity and growth in labour productivity, return on investment and the sustainability of agricultural production.

The study showed that the introduction of innovative technologies in the agricultural sector is a key factor in increasing its economic efficiency and competitiveness. International experience demonstrates a direct correlation between the level of innovation adoption and growth in labour productivity, return on investment, and sustainability of agricultural production.

An analysis of the experience of seven leading countries (the United States, the Netherlands, Israel, Germany, China, India, and Brazil) has identified key factors for the successful introduction of innovations, including the integration of science, business and government, infrastructure development, targeted government support, training, access to finance and export orientation.

The current state of Kazakhstan' s agricultural sector is characterised by a low level of innovation technology adoption (5% of enterprises), insufficient investment in innovation (0.5% of agricultural GDP) and low labour productivity growth (110% for 2018-2024). The main problems are the inefficient use of state support, insufficient infrastructure development, weak integration of science and business, a shortage of skilled personnel, and limited access to financing.

The proposed model for introducing innovative technologies in Kazakhstan' s agricultural sector is based on an analysis of international experience and the adaptation of best practices, taking into account national characteristics. The model includes institutional, technological, financial, educational and infrastructure components with a phased implementation mechanism.

The projected results of the model' s implementation by 2033 include an increase in the share of enterprises implementing innovations to 40%, a 150-200% increase in labour productivity, a 20-30% reduction in production costs, and a 2-3-fold increase in agricultural exports.

To assess the economic efficiency of innovation

implementation, a formula has been proposed that takes into account not only financial indicators but also the contribution to environmental sustainability and export potential.

The implementation of the proposed model will significantly increase the economic efficiency of Kazakhstan' s agricultural sector, ensure its sustainable development and competitiveness in international markets.

The key to success is a systematic approach and consistent implementation of all components of the model, taking into account regional characteristics and different types of farms.

The proposed model is fully consistent with the strategic priorities of the Republic of Kazakhstan, as set out in the Concept for the Development of the Agro-Industrial Complex of the Republic of Kazakhstan for 2021-2030 and the National Project for the Development of the Agro-Industrial Complex for 2021-2025. The five-component structure of the model corresponds to the five priority areas of the National Project: institutional development, technological modernisation, ensuring financial accessibility, human capital development and infrastructure improvement. The implementation of the model will contribute to the achievement of the target indicators of state programmes, including a 2.5-fold increase in labour productivity by 2030, an increase in the share of processed agricultural products to 70% and a twofold increase in exports of agro-industrial products.

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