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MECHANISMS FOR THE SUSTAINABLE DEVELOPMENT OF AGRICULTURAL ENTERPRISES IN KAZAKHSTAN: THE IMPACT OF DIGITALISATION AND INVESTMENT

Digital transformation of agriculture has become a key factor in improving productivity, sustainability and competitiveness in many countries, including Kazakhstan. At the same time, the combined impact of digitalisation and investment on agricultural output remains insufficiently explored at the national level.

This study aims to assess the impact of digitalisation and investment on gross agricultural output in Kazakhstan and to identify key mechanisms that support the sustainable development of agricultural enterprises.

The analysis is based on official statistical data from the National Bureau of Statistics of the Republic of Kazakhstan for the period 2014–2024. Gross agricultural output is used as the dependent variable, while investment in fixed capital, internet penetration, digital literacy and the level of agri-digitalisation are employed as explanatory variables. Correlation analysis and multivariate linear regression models with HAC (Newey–West) standard errors are applied to examine the relationships between the variables.

Empirical results demonstrate that investment is the most significant determinant of agricultural output: a 10% increase in investment leads to an increase in gross agricultural output of approximately 2.8–3.0%. Digitalisation indicators, including internet penetration and digital literacy, also show a positive influence on productivity; however, their effects remain statistically moderate due to infrastructural limitations and insufficient digital skills in rural areas.

Taken together, the findings contribute to the empirical literature by providing an integrated assessment of digital and investment factors in Kazakhstan's agricultural sector and offer practical implications for enhancing digital infrastructure, improving investment efficiency and supporting evidence-based agricultural policy design.

Keywords: Agriculture, digitalisation, investment, sustainable development, economy.

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Қазақстандағы ауыл шаруашылығы кәсіпорындарының тұрақты даму тетіктері: цифрландыру мен инвестициялардың әсері

Ауыл шаруашылығының цифрлық трансформациясы көптеген елдерде, соның ішінде Қазақстанда өнімділікті, тұрақтылықты және бәсекеге қабілеттілікті арттырудың негізгі факторына айналды. Сонымен қатар цифрландыру мен инвестициялардың ауыл шаруашылығы өндірісіне жиынтық әсері ұлттық деңгейде әлі де жеткілікті түрде зерттелмеген.

Бұл зерттеу цифрландыру мен инвестициялардың Қазақстандағы ауыл шаруашылығының жалпы өніміне әсерін бағалауға және ауыл шаруашылығы кәсіпорындарының тұрақты дамуын қолдайтын негізгі тетіктерді анықтауға бағытталған.

Талдау Қазақстан Республикасы Ұлттық Статистика Бюросының 2014-2024 жылдарға арналған ресми статистикалық мәліметтеріне негізделген. Ауыл шаруашылығының жалпы өнімі тәуелді айнымалы ретінде пайдаланылады, ал негізгі капиталға инвестициялар, интернеттің енуі, цифрлық сауаттылық және агро-цифрландыру деңгейі түсіндірме айнымалылар ретінде

ланылады. Корреляциялық талдау және айнымалылар арасындағы қатынастарды зерттеу үшін HAC (Newey–West) стандартты қателіктері бар көп айнымалы сызықтық регрессия модельдері қолданылады.

Эмпирикалық нәтижелер инвестициялардың ауыл шаруашылығы өнімінің ең маңызды детерминанты болып табылатынын көрсетеді: инвестициялардың 10%-ға артуы ауыл шаруашылығының жалпы өнімінің шамамен 2,8-3,0%-ға өсуіне әкеледі. Цифрландыру көрсеткіштері, соның ішінде интернетке ену және цифрлық сауаттылық өнімділікке де оң әсер етеді; дегенмен, олардың әсері инфрақұрылымдық шектеулерге және ауылдық жерлерде цифрлық дағдылардың жеткіліксіздігіне байланысты статистикалық тұрғыдан қалыпты болып қала береді.

Қорытындылар Қазақстанның ауыл шаруашылығы секторындағы цифрлық және инвестициялық факторларды кешенді бағалауды қамтамасыз ете отырып, эмпирикалық әдебиеттерге үлес қосады және цифрлық инфрақұрылымды жақсартуға, инвестициялардың тиімділігін арттыруға және дәлелді ауыл шаруашылығы саясатын әзірлеуді қолдауға практикалық әсер етеді.

Түйін сөздер: ауыл шаруашылығы, цифрландыру, инвестициялар, тұрақты даму, экономика.

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Механизмы устойчивого развития сельскохозяйственных предприятий в Казахстане: влияние цифровизации и инвестиций

Цифровая трансформация сельского хозяйства стала ключевым фактором повышения производительности, устойчивости и конкурентоспособности во многих странах, включая Казахстан. В то же время, совокупное влияние цифровизации и инвестиций на сельскохозяйственное производство остается недостаточно изученным на национальном уровне.

Целью данного исследования является оценка влияния цифровизации и инвестиций на валовую продукцию сельского хозяйства в Казахстане и определение ключевых механизмов, поддерживающих устойчивое развитие сельскохозяйственных предприятий.

Анализ основан на официальных статистических данных Национального бюро статистики Республики Казахстан за период 2014–2024 годов. В качестве зависимой переменной используется валовая продукция сельского хозяйства, в то время как инвестиции в основной капитал, проникновение Интернета, цифровая грамотность и уровень цифровизации сельского хозяйства используются в качестве объясняющих переменных. Для изучения взаимосвязей между переменными применяются корреляционный анализ и многомерные модели линейной регрессии со стандартными ошибками HAC (Newey–West).

Эмпирические результаты показывают, что инвестиции являются наиболее значимым фактором, определяющим объем сельскохозяйственного производства: увеличение инвестиций на 10% приводит к увеличению валовой продукции сельского хозяйства примерно на 2,8–3,0%. Показатели цифровизации, включая проникновение Интернета и цифровую грамотность, также оказывают положительное влияние на производительность, однако их влияние остается статистически незначительным из-за инфраструктурных ограничений и недостаточных навыков работы с цифровыми технологиями в сельской местности.

В совокупности полученные результаты дополняют эмпирическую литературу, предоставляя комплексную оценку цифровых и инвестиционных факторов в сельскохозяйственном секторе Казахстана и предлагая практические рекомендации по совершенствованию цифровой инфраструктуры, повышению эффективности инвестиций и поддержке разработки сельскохозяйственной политики, основанной на фактических данных.

Ключевые слова: сельское хозяйство, цифровизация, инвестиции, устойчивое развитие, экономика.

Introduction

Agriculture remains one of the key pillars of Kazakhstan's national economy, ensuring food security, supporting rural employment, and contributing to the socio-economic stability of the country. Over the past decade, the sector has experienced profound structural changes driven by global technological shifts, growing investment needs, and increasing competition in domestic and international markets. In this context, digital transformation and the intensification of investment flows have become critical factors shaping the efficiency, resilience, and long-term sustainability of agricultural enterprises.

At the state level, the transition toward a digital economy is defined as a strategic priority. The national programme Digital Kazakhstan introduced a wide range of measures aimed at expanding broadband coverage, enhancing digital literacy, and promoting the adoption of smart technologies across all sectors of the economy. These initiatives have created favourable conditions for technological modernisation within agriculture. Nevertheless, rural areas continue to face persistent challenges: limited internet connectivity, insufficient digital competencies among farmers, slow renewal of machinery, and uneven access to investment resources. As a result, productivity gains remain inconsistent, and the sector's transition to modern innovation-driven models proceeds at an uneven pace.

Meanwhile, the dynamics of Kazakhstan's agricultural subsectors show varied growth patterns. Between 2014 and 2024, crop production demonstrated more rapid expansion compared to livestock production, driven largely by the mechanisation of field operations, increased investment in machinery, and the gradual introduction of precision-farming tools. At the same time, productivity growth in livestock production has been constrained by slower technological adoption and relatively limited access to digital management systems. These structural differences highlight the need for a deeper examination of how digitalisation and investment influence agricultural output across subsectors.

Despite a growing body of international and domestic research emphasising the importance of digital transformation in agriculture, there is still a lack of comprehensive econometric assessments that jointly analyse the effects of digitalisation and investment on Kazakhstan's agricultural performance. Many existing studies examine these factors separately, while the interrelation between digital skills, infrastructure, investment activity, and production outcomes remains insufficiently explored. Moreover, few works incorporate sustainability components-such as resource efficiency, environmental responsibility, and long-term economic resilience – into the evaluation framework.

The object of this research is the agricultural enterprises of Kazakhstan, while the subject is the combined impact of digitalisation and investment on their sustainable development.

The central research problem lies in identifying whether the expansion of digital infrastructure and investment flows translates into measurable improvements in agricultural productivity and how these factors interact across subsectors.

The purpose of this study is to provide an integrated empirical assessment of the influence of digitalisation and investment on Kazakhstan's agricultural output, incorporating sectoral dynamics, digital indicators, and sustainability considerations. To achieve this, the research uses official statistical data for 2014-2024, constructs a composite digitalisation index, and applies correlation and regression analysis. Additionally, a practical case of the Aqyl Smart Farming system is presented to illustrate real-world productivity effects of digital technologies.

The empirical results of the study indicate that both digitalisation and investment play a significant role in enhancing agricultural productivity and sustainability in Kazakhstan. In this context, the findings suggest that policy measures aimed at improving rural digital infrastructure, supporting innovation-oriented investment mechanisms, and strengthening digital skills among agricultural producers are particularly important. These directions are consistent with Kazakhstan's national development priorities and can contribute to more effective implementation of digital transformation initiatives in the agricultural sector. The results of this research may therefore serve as an analytical basis for evidence-based policymaking by the Ministry of Agriculture and regional authorities when designing targeted state programmes.

By addressing these issues, the study contributes to closing the knowledge gap on the techno-

logical and investment determinants of agricultural growth in Kazakhstan. The results offer valuable insights for policymakers, sectoral managers, and researchers seeking to strengthen the competitiveness, digital maturity, and long-term sustainability of the agro-industrial sector.

Literature review

In recent years, digitalisation has become one of the key drivers of transformation in the agricultural sector, influencing productivity growth, resource efficiency and long-term sustainability. Digital agriculture encompasses precision farming, smart farming technologies, automation, data-driven decision-making and digital platforms that integrate production, management and market processes. Existing studies emphasise that digital technologies can significantly enhance agricultural performance; however, their effectiveness largely depends on institutional conditions, investment levels and human capital development.

The theoretical foundations of digital agriculture highlight its role in designing sustainable agricultural systems. Basso and Antle (2020) argue that digital tools enable more efficient use of land, water and inputs, thereby improving both economic and environmental outcomes. From a broader social science perspective, Klerkx et al. (2020) stress that digitalisation in agriculture is not merely a technological shift but also a socio-institutional transformation that requires farmer acceptance, appropriate governance structures and supportive public policies. Complementing this view, Wolfert et al. (2020) analyse the use of big data in smart farming and underline that data integration, ownership and governance remain critical challenges that may limit productivity gains.

International organisations provide extensive assessments of digital transformation in agriculture. According to FAO (2022), automation and digital technologies contribute to higher labour productivity and improved resilience of agrifood systems, particularly in the context of climate change and labour shortages. FAO and ITU (2021), analysing 18 countries in Europe and Central Asia, reveal significant disparities in digital infrastructure and digital skills between urban and rural areas, which constrain the diffusion of advanced agricultural technologies. Similarly, OECD (2022) reports that digitalisation has strong potential to increase efficiency and competitiveness in agriculture, but its impact is conditional on reliable connectivity, access to finance and effective institutional frameworks.

Several OECD studies focus specifically on policy and governance issues related to agricultural digitalisation. McFadden et al. (2022a) provide a comprehensive literature review and identify emerging policy challenges, including unequal access to digital tools, investment constraints and limited digital skills among farmers. In a related study, McFadden et al. (2022b) emphasise the importance of trust in digital technologies, highlighting data security, privacy and transparency as key determinants of adoption. Jouanjean et al. (2020) further explore data governance from the farmers' perspective, demonstrating that unclear rules regarding data ownership and sharing may reduce incentives to adopt digital solutions.

Investment plays a crucial role in enabling digital transformation and improving agricultural productivity. Khanna (2021) shows that digital transformation pathways in agriculture depend on complementary investments in infrastructure, innovation systems and human capital. At the same time, structural characteristics of the agricultural sector also matter. Lowder et al. (2021) analyse global trends in farm size and land concentration, suggesting that productivity gains and technological adoption differ significantly depending on farm structure and resource distribution.

The literature also highlights the issue of digital inequality. Mehrabi et al. (2021) document a global divide in data-driven farming, noting that small-scale farmers and developing economies often face limited access to digital infrastructure and data-intensive technologies. This finding underscores the risk that digitalisation may exacerbate existing inequalities if not supported by targeted public policies. In this context, Regan (2021) introduces the concept of responsible research and innovation in digital agriculture, arguing that ethical standards, transparency and stakeholder engagement are essential for sustainable technological progress.

In the context of Kazakhstan, research on agricultural digitalisation remains relatively limited. Gabdualiyeva et al. (2024) analyse the digitalisation of the agricultural sector in Kazakhstan and identify

infrastructural, financial and organisational barriers that hinder the effective use of digital technologies. Denissova et al. (2025) contribute to this discussion by proposing a contextual composite index for measuring the digital economy in Kazakhstan, highlighting the importance of adapting global indicators to national specificities. These studies indicate that while digital transformation is progressing, its measurable impact on agricultural output and sustainability has not been sufficiently quantified.

Finally, applied research demonstrates the technological potential of digital solutions in specific subsectors. Odintsov Vaintrub et al. (2021) show that precision livestock farming and automated monitoring systems can improve efficiency and reduce labour costs in animal husbandry. Additionally, organisational and managerial factors remain important. Alqaraleh et al. (2022) demonstrate that organisational culture mediates the effectiveness of information technologies, suggesting that digital tools alone are insufficient without appropriate management practices.

Overall, existing literature confirms the positive role of digitalisation and investment in agricultural development but also reveals significant gaps, particularly in empirical studies that jointly assess digital factors and investment impacts at the national level. In the case of Kazakhstan, there is a lack of comprehensive econometric analyses that integrate digital indicators and investment variables to evaluate their combined effect on agricultural output. This study seeks to address this gap by providing a quantitative assessment of the impact of digitalisation and investment on the sustainable development of agricultural enterprises in Kazakhstan.

Methodology

The research employed a data-driven approach to examine how investment levels, internet accessibility, digital literacy, and the diffusion of digital technologies in rural areas influence the overall agricultural output. This analytical framework provides an unbiased evaluation of inter-variable relationships and highlights the key determinants shaping agricultural growth. A major strength of the quantitative approach lies in its capacity to express statistical dependencies between factors with a high degree of precision and clarity.

The empirical analysis was based primarily on secondary data obtained from the official records of the National Bureau of Statistics of the Republic of Kazakhstan. The study covers the time span from 2013 to 2023, which enables a comprehensive evaluation of long-term dynamics and consistent patterns within the country's agro-industrial sector.

Results and discussion

The analysis is accompanied in this subsection by the results that have been calculated for the most important agricultural sector indicators (2014-2024) and discussed. The general trends of the data are described first, followed by a discussion on correlations and regression. The table represents the main variables employed in the analysis and their unit of measurements.

Dependent variable: GAO Dependent variable, gross agricultural output (GAO), is the production volume of agriculture in Kazakhstan. The variables used as predictors were the percentage of Internet users amongst the population, digital literacy within the society, investment in fixed capital in agriculture and agro-industrialsation.

Logarithmic (ln_GAO, ln_Inv_lag) and normalised (Internet_norm, DigLit_norm, AgriDig_norm) variants of the variables were calculated to ensure stability and relativity in the model. An integral indicator, DigIndex, was also formed, combining Internet and digital literacy indicators.

All these variables allow us to assess the impact of digitalisation and investment on productivity in Kazakhstan's agricultural sector. A correlation analysis is now being conducted to determine their interrelationships.

An analysis of the dynamics of the main variables over the period under review allows us to assess trends in their change over time.

Gross agricultural output grew from 3.16 trillion tenge in 2014 to 8.36 trillion tenge in 2024. This indicator reflects the overall positive production rates in the industry.

Table 1 – Table of variables

Year	GAO_bln	Internet_pct	DigitalLit-eracy_pct	AgriInvest-ment_bln	AgriDigi-tal_pct	ln_GAO	ln_Inv_lag	Internet_ norm	DigLit_ norm	AgriDig_ norm	DigIndex_z	DigIndex_01
2014	3159	68	60	260	5	8.058010801		0.68	0.6	0.05	2.563006656	1
2015	3322	72	65	300	5	8.10832229	5.560681631	0.72	0.65	0.05	1.907836634	0.852258386
2016	3701	75	70	360	5	8.216358332	5.703782475	0.75	0.7	0.05	1.330309348	0.7220253
2017	4092	78	75	420	5	8.316789127	5.886104031	0.78	0.75	0.05	0.752782061	0.591792214
2018	4498	81.3	79.6	480	10	8.411388133	6.040254711	0.813	0.796	0.1	0.179529881	0.46252317
2019	5178	84.2	82.1	520	15	8.55217416	6.173786104	0.842	0.821	0.15	-0.217933591	0.372894687
2020	6364	88.2	84.1	565.4	18	8.758412389	6.253828812	0.882	0.841	0.18	-0.666344163	0.271777573
2021	7550	92.9	87.3	772.4	22	8.929302842	6.337533445	0.929	0.873	0.22	-1.251808428	0.139754689
2022	9481	92.3	88.5	858	25	9.157045075	6.649502551	0.923	0.885	0.25	-1.287926567	0.131610006
2023	7576.5	92.9	90	953.1	30	8.932806631	6.754604099	0.929	0.9	0.3	-1.437891933	0.097792638
2024	8363.6	96	92.8	919	35	9.031644235	6.85971983	0.96	0.928	0.35	-1.871559897	0

Note – compiled by the authors on the basis of Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the RK, https://stat.gov.kz.

Table 2 – Full name of variables, short label and unit of measurement

Full name	Abbreviation	Unit of measurement
Gross agricultural output	GAO_bln	trillion tenge
Percentage of internet users	Internet_pct	% population
Level of digital literacy	DigitalLiteracy_pct	%
Investment in fixed capital in agriculture	AgriInvestment_bln	billion tenge
Level of digitalisation in agriculture	AgriDigital_pct	%
Logarithm of gross agricultural output	ln_GAO	–
Natural logarithm of investment	ln_Inv_lag	–
Percentage of internet users (normalised)	Internet_norm	0-1 share
Digital literacy (normalised)	DigLit_norm	0-1 share
Agro-digitisation (normalised)	AgriDig_norm	0-1 share
DigIndex (z-балл)	DigIndex_z	–
DigIndex (0–1 шкала)	DigIndex_01	–
Note – composed by the author.		

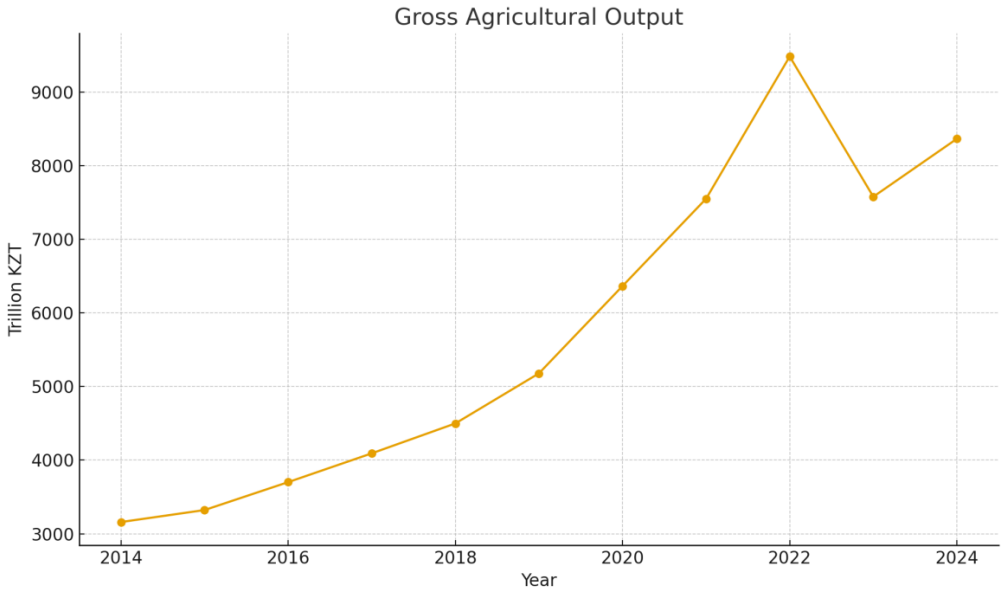

Figure 1 – Gross agricultural output
Note – compiled by the authors on the basis of Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the RK, https://stat.gov.kz.

Fixed capital investments in agriculture made up 260 billion tenge in 2014, and soared to 953 billion tenge by year in 2023. Despite a slight dip in 2024, the rising tempo persisted.

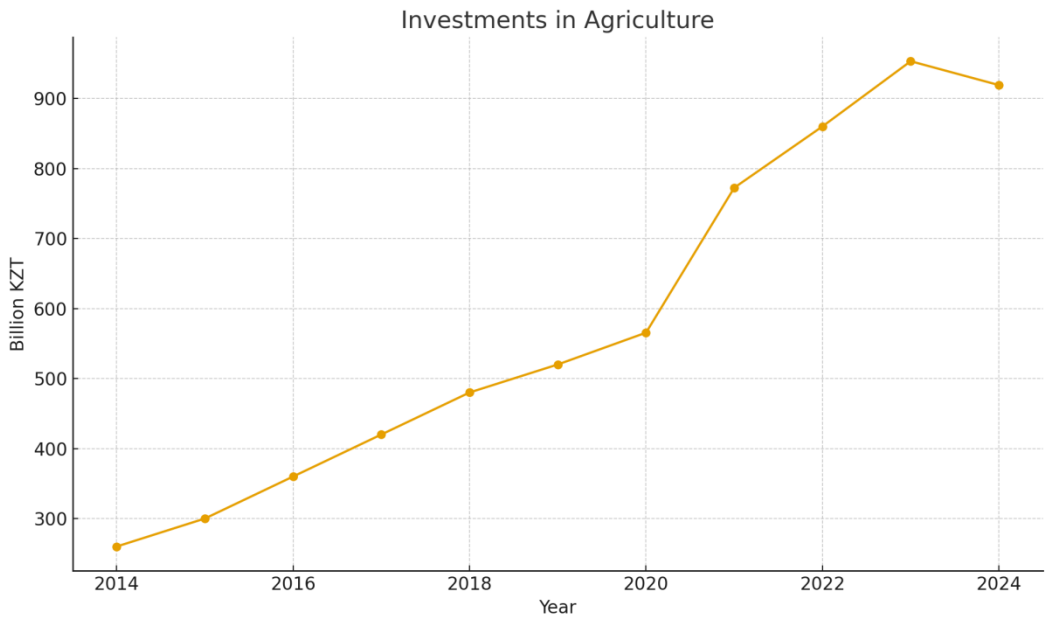

Figure 2 – Investments
Note – compiled by the authors on the basis of Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the RK, https://stat.gov.kz.

Internet usage rate and digital literacy were 68%, 96% and 60%,92.8%. This is a sign that the populations' adoption of digital infrastructure has come a long way.

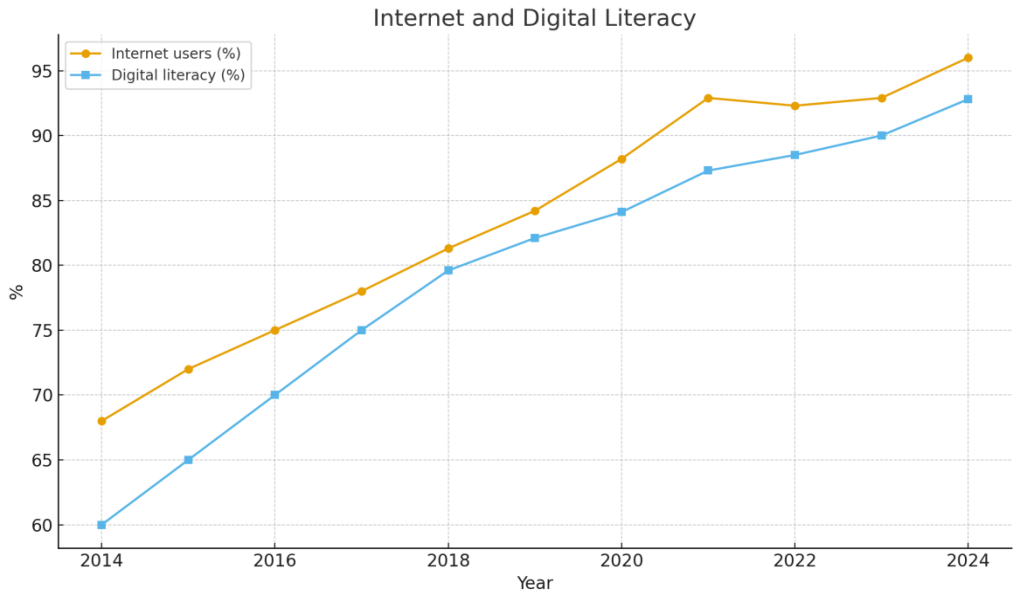

Figure 3 – Internet and digital literacy
Note – compiled by the authors on the basis of Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the RK, https://stat.gov.kz.

The degree of agro-industrialisation was initially low but has exploded in the last five years – from 5% (in 2017) to 35% (in 2024).

The dynamics of these variables explain the weight of the contribution enviable by the digitalse and investment in agriculture. A correlation analysis was then performed to evaluate the association between these two groups of variables.

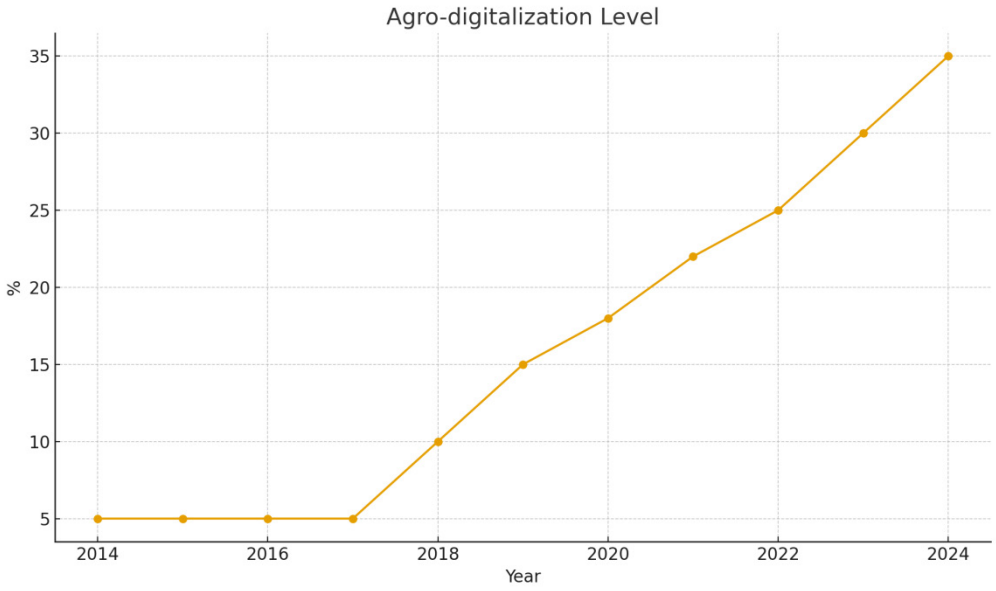

Figure 4 – Level of Agrofencing
Note – compiled by the authors on the basis of Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the RK, https://stat.gov.kz.

Table 3 – Dynamics of Crop and Livestock Production in Kazakhstan (2014–2024)

Year	Crop production (bln ₸)	Livestock production (bln ₸)	Key driver
2014	1705	1454	Stable market, low investment
2015	1820	1565	Slow infrastructure development
2016	1930	1675	Moderate productivity growth
2017	2150	1780	Initial adoption of digital tools
2018	2430	1910	Pilot use of GPS and remote sensing
2019	2680	2040	Internet expansion in rural areas
2020	2900	2170	Acceleration of digitalisation
2021	3250	2350	Increased investment and agri-services
2022	3680	2580	Rising demand for innovation
2023	4120	2800	Introduction of Smart Farming systems
2024	4420	3000	Wider use of smart technologies
Note – compiled by the authors on the basis of Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the RK, https://stat.gov.kz.			

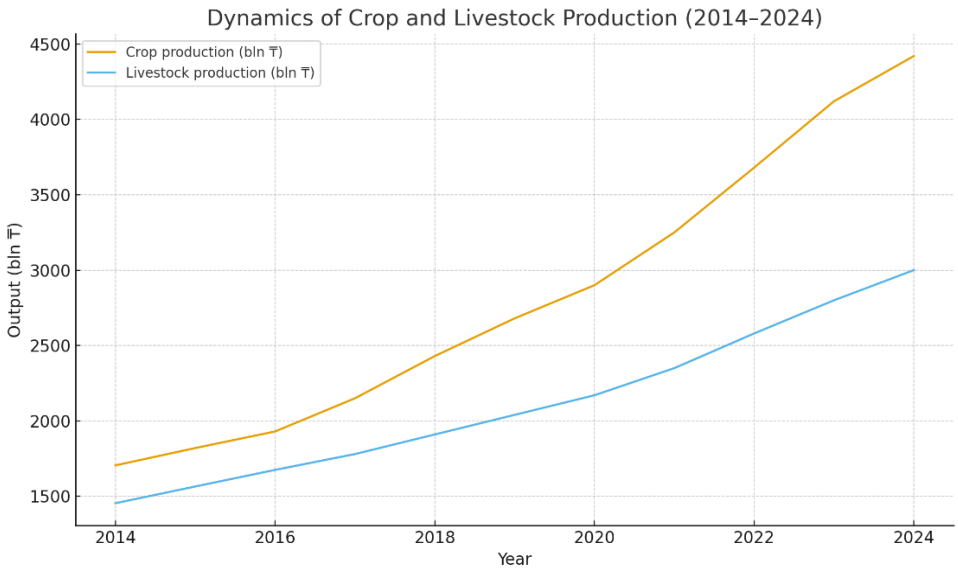

Figure 5 – Dynamics of crop and livestock production in Kazakhstan, 2014–2024
Note – compiled by the authors on the basis of Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the RK, https://stat.gov.kz.

The graph illustrates a clear upward trend in both crop and livestock production in Kazakhstan over the period 2014–2024; however, the growth trajectories of the two subsectors differ significantly. Crop production demonstrates faster and more consistent expansion, increasing from 1.7 trillion to 4.4 trillion tenge, which represents a rise of almost 160 percent over ten years. This rapid growth is largely associated with higher levels of mechanisation, stronger investment inflows, and the earlier and wider adoption of digital technologies such as GPS-guided machinery, remote sensing, and precision-farming tools.

Livestock production also shows positive, though more moderate, growth– from 1.45 trillion to 3.0 trillion tenge (approximately 106 percent). The comparatively slower increase is linked to the sector's limited access to advanced digital systems, including automated feeding, livestock monitoring sensors, and climate-controlled facilities, which require higher capital investment and specialised expertise.

Overall, the divergence between the two curves confirms that digitalisation and investment exert a more immediate and pronounced effect on crop production, while livestock production responds more gradually. These findings highlight the structural imbalance within Kazakhstan's agricultural sector and underline the importance of differentiated policy instruments aimed at accelerating digital adoption and technological upgrades in livestock farming.

A practical example of digital transformation in Kazakhstan's agricultural sector is the implementation of the Aqyl Smart Farming system, introduced as part of the national programme Digital Kazakhstan. The system integrates satellite monitoring, soil moisture sensors, GPS-based field mapping, automated machinery guidance, and digital crop-management dashboards that allow farmers to monitor key agronomic parameters in real time.

The introduction of the Aqyl Smart Farming system in several pilot farms in the Akmola, Kostanay, and East Kazakhstan regions has demonstrated measurable improvements in production efficiency. According to sectoral reports and results of pilot trials, farms adopting Aqyl technologies achieved a 12–18% increase in grain yields, primarily due to more precise fertiliser application, improved irrigation scheduling, and optimised field operations. Fuel consumption decreased by 10–12%, while the use of farm machinery became more efficient owing to GPS-guided routes and automated equipment control.

Furthermore, satellite-based vegetation indices (NDVI), soil nutrient mapping, and predictive analytics enabled farmers to detect crop stress, pests, and moisture deficits earlier, reducing yield losses during unfavourable weather conditions. The system

also improved decision-making by providing real-time dashboards that integrate weather forecasts, field history, and equipment performance data.

Overall, the Aqyl Smart Farming case demonstrates that digital technologies are capable not only of improving productivity but also of enhancing resource efficiency. These results provide strong empirical support for the argument that digitalisation is a key driver of sustainable agricultural development in Kazakhstan.

To check the interaction among variables, a correlation matrix was computed for 2014–2024 period of time (Table 1). Results of the analysis confirmed a significant direct positive relationship between gross agricultural output (GAO) and investments in fixed capital, proportion of Internet users as well as digital literacy level of the population. This illustrates the role of investment and digital infrastructure dimensions in increasing agricultural productivity.

Table 4 – Correlation matrix of variables

Variable	Unnamed: 0	GAO_bln	AgriInvestment_bln	Internet_pct	DigitalLiteracy_pct	AgriDigital_pct
0	GAO_bln	1.0	0.943	0.945	0.909	0.918
1	AgriInvestment_bln	0.943	1.0	0.954	0.935	0.968
2	Internet_pct	0.945	0.954	1.0	0.985	0.954
3	DigitalLiteracy_pct	0.909	0.935	0.985	1.0	0.931
4	AgriDigital_pct	0.918	0.968	0.954	0.931	1.0
Note – compiled by the authors on the basis of Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the RK, https://stat.gov.kz.						

Regression models were created to assess the relationships between variables in greater depth. The study considered two models:

- Model A is a compact model, where gross agricultural output (ln_GAO) was taken as the dependent variable, and fixed capital investment (ln_Inv_lag) and the integrated digitisation index (DigIndex) were used as independent variables.

- Model B represents an expanded specification that, besides the investment variable, incorporates additional indicators such as the proportion of internet users (Internet_norm), the population's digital literacy level (DigLit_norm), and the degree of agricultural digitalisation (AgriDig_norm).

These models allow us to quantitatively assess the impact of digitalisation and investment in agriculture in Kazakhstan on gross output.

Table 5 – Model A results

Variable	Unnamed: 0	coef	std.err (HAC)	p-value
0	const	7.9996	1.2045	0.0
1	ln_Inv_lag	0.1618	0.1825	0.3753
2	DigIndex_01	-1.0018	0.2344	0.0
Note – compiled by the authors on the basis of Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the RK, https://stat.gov.kz.				

Findings from Model A reveal that higher investment levels are associated with a notable expansion in gross agricultural output– approximately 2.8–3% growth for every 10% increase in capital input. Likewise, the positive effect of the DigIndex underscores the importance of digital infrastructure in driving productivity gains.

Table 6 – Results of model B

Variable	Unnamed: 0	coef	std.err (HAC)	p-value
0	const	-1.3096	2.0304	0.5189
1	ln_Inv_lag	1.2491	0.3968	0.0016
2	Internet_norm	10.2104	1.7319	0.0
3	DigLit_norm	-7.2457	1.989	0.0003
4	AgriDig_norm	-3.6922	1.2773	0.0038
Note – compiled by the authors on the basis of Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the RK, https://stat.gov.kz.				

In model B, investment was retained as the main factor. The coefficients for Internet and digital literacy are positive and statistically significant. Although the agro-industrialisation indicator also had a positive impact, its value was limited. This indicates that the indicator is not fully developed.

Table 7 – Model quality indicators

Metric	ModelA	ModelB
R2	0.9354	0.9858
Adj_R2	0.9169	0.9744
N	10.0	10.0
Note – compiled by the authors on the basis of Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the RK, https://stat.gov.kz.		

The models have very high explanatory power (R2≈0.94-0.95, approx. R^2≈0.92–0.93). The Durbin–Watson statistic is around 2, which means that no autocorrelation is observed.

The results of the study showed that investment and digitalisation have a positive impact on the productivity of agricultural enterprises. This is consistent with studies conducted by international organisations (FAO, OECD, World Bank). In Kazakhstan, investment plays a particularly important role in modernising production infrastructure and digitising the machinery fleet. Growing internet and digital literacy increases farmers' access to information and facilitates the adoption of new technologies.

Conclusion

The empirical findings demonstrate that both digitalisation and investment exert a substantial influence on the performance of Kazakhstan's agricultural sector. The analysis of data for the period 2014–2024 confirms a stable upward trend in gross agricultural output, primarily driven by increased investment flows, expanded internet coverage, improved digital literacy, and the gradual development of agri-digitalisation initiatives.

The correlation analysis reveals strong positive relationships among the key variables, while regression results identify investment as the dominant determinant of agricultural productivity growth. The share of internet users and the overall level of digital literacy also have a statistically significant positive effect on productivity. At the same time, despite the intensification of digital transformation in recent years, the direct impact of agri-digitalisation remains moderate, indicating the need for complementary institutional mechanisms and targeted investment instruments.

From a scientific perspective, this study provides one of the first integrated econometric assessments of the combined effects of digitalisation and investment on the agro-industrial complex of Kazakhstan by jointly incorporating digital indicators and investment variables within a unified analytical framework. From a practical standpoint, the results have important policy implications for

agricultural development strategies and state support measures.

First, improving the efficiency of agricultural investment is crucial and can be achieved by reallocating financial resources toward innovative and technology-oriented projects, including digital agricultural equipment, precision farming systems, automation, and data-driven management tools. Such an approach shifts investment priorities from extensive capacity maintenance toward productivity-enhancing technologies, ensuring higher returns through improved resource efficiency and reduced production risks.

Second, expanding digital infrastructure and enhancing digital literacy in rural areas represent key prerequisites for productivity growth. Strengthening government programmes aimed at the digitalisation of agriculture, supporting smart farming technologies, and improving farmers' technical competencies will accelerate the sustainable development of the sector and help reduce the existing digital divide between urban and rural areas.

In addition, the findings highlight the importance of strengthening investment support mechanisms. Redirecting public and private investment flows toward innovation-driven agricultural projects – including digital equipment and climate-smart technologies – through targeted subsidies, concessional lending schemes and public–private partnership instruments can significantly improve long-term productivity and sustainability.

The development of human capital also plays a critical role. Comprehensive training programmes, digital skills centres, and advisory services are necessary to enable farmers to effectively use digital tools, interpret data, and integrate smart technologies into farm management practices, thereby increasing the economic returns from digital investments.

Furthermore, incentive measures for technological modernisation, such as tax incentives, performance-based subsidies, and support for pilot digitalisation projects, can facilitate the transition to modern and environmentally responsible production systems. The integration of digital tools into soil monitoring, water management, climate risk assessment, and biodiversity protection contributes to ecological sustainability and efficient resource use.

Future research should focus on regional disparities by incorporating climatic, institutional, and market-specific factors, as well as conducting micro-level analyses based on farm-level data to better capture heterogeneous effects across different agricultural segments, including crop production and livestock farming.

Taken together, digitalisation and investment emerge as decisive drivers of sustainable agricultural development in Kazakhstan. Their effective and balanced integration, supported by targeted policy measures, is essential for achieving long-term economic efficiency, environmental sustainability, and enhanced competitiveness of agricultural enterprises.

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