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Development of public-private partnerships in the agriculture of Kyrgyzstan in the context of the experience of the Republic of Belarus

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Abstract. Public-private partnership (PPP) plays a key role in the development of agriculture by attracting investment, modernising infrastructure, and enhancing the agricultural sector's efficiency. This article examined the prospects for developing PPPs in the agriculture of the Kyrgyz Republic, taking into account the experience of the Republic of Belarus. The regulatory framework governing the mechanisms of interaction between the state and the private sector in both countries was analysed, alongside a review of existing models of cooperation, including concessions, investment agreements, and cluster initiatives. Belarus possesses considerable experience in implementing state support programmes for agriculture, including subsidies, tax incentives, and the establishment of agro-industrial clusters and cooperatives. These measures have significantly improved the country's level of food security and export potential. Meanwhile, Kyrgyzstan faces several challenges, such as a shortage of Winvestment, outdated infrastructure, and a low level of adoption of innovative technologies. The article proposed recommendations for adapting successful Belarusian practices to Kyrgyz conditions, including the improvement of legislative mechanisms, the creation of favourable conditions for investors, the development of agrotechnology parks, and the digitalisation of agriculture. The need to expand international cooperation and exchange of experience between the two countries was emphasised, to establish a sustainable PPP model that supports the growth of Kyrgyzstan's agro-industrial sector. Particular attention was given to the creation and development of large state-owned agricultural enterprises on 25% of state land from the fund for the redistribution of irrigated arable land designated for agricultural use in the rural communities (ayyl aymagy). The establishment of such enterprises is intended to implement a balanced agricultural policy that promotes the support of rural areas, the development of agricultural infrastructure, and the creation of employment opportunities. This approach is expected to stimulate the local economy and contribute to ensuring the food security of the Kyrgyz Republic

Keywords: investment; agro-industrial sector; irrigated arable land; agricultural land redistribution fund; food security

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Introduction

Amidst globalisation, climate change, and the modernisation of agricultural technologies, the agrarian sector of the Kyrgyz Republic confronts a series of challenges necessitating adaptation to new conditions. The socio-economic advancement of agricultural production and the creation of stable employment are key factors in enhancing the quality of life in rural areas and reducing migration levels. Agricultural development plays a crucial role in ensuring food security, improving living standards, preserving cultural heritage and the national gene pool, as well as in protecting state borders and the environment (Britwum & Demont, 2022). The agro-industrial complex (AIC) serves as the primary source for food production and other agricultural commodities, supplying raw materials essential for the smooth operation of the processing industry, fostering exports, and boosting the country's economic stability.

To ensure food security, not only are production volumes crucial, but also the efficient use of land and water resources, the environmental sustainability of agriculture, the development of agrotechnologies, and the improvement of living conditions for rural residents (Mostova & Hutorov, 2022). These are key factors determining the sustainability and productivity of agricultural production; this affects not only the volume of output but also the preservation of ecological balance, which is critically important for future generations (Saikanth *et al.*, 2023). Therefore, it is essential to give particular attention to the comprehensive development of the agrarian sector, encompassing the process of creating and implementing a strategy aimed at the all-around improvement of agriculture and related industries. This includes not only increasing agricultural production but also improving infrastructure, technologies, human resources, and developing marketing and market relations. Specifically, as highlighted by M. Wrzecińska *et al.* (2023), the implementation of IT solutions in agriculture leads to cost reduction, increased efficiency, and improved food security. Furthermore, T. Omoshev *et al.* (2024) have demonstrated that green technologies in the agricultural sphere can enhance crop yields and increase livestock production volumes.

One effective mechanism for modernising agriculture is state agricultural enterprises (SAEs) based on public-private partnerships (PPPs), which allows for the attraction of private investment, enhanced management efficiency of agricultural enterprises, and the implementation of innovative technologies. In a context of limited budgetary resources, SAEs based on PPPs become a key instrument for the sustainable development of the agricultural sector, contributing to technological modernisation, the creation of new jobs, and increased product competitiveness. The experience of the Republic of Belarus is of particular interest to countries within the Eurasian Economic Union (EAEU), where state policy plays a crucial role in modernising the agro-industrial complex (AIC). This is reflected in various programmes and strategies aimed at stimulating the growth of agricultural production, increasing its efficiency, and improving working conditions.

A crucial element of the Republic of Belarus's agrarian policy is the implementation of innovative technologies. Here, modernisation encompasses the introduction of highly effective technologies, novel agrotechnical methods including process automation, the use of high-yield crop varieties and hybrids, and environmentally friendly production techniques, alongside the updating of machinery and equipment, notably that which is domestically produced (Minina, 2022). A significant proportion of agricultural production in Belarus is concentrated within the state sector, and the Belarusian AIC model serves as an example of effectively organised agriculture and the food industry within a state-oriented economy. This model facilitates the integration of production, processing, and marketing, underpinned by a substantial degree of state regulation and support. This ensures more stable planning and the implementation of long-term strategies geared towards national food security (Obukhova, 2021).

The experience of the Republic of Belarus indicates that centralised state management of the agrarian sector, the implementation of agro-industrial holdings and cooperative models, the systematic development of agrotowns and agricultural enterprises, alongside state support, all contribute to increasing agricultural efficiency, developing rural infrastructure, and improving the socio-economic status of the rural population. In this context, studying the Belarusian experience and adapting it to the conditions in Kyrgyzstan holds significant academic and practical value. The two countries share common characteristics, such as their development trajectory as part of the Soviet Union, the evolution of national institutions, and challenges in the areas of economics, education, and social welfare.

This study was aimed at identifying opportunities for utilising elements of the Belarusian agro-industrial complex model within the Kyrgyz Republic to enhance agricultural productivity, improve the economic performance of agricultural enterprises, and foster the development of rural areas. The research aim was to analyse and substantiate the possibilities for the creation and development of state agricultural enterprises in the Kyrgyz Republic, taking into account the experience of agricultural convergence in the Republic of Belarus, as well as to develop recommendations for improving agrarian policy and increasing the efficiency of the agricultural sector. The object of the research was the state agricultural enterprises of the Kyrgyz Republic in the context of their formation, development, and functioning, drawing on the experience of agricultural convergence in the Republic of Belarus. The subject of the research was the mechanisms of publicprivate partnership applied in the agricultural sector of the Kyrgyz Republic and their potential adaptation based on the Belarusian experience.

Materials and Methods

The research was based on an analysis of theoretical and empirical data characterising the development of agricultural production in the Kyrgyz Republic and the Republic of Belarus, with particular attention paid to the role of Belarusian state agricultural enterprises in ensuring food security and economic stability. The history of the sovereign Kyrgyz economy was studied, where a significant element is the transition from a planned to a market economy, along with the challenges associated with climatic conditions, land issues, and financing (Umarova, 2015).

The materials used included: regulatory legal acts and state programmes governing the agrarian sector in Kyrgyzstan and Belarus; statistical data on the agro-industrial complex of both countries; archival materials concerning the activities of state agricultural enterprises; academic publications, monographs, and articles on agricultural convergence and state management in the AIC; and data from expert interviews with representatives of the agricultural sector, state bodies, and research institutions. Particular focus was placed on analysing statistical data regarding agriculture in Kyrgyzstan and Belarus, including production volumes and agricultural production efficiency (National Statistical Committee of Belarus, n.d.; National Statistical Committee of the Kyrgyz Republic, n.d.).

The methodological basis of the research included: an analysis of the regulatory framework governing the development of the agro-industrial complex; a comparative analysis of state agricultural management models in Belarus and Kyrgyzstan; a systemic analysis of state agricultural enterprise mechanisms based on public-private partnerships and their adaptation to Kyrgyz conditions; and an economic and statistical analysis of the efficiency of agricultural enterprises. This comprehensive and multifaceted research task necessitated considering numerous aspects, including management strategies and principles, as well as the socio-economic characteristics of these countries. This approach allowed for a more detailed identification of the general differences in approaches to solving agricultural production challenges, where Belarus employs a more controlled and planned model, whilst Kyrgyzstan utilises a more liberal and market-oriented model.

Results and Discussion

The need for a balanced state agrarian policy

The agrarian specificity of mountainous Kyrgyzstan is a historically established fundamental value for the Kyrgyz people and state, founded on a synthesis of the best national farming experience and modern ideas. The state of agriculture has consistently reflected the level of development of Kyrgyz statehood and indicated the degree of the country's socio-economic progress across different historical periods. To ensure the well-being of the population and national food security, it is imperative to adopt the experience of developed countries. In these nations, the natural potential for agricultural sector development is amplified by the high intensity and effectiveness of innovation adoption, where traditional farming methods are boldly departed from to ensure abundant food production while preserving and enhancing soil fertility. These solutions will collectively help create conditions for attracting investment into the development and implementation of innovative agrarian production practices aimed at increasing agricultural efficiency, improving product quality, and enhancing soil fertility. They should facilitate the establishment of modern agro-industrial complexes, agrotowns, and clusters, as well as improve the logistics, marketing, and management of agricultural products (Resolution..., 2017).

One of the key aspects of researching this topic is not merely the analysis of the current state but also the development and implementation of effective measures to address the challenges facing the agricultural sector and the social development of rural areas. In an era of globalisation, Kyrgyzstan must compete with global agrarian economies, necessitating a systematic approach and strategic planning. As is well known, the transition process from a planned to a market economy was complex and multifaceted, presenting numerous economic, social, and political issues, accompanied by significant challenges in both the economic and social spheres. In the agricultural sector of the Kyrgyz Republic, this process involved the dismantling of the old system and the creation of a new one, requiring considerable effort from the state, international organisations, and the rural population (Umarova, 2015).

Currently, the country's rural population faces significant migration to large cities and abroad, leading to socio-economic imbalance and creating a "migration pit" in the villages of the Kyrgyz Republic. The causes of this include social inequality and unemployment, exacerbated by low seasonal wages for hired labour. The economic concentration history in South Korean metropolises serves as an important lesson: a mass exodus of young people from rural regions resulted in declining birth rates and an ageing population (Pareliussen, 2025). It is crucial for Kyrgyzstan to consider these risks and develop measures that will facilitate balanced rural development, creating conditions for living and working in the regions. To overcome these challenges, a balanced economic policy must be developed and implemented, aimed at supporting rural regions, developing agricultural infrastructure, and creating employment opportunities, thereby stimulating local economies. In this context, the experience of the development of the agro-industrial complex (AIC) in Belarus, including state support for agrotowns and agricultural enterprises, is of particular interest to the Kyrgyz Republic.

According to data from the National Statistical Committee of the Kyrgyz Republic (n.d.), as of 2025, the majority of arable land in Kyrgyzstan (72.2%) is held by peasant (farmer) households, covering a total area of 928.5 thousand hectares. However, a significant proportion of these households own only 1-3 hectares of arable land, which limits their capacity for large-scale agricultural production (Karabaev & Umarova, 2025). Furthermore, there is a discernible trend towards further fragmentation of agricultural land. At the beginning of 2023, 361.5 thousand peasant (farmer) households were registered in the country, whereas in 2022, their number stood at 356.8 thousand, indicating an increase of 4.7 thousand households in just one year (National Statistical Committee of the Kyrgyz Republic, n.d.). Such fragmentation of landholdings poses additional challenges for the sustainable development of the agrarian sector, necessitating effective measures for the consolidation and cooperation of agricultural producers. These measures encompass vital elements aimed at enhancing agricultural efficiency and ensuring resilience to external economic and natural risks.

On small areas of irrigated arable land, small peasant households (SPHs) encounter difficulties in effectively carrying out agricultural tasks such as crop rotation and agrotechnical measures aimed at preventing soil degradation. This approach by small peasant households to the land leads to a gradual deterioration in the quality of arable land and a reduction in its fertility year by year. Despite this, the majority of agricultural produce in the Kyrgyz Republic is generated by small peasant households, which face several challenges limiting their development:

- small peasant households frequently suffer from a lack of financial resources, restricting their ability to acquire modern machinery and implement innovative agrotechnical solutions that could improve soil fertility. This, in turn, diminishes their competitiveness in the market;
- the limited area of irrigated arable land does not permit substantial expansion of production, hindering the diversification of economic activities and constraining opportunities for significant income growth;
- limited access to modern agricultural machinery results in high production costs and reduced productivity. Furthermore, small holdings often lack the capacity to employ skilled labour;
- a restricted volume of production decreases the attractiveness of their produce to large buyers, leading to sales issues, harvest losses, and diminished income;
- a shortage of resources and knowledge impedes the adoption of modern agrotechnologies, which lowers yields, degrades product quality, and negatively impacts production profitability;
- the scarcity of irrigation water and the absence of effective mechanisms for protection against drought and other adverse weather conditions render small holdings particularly vulnerable to climate change.

Therefore, considering the agrarian specificities of Kyrgyzstan and the challenges confronting small peasant households, studying and adapting the experience of developed countries, particularly concerning the implementation of innovations and the formation of effective agro-industrial structures, appears to be a crucial direction for ensuring the sustainable development of agriculture and the country's food security.

The role of large farmers, potential for cooperation, and administrative-territorial reform

Contemporary agriculture in the Kyrgyz Republic includes large-scale farmers who own considerable land areas and lease irrigated arable land from small peasant households (SPHs). These farmers are equipped with modern machinery and seek to expand their landholdings, including utilising the Agricultural Land Redistribution Fund (ALRF), which enables them to achieve maximum economic returns. Leasing additional land serves as a strategy for increasing production volumes, improving financial performance, and enhancing market competitiveness, leading to an annual increase in agricultural output. However, such farmers are typically not invested in long-term measures to improve the fertility of leased land, which could pose a challenge to the sustainability of the agrarian sector in the future. Whilst these Kyrgyz farmers undoubtedly contribute to resolving some local socio-economic issues in rural areas, a more comprehensive approach, involving state intervention and other social institutions, is required for more significant changes in the socio-economic sphere, such as poverty eradication. Addressing issues like the low level of professional education or problems with rural employment, population migration, and infrastructure improvement demands a broader strategy, including the involvement of the state and other social institutions.

The administrative-territorial reform conducted in the Kyrgyz Republic has opened up significant opportunities for implementing initiatives aimed at establishing large cooperatives on land from the ALRF. These cooperatives are gradually increasing their acquisition of modern machinery and adopting more effective working methods. Decree of the President of the Kyrgyz Republic No. 202 "On Measures for the Further Development of the Agro-Industrial Complex of the Kyrgyz Republic" (2024) makes provision for financial and material support for such cooperatives, thereby contributing to their development and the strengthening of the country's agricultural sector.

The potential of the agricultural sector in the Kyrgyz Republic is evident, and the time has come to seek avenues for effective development and to undertake extensive work to address the accumulated problems, including enhancing soil fertility (Karabaev *et al.*, 2016). The challenges facing rural territories have been accumulating over the years, and it is now time to move towards comprehensive and complete solutions. It is crucial that agricultural production not only increases labour productivity but also contributes to strengthening the foundations of statehood. To elevate the agro-industrial complex of the Kyrgyz Republic to a qualitatively new level and achieve objectives such as increasing gross output and improving the socio-economic situation in rural areas, a comprehensive strategy must be implemented. This demands a multifaceted approach: a new agrarian policy incorporating modernisation, support, training, infrastructure enhancement, and sustainable resource utilisation, facilitated by state support with the involvement of investments and public-private partnerships.

Against this backdrop, the operational experience of large agricultural enterprises in countries like Belarus, China, and Israel is of considerable interest. It is necessary to carefully study the experience of these countries, adapting it to the specific conditions of Kyrgyzstan, paying particular attention to the development experience of Belarus's AIC. In this regard, a significant step is the Decision of the Supreme Eurasian Economic Council (2024), which opens up new opportunities for Kyrgyzstan to adopt advanced Belarusian experience in the agrarian sector.

State support and strategic planning

The development of large state agricultural enterprises (SAEs) based on public-private partnership is a priority for strong nations, contributing to job creation in rural regions. Against this backdrop, a new phenomenon emerges – the innovation economy, in which creative thinking, inventiveness, and social skills come to the fore (de Barros *et al.*, 2025). This is particularly significant for depressed rural territories where unemployment levels often remain high. State agricultural enterprises can play a key role in stimulating rural infrastructure development by establishing agrotowns, which, in turn, help improve living conditions in the countryside and attract young people. SAEs based on public-private partnerships contribute to the development of agri-clusters, fostering the creation of jobs (for highly qualified specialists and workers across various professions), thereby reducing unemployment levels in rural areas and advancing the country's agricultural economic sector. Consequently, the successful development of agri-clusters positively impacts economic sustainability and the social well-being of the rural population.

It is also important not to overlook the recent Soviet experience with agri-firms, such as the state farms (sovkhozes), where a colossal potential for the "effect of scale" was realised in the production of a wide range of agricultural products. Many peasants who lived through the era of Soviet state farms were accustomed to centralised management and a stable wage that was dependent not on market conditions but on planned and cluster-based production. Therefore, they may feel more comfortable and secure in state agricultural enterprises (SAEs) based on public-private partnership than in private farming households, where income is contingent upon market fluctuations and personal risks. For some peasants, state agricultural enterprises may be associated with future security, social protection, and support, rather than the uncertainty that can accompany private entrepreneurship, particularly on the small land plots characteristic of small peasant households. This may help explain why peasants are not as actively inclined towards forming cooperatives or working on private farming households. Furthermore, in Kyrgyz villages with a post-Soviet legacy, the memory of Soviet times and the culture of state collectivisation often still persists, influencing peasants' perception of different types of farming – socialist versus capitalist.

Thus, the experience of former Soviet state farms in the agricultural sector of the Kyrgyz Republic can be beneficial for the adoption of new technologies, the organisation of work, the utilisation of land and resources, and personnel training. Many technologies, scientific developments, and practices implemented in the former Soviet Union can still prove useful if correctly adapted to current realities. For successful development in this area, it is essential to formulate a clear and effective state economic policy aimed at the planning and development of the production capacities of state agricultural enterprises.

Agricultural convergence for the Kyrgyz Republic, through the transfer of experience and the adoption of best practices from Belarus, has the potential to significantly enhance production outcomes. It is important to remember that the adaptation of the Belarusian experience should be flexible and account for the climatic, economic, and cultural specificities of the country. Kyrgyzstan's high rates of economic development in recent years create an opportunity for increased support for agricultural production. In this context, particular attention should be paid to the creation and development of state agricultural enterprises based on public-private partnership, which will operate cooperatively on lands from the Agricultural Land Redistribution Fund (ALRF). Currently, ALRF lands occupy an average of 1-1.5 thousand hectares of irrigated arable land in each rural community (ayyl aymagy) (National Statistical Committee of the Kyrgyz Republic, n.d.).

Leveraging such extensive areas of irrigated arable land, along with state-owned pasture lands in rural communities (averaging 40-60 thousand hectares), state agricultural enterprises can possess innovative material and technical resources compared to their private counterparts. They can count on state land, subsidies, investments, and other forms of support. This constitutes a significant factor in ensuring their competitiveness in both domestic and international markets. Thus, the development of innovations in material and technical resources helps state agricultural enterprises better adapt to economic and political crises and the challenges of global climate change, ensuring their stable operation in the long term.

These advantages establish state agricultural enterprises as important players in the country's agricultural economic sector. They are capable of sustaining high growth rates, developing the agroindustrial sector as a whole, and becoming a primary instrument for implementing advanced state agrarian policy. The establishment of such enterprises will make a substantial contribution to the national economy and improve the well-being of the rural population. A key objective for state agricultural enterprises operating on a public-private partnership basis is to increase the production of domestic agricultural products, which will not only enhance the country's food security but also reduce reliance on imports.

In the near term, the government faces the task of completely reformatting the agricultural production of the Kyrgyz Republic to ensure its comprehensive development and deep integration into the Eurasian and global economic spheres (Umarova, 2015). Consequently, it is essential to create and develop state agricultural enterprises based on public-private partnerships in each region of the Kyrgyz Republic. These enterprises should act as "locomotives", driving the country's agriculture forward, fostering the strengthening of investment and cooperative collaboration at the international level, and expanding trade and economic ties.

The research has indicated that the agrarian sector of the Kyrgyz Republic remains one of the key areas of the economy; however, its development is hampered by several challenges: a high degree of fragmentation among farming households and a lack of large agricultural enterprises; insufficient funding and limited access to modern technologies; a low level of cooperation between agricultural producers; weak state support; and the absence of a long-term strategy for the sector's development. These factors impede the growth of labour productivity in agriculture and worsen the economic situation of the rural population.

Comparative analysis of agrarian models in Belarus and Kyrgyzstan and proposals for modernisation

Analysis of the Belarusian experience has enabled the identification of several key mechanisms that contribute to the sustainable development of the agrarian sector: active state participation in agricultural management; the formation of large agro-industrial holdings and cooperatives; the development of agrotowns and rural infrastructure; state support programmes for farmers, including subsidies and tax incentives; and the implementation of digital technologies and automated agricultural management systems. These measures have ensured a high level of food security in Belarus. According to data from the National Statistical Committee of Belarus (n.d.), for key types of food products, the self-sufficiency level exceeds 100%, including dairy products, meat, eggs, vegetables, and potatoes. The export potential in the agrarian sector is significant: Belarusian produce was supplied to 117 countries, 19 of which became new sales markets in 2025. The main export commodities comprise: dairy products, meat, grains and legumes, rapeseed, and sugar beet.

A comparative analysis of the agrarian models of the Kyrgyz Republic and Belarus has shown that in Belarus, agriculture is developed under strict state control, whereas in Kyrgyzstan, a market-oriented approach prevails. Furthermore, large state agricultural enterprises have not been established in the Kyrgyz Republic, unlike in Belarus, which operates a system of agro-holdings. The Belarusian model is geared towards long-term development and stability, while the Kyrgyz agricultural sector is subject to seasonal fluctuations and instability. These disparities necessitate adapting the Belarusian experience to Kyrgyz conditions, taking into account the country's specific economic and institutional context.

As a result of the research, the following measures are proposed: the creation of pilot large agricultural enterprises based on public-private partnership on land from the redistribution fund; the formation of agro-holdings integrating small and medium peasant (farming) households; the implementation of state support programmes, including subsidies, tax incentives, and credit provision; the development of agricultural cooperatives following the model of Belarusian agro-industrial associations; and the digitalisation of the agricultural sector, involving the implementation of automated accounting and management systems for agriculture. As noted in Decree of the President of the Kyrgyz Republic No. 122 "On Measures to Further Improve Digital Transformation in Public Administration" (2023), the introduction of digital technologies for managing the production of state agricultural enterprises allows processes, particularly financial reporting, to become more transparent, automates tasks, reduces the influence of the human factor, and enhances control over the expenditure of funds. To this end, Order of the Cabinet of Ministers of the Kyrgyz Republic No. 444-r "On approval of the Action Plan for the implementation of the Concept of Digital Transformation of the Kyrgyz Republic for 2024-2028" (2024) was also adopted.

Thus, the digitalisation of governmental control over state agricultural enterprises encompasses operational management, long-term planning, and oversight of their activities to ensure the efficient use of resources, particularly land and water resources, as well as the fulfilment of state objectives for sustainable agricultural development and maintaining national food security (Stender *et al.*, 2024).

The research findings corroborate the feasibility of adapting elements of the Belarusian model for modernising the agrarian sector of the Kyrgyz Republic. The Belarusian model could represent a significant stride towards enhancing the efficiency of Kyrgyzstan's agriculture, given Belarus's considerable achievements in the agrarian sector through the implementation of comprehensive and innovative approaches within its agro-industrial complex (AIC). However, there are debatable questions necessitating further investigation: the optimal equilibrium between state regulation and market mechanisms; the financing and profitability of state agricultural enterprises; the willingness of farmers to cooperate; and institutional changes, i.e., the reforms required within the sphere of agrarian policy to enact the proposed measures. For the successful implementation of the proposed model, comprehensive reforms are essential, including legislative amendments, investment support, the adoption of modern technologies, and the establishment of a state support system for the agrarian sector.

Conclusions

Large agricultural enterprises, established based on public-private partnerships, play a pivotal role in the modernisation and sustainable development of the agrarian sector. They not only contribute to addressing the priority objectives of state agrarian policy but also act as catalysts for technological and managerial transformations within agriculture. Fundamentally, such structures are oriented towards achieving strategic goals – increasing gross agricultural output, enhancing their competitiveness in domestic and international markets, and significantly improving labour productivity through the implementation of high-technology economic elements, digitalisation, and advanced methods for managing production and logistics processes. Owing to the scale of their operations, such enterprises are capable of substantially reducing production costs by leveraging economies of scale, centralised procurement of raw materials, machinery, fuel, and other resources on favourable terms, and access to modern agrotechnologies. This, in turn, facilitates the prompt adoption of superior crop varieties and hybrids, highly productive livestock breeds, efficient feed production models, precision farming systems, and climate-adapted technologies, which is particularly pertinent given the context of climate change.

Large agrarian structures operating within the framework of PPPs actively engage with relevant universities, research institutions, and international organisations. This collaboration facilitates the transfer of knowledge and technology, contributes to the development of applied science, enables the organisation of internships and professional development programmes for specialists, and stimulates the adoption of innovative solutions in agricultural practice. Furthermore, it creates a conducive environment for attracting investment into the agrarian sector, including in the areas of agritech startups, biotechnologies, and digital platforms. Well-established logistics, extensive use of digital accounting, monitoring, and planning systems, and the diversification of production activities contribute to the formation of sustainable marketing strategies, the expansion of sales markets, increased adaptability to market fluctuations, and the strengthening of enterprises' financial stability. Simultaneously, the development of brands, certification of products according to international standards, and the cultivation of export potential have become increasingly significant.

The social significance of such enterprises should also be emphasised: they contribute to job creation, improving living standards in rural regions, developing social infrastructure, reducing unemployment and the exodus of young people to cities, and help address pressing social issues, including ensuring food security. Public-private partnership opens up broad prospects for the adoption of "green" technologies, organic farming, environmentally safe production, waste recycling, and the formation of agro-ecological clusters. Furthermore, PPPs facilitate cooperation between small and large producers, the formation of value chains, and the application of a cluster approach to managing the agro-industrial complex. The operational experience of large agricultural enterprises within the framework of public-private partnership confirms their high potential as an instrument for sustainable agricultural development. In the future, particular attention should be given to optimising the mechanisms of interaction between the state and the private sector, developing models for managing agricultural risks, enhancing partnership transparency, implementing digital solutions in agromanagement, and developing regional agro-industrial clusters, taking into account territorial specificities and local needs.

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Беларусь Республикасынын тажрыйбасынын контекстинде Кыргызстандын айыл чарбасында мамлекеттик-жеке өнөктөштүктү өнүктүрүү

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Аннотация. Мамлекеттик-жеке өнөктөштүк (МЖӨ) айыл чарбасын өнүктүрүүдө, инвестицияларды тартууда, инфраструктураны модернизациялоодо жана агрардык сектордун натыйжалуулугун жогорулатууда негизги ролду ойнойт. Бул макалада Беларусь Республикасынын тажрыйбасын эске алуу менен Кыргыз Республикасынын айыл чарбасында мамлекеттик-жеке өнөктөштүк өнүктүрүүнүн келечеги изилденген. Эки өлкөдө мамлекет менен жеке сектордун өз ара аракеттенүү механизмдерин жөнгө салуучу ченемдик-укуктук база талданат, ошондой эле кызматташуунун колдонуудагы моделдери, анын ичинде концессиялар, инвестициялык макулдашуулар жана кластердик демилгелер каралат. Беларусь айыл чарбасын колдоонун мамлекеттик программаларын ишке ашырууда олуттуу тажрыйбага ээ, анын ичинде субсидиялоо, салык жеңилдиктери, агроөнөр жай кластерлерин жана кооперативдерди түзүү. Бул өлкөнүн азык-түлүк коопсуздугунун деңгээлин жана экспорттук потенциалын олуттуу жогорулатууга мүмкүндүк берди. Ошол эле учурда Кыргызстан инвестициялардын жетишсиздиги, эскирген инфраструктура жана инновациялык технологияларды жайылтуунун деңгээлинин төмөндүгү сыяктуу бир катар көйгөйлөргө туш болууда. Макалада Беларустун ийгиликтүү тажрыйбаларын Кыргыз шарттарына адаптациялоо, анын ичинде мыйзамдык механизмдерди өркүндөтүү, инвесторлор үчүн жагымдуу шарттарды түзүү, агротехнопарктарды өнүктүрүү жана айыл чарбасын санариптештирүү боюнча сунуштар сунушталат. Кыргызстандын агроөнөр жай комплексинин өсүшүнө өбөлгө түзгөн мамлекеттик-жеке өнөктөштүктүн туруктуу моделин түзүү үчүн эки өлкөнүн ортосунда эл аралык кызматташтыктын жана тажрыйба алмашууну кеңейтүү зарылчылыгы баса белгиленет. Айыл аймагынын айыл чарба багытындагы сугат айдоо жерлерин кайра бөлүштүрүү фондунан мамлекеттик жерлердин 25 % га ири мамлекеттик агрардык ишканаларды түзүүгө жана өнүктүрүүгө өзгөчө көңүл бурулат. Мындай ишканаларды түзүү айыл аймактарын колдоого, Айыл чарба инфраструктурасын өнүктүрүүгө жана жумуш орундарын түзүүгө көмөктөшүүчү тең салмактуу агрардык саясатты ишке ашырууга багытталган. Мындай мамиле жергиликтүү экономиканы өбөлгөлөйт жана Кыргыз Республикасынын азык-түлүк коопсуздугун камсыз кылууга өбөлгө түзөт

Негизги сөздөр: инвестициялар; агроөнөр жай комплекси; сугат айдоо жерлери; Айыл чарба багытындагы жерлерди кайра бөлүштүрүү фонду; азык-түлүк коопсуздугу

Развитие государственно-частного партнерства в сельском хозяйстве Кыргызстана в контексте опыта Республики Беларусь

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Аннотация. Государственно-частное партнерство (ГЧП) играет ключевую роль в развитии сельского хозяйства, способствуя привлечению инвестиций, модернизации инфраструктуры и повышению эффективности аграрного сектора. В данной статье исследовались перспективы развития ГЧП в сельском хозяйстве Кыргызской Республики с учетом опыта Республики Беларусь. Проанализирована нормативно-правовая база, регулирующая механизмы взаимодействия государства и частного сектора в обеих странах, а также рассмотрены существующие модели сотрудничества, включая концессии, инвестиционные соглашения и кластерные инициативы. Беларусь обладает значительным опытом в реализации государственных программ поддержки сельского хозяйства, включая субсидирование, налоговые льготы, создание агропромышленных кластеров и кооперативов. Это позволило существенно повысить уровень продовольственной безопасности и экспортный потенциал страны. В то же время Кыргызстан сталкивается с рядом проблем, таких как нехватка инвестиций, устаревшая инфраструктура и низкий уровень внедрения инновационных технологий. В статье предложены рекомендации по адаптации успешных белорусских практик к кыргызским условиям, включая совершенствование законодательных механизмов, создание благоприятных условий для инвесторов, развитие агротехнопарков и цифровизацию сельского хозяйства. Подчеркнута необходимость расширения международного сотрудничества и обмена опытом между двумя странами для формирования устойчивой модели ГЧП, способствующей росту агропромышленного комплекса Кыргызстана. Особое внимание уделено созданию и развитию крупных государственных аграрных предприятий на 25 % государственных земель из фонда перераспределения орошаемой пашни сельскохозяйственного назначения айыл аймагы. Формирование таких предприятий направлено на реализацию сбалансированной аграрной политики, способствующей поддержке сельских регионов, развитию инфраструктуры сельского хозяйства и созданию рабочих мест. Такой подход стимулирует местную экономику и способствует обеспечению продовольственной безопасности Кыргызской Республики

Ключевые слова: инвестиции; агропромышленный комплекс; орошаемые пашни; фонд перераспределения земель сельскохозяйственного назначения; продовольственная безопасность

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Effectiveness of manure under protected cultivation conditions

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Abstract. In modern agriculture, optimising the use of fertilisers is a key factor in enhancing cucumber yields. Manure, as a traditional organic fertiliser, alongside modern agronomic inputs such as mineral fertilisers and nanohumic substances, plays an important role in supplying plants with essential nutrients. This study aimed to conduct a comparative analysis of the effectiveness of traditional organic fertiliser (manure) when applied alone and in combination with nanohumic substance and mineral fertilisers on cucumber crops under greenhouse conditions. Such a comparison made it possible to determine optimal fertilisation strategies to achieve maximum cucumber yields. The research was carried out in greenhouse conditions using the cucumber hybrid Absolut. Various combinations of fertilisers, including manure, mineral fertilisers, and nanohumic substances, were applied during the experiment, followed by an analysis of their effects on yield and fruit quality. A positive influence of the full range of fertilisers – both mineral and manure, whether applied individually or in combination with nanohumic substance – on the productivity of cucumber plants were established. A particularly significant increase in cucumber yield was observed following the application of manure, although the average fruit weight was lower compared to the use of mineral fertilisers. However, the number of fruits per square metre significantly exceeded that recorded

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with mineral fertilisers, resulting in a higher overall yield. Thus, the application of mineral fertilisers increased cucumber yield to 14.88 kg per square metre, which was double the control value. When manure was used, the yield rose to 16.38 kg per square metre, representing a 10.08% increase compared with mineral fertilisers and a 2.2-fold increase over the control. The results of this study may be used by greenhouse operations and farmers to optimise cucumber fertilisation systems, thereby improving both yield and product quality

Keywords: greenhouse cultivation; organic fertiliser; mineral fertiliser; nanohumic substance; cucumber productivity; yield structure; fruit weight

Introduction

In modern agriculture, particularly in the context of finite resources and increasing demand for vegetable produce, optimising fertiliser application is a pivotal factor in enhancing crop yields. Among the diverse range of fertilisers, considerable attention is given to both traditional organic fertilisers, such as manure, and modern agrotechnical agents, including mineral fertilisers and nanohumic substances. Manure, as a widely utilised organic amendment, is recognised for its beneficial properties, such as improving soil structure and supplying plants with essential nutrients. However, its efficacy can fluctuate depending on cultivation conditions and its combination with other fertilisers. Mineral fertilisers, conversely, provide plants with readily available macro- and micronutrients, thereby promoting rapid growth and development (Kravchenko & Bykova, 2023). Nevertheless, as highlighted by L. Skivka & S. Hudz (2021), their excessive application can lead to detrimental environmental consequences and negatively impact production quality.

One promising avenue for improving ecological farming technology lies in the application of a group of natural, high-molecular-weight substances of the humate type, which exhibit high physiological activity. As noted by A. Maffia *et al.* (2025), nanohumic substances, as relatively novel agrotechnical agents, possess the potential to enhance fertiliser use efficiency and improve plant growth by stimulating physiological processes. Nanohumic substances are colloidal particles produced through physical or chemical treatment of humic substances (Verma *et al.*, 2022). Technologies based on physical methods of nanoparticle production are considered the safest (Ayenew *et al.*, 2025). Primarily, nanohumic substances increase the activity of biochemical processes in plants, particularly stimulating root system development. This simultaneously enhances the permeability of cell walls, facilitating the expansion of cell membrane size for the uptake of ions necessary for root growth and development, and activates the enzyme systems responsible for this process. It is also believed that humic substances act not only on plants but also exert a significant positive effect on the soil, improving its structure, denaturing particles, dissolving calcium and magnesium carbonate minerals (which are abundant in these soils), phosphate, and other sparingly soluble salts. This increases agrophysical properties (such as porosity, water-air, and thermal regimes), participates in adsorption processes, and stimulates the activity of beneficial soil microorganisms.

In the context of modern agriculture in the Kyrgyz Republic, where cucumbers are a significant vegetable crop, optimising fertilisation regimes to enhance their productivity is of particular importance. Consequently, investigating the influence of novel agrotechnical agents, such as nanohumic substances, on cucumber yields represents a pertinent research objective (Selivanova, 2013). As one of the most popular greenhouse crops, cucumbers necessitate optimal nutrient provision to achieve high yields and quality produce. Therefore, examining the impact of various types of fertilisers, including manure, mineral fertilisers, and nanohumic substances, on cucumber productivity is a relevant task. Contemporary studies, such as the research by D. Khomiakov *et al.* (2020), indicate that the combined application of organic and mineral fertilisers can exert a synergistic effect, contributing to increased cucumber yield and quality. For instance, research demonstrates that using manure in conjunction with mineral fertilisers can ameliorate soil structure and furnish plants with essential nutrients, leading to enhanced yields (Kireev *et al.*, 2010). Concurrently, as A. Emelyanova & A. Novikova (2022) observe, the deployment of nanoparticles can help improve fertiliser use efficiency and stimulate plant growth by promoting physiological processes.

In greenhouse cucumber production, alongside adherence to cultivation techniques, optimal soil water-air balance, and pest and disease control, significant importance is placed on establishing optimal nutrient levels. This is because insufficient light during the colder months necessitates enhanced nutrient provision to the cucumber root system. Simultaneously, creating conditions that facilitate accelerated metabolic processes within the plant, through the application of physiological or biological growth and development stimulants, is equally crucial (Derevyanchenko *et al.*, 2023). In Kyrgyzstan, preparations derived from processing brown coal from the KaraKeche deposits in the Naryn Region have become widely used on field crops for this purpose. While the application technology for many field crops has been reasonably well-established, this process has not yet significantly extended to vegetable crops, particularly those grown under protected cultivation.

Despite a considerable body of research dedicated to investigating the influence of fertilisers on cucumber productivity, a need persists for further studies to determine optimal fertilisation strategies, especially within the context of greenhouse cultivation. Specifically, it is necessary to examine the impact of combining manure with nanohumic substances on cucumber productivity and to ascertain the optimal ratios of organic and mineral fertilisers for achieving maximum yield and produce quality. Accordingly, this study aimed to investigate the effect of various types of fertilisers, including manure, mineral fertilisers, and nanohumic substances, on cucumber productivity under greenhouse conditions.

Materials and Methods

The experiments were conducted during 2023-2024 in the collection nursery greenhouse at the Kyrgyz National Agrarian University, which features state-of-the-art technological and structural designs in this field. The project was provided by Korean specialists. The total area of the greenhouse is 240 m^2, with a usable area of 192.5 m^2. The facility comprises three sections; the first block houses the control equipment – a temperature control panel for the greenhouse, that operates around the clock. Temperature regulation is achieved by opening and closing supplementary vents located on the sides and roof of the greenhouse, which operate in both manual and automatic modes. Direct temperature monitoring is carried out using thermometers positioned above and below the soil. These thermometers are connected to the control panel, which, based on the signals received, automatically activates devices for supplying either cooled or heated air to the plant growth and development zones (manual mode is also available if required). During the colder period, heat is also supplied through the soil via heating pipes situated at a depth of 30 cm. The temperature was maintained at no lower than 15°C-18°C in the soil and 26°C-28°C in the air during the cold season. The heating system for the winter period was supplied by a solid-fuel stove, to which the soil and air heating systems for the greenhouse were connected.

The second and third sections housed the experimental crops – cucumbers and tomatoes – which constituted the subjects of this study. Each plot measured 3.64 m^2 (5.2 m in length and 0.7 m in width). The F1 hybrid of the cucumber variety Absolute was used for the research. Planting was carried out in ordinary grey soil, with the application of fertilisers at rates of 25 g nitrogen, 35 g phosphorus, 70 g potassium, and 15 kg of manure per m^2, respectively. The mineral fertilisers used were ammonium nitrate (34.5% nitrogen), ammophos (10.0% nitrogen and 49.0% phosphorus), and potassium chloride (60.0% potassium oxide), along with fresh manure having standard nitrogen, phosphorus, and potassium content and a moisture level of 78.0% (Borisov, 1978). Prior to commencing the experiment, all necessary preparatory work for cultivating vegetables in protected conditions was conducted following established protocols, including soil and seedling preparation, disinfection, etc. Seedlings were planted using a string guide in a two-row scheme, with a distance of 50 cm between rows and 40 cm between plants within a row, resulting in a bed width of 90 cm. Harvesting was performed in the morning, three times per week, with fruits being weighed on electronic scales and their quantity simultaneously counted for each experimental treatment.

In Kyrgyzstan, the use of various humate derivatives is prevalent, with sodium humates (such as Kyrgyz-Gumat, Nanogumus, Bioplant Flora, etc.) being the most frequently employed in practice. Among these is an innovative preparation, "Nanogumate", produced by OJSC Union Group, Kyrgyz Republic. This product is based on the comminution of humic substances into molecular fragments as small as 45 nm. This specific preparation was provided to the researchers by the Cabinet of Ministers of the Kyrgyz Republic and the Ministry of Water Resources, Agriculture, and Processing Industry for testing on cucumber crops under protected cultivation conditions. This particular product is obtained by crushing natural humic substances to a molecular nanostructure of less than 5 nm. Consequently, the resulting humic nanoparticles are exclusively of natural origin, having been formed from natural raw material – leonardite, found within brown coal. The research adhered to the principles of the Convention on Biological Diversity 1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973).

Results and Discussion

As evidenced by the experimental results, cucumber yield varied between 6.67 and 20.28 kg per 1 m^2 of cultivated area, depending on the treatment (Table 1).

Table 1. Cucumber yield, kg per 1 m^2 of cultivated area, experiment 1

No.	Treatment	Yield by replication				Increase			
						kg		%	
		I	II	III	Average	Over control	Over mineral fertiliser	Over control	Over mineral fertiliser
1	No fertiliser (control)	7.60	8.91	6.67	7.71	–	–	100	–
2	Mineral fertilisers	18.30	14.00	12.34	14.88	7.16	–	192.35	100
3	Manure	20.28	16.70	12.15	16.38	8.66	1.5	212.18	110.08

Source: compiled by the authors

It was established that improving the nutritional conditions for cucumbers plays a significant role in enhancing crop productivity. Specifically, the application of a full complement of mineral fertilisers contributed to an average cucumber yield increase across three replicates to 14.88 kg per 1 m^2 of area. This represents an increase of 7.16 kg/m^2 over the control, or 192.75%. An even more notable increase in yield was observed with the application of manure, where 16.38 kg of cucumbers were harvested per square metre. This is 8.66 kg or 2.12 times higher than the unfertilised control plots. This yield also surpasses the mineral fertiliser treatment by 10.28%. Consequently, manure serves as a beneficial nutritional source for cucumber growth and development when cultivated in field soil (native soil) as a spring-summer protected crop.

An analysis of the elements contributing to cucumber yield structure provides interesting insights. These analyses reveal which structural components primarily contribute to the additional yield observed with the application of mineral and organic fertilisers. As shown in Table 2, a significant component of the yield structure is the weight of individual fruits. The data indicates that, without fertilisation, the native soil can produce fruits weighing between 82.87 and 93.76 g. Fertiliser application demonstrably contributed to a noticeable increase in the weight of each cucumber fruit.

Table 2. Individual fruit weight, g, experiment 1

No.	Treatment	Individual fruit weight by replicates				Increase			
						g		%	
		I	II	III	Average	Over control	Over mineral fertiliser	Over control	Over mineral fertiliser
1	No fertiliser (control)	93.76	90.11	82.87	88.91	–	–	100	–
2	Mineral fertilisers	108.83	109.54	97.21	105.19	16.28	–	118.31	100
3	Manure	103.94	103.16	92.14	99.75	10.84	–5.44	112.19	94.83

Source: compiled by the authors

However, the impact of the fertilisers on this parameter was not uniform. The greatest increase in individual fruit weight was observed with the application of mineral fertiliser, where the additional weight reached 16.28 g, an increase of 118.31% over the control. In contrast, while manure increased the weight of individual cucumbers by 10.84 g, or 112.19%, compared to the control, this was 5.44 g less than the increase seen with mineral fertilisers, representing 94.83% of the increase obtained with the mineral treatment.

Another significant component influencing cucumber yield is the number of fruits harvested per unit area of the experiment. As shown in Table 3, the fertiliser treatments substantially increased the number of fruits per plant. While an average of 316 fruits were formed per unit area over the entire growing season in the control, the mineral fertiliser treatment yielded 593 standard fruits from the same area. This represents an increase of 197 fruits, or 162.34%, compared to the unfertilised treatment.

Table 3. Number of fruits per unit area, pcs, experiment 1

No.	Treatment	Number of fruits by replicates				Increase			
						pcs		%	
		I	II	III	Average	Over control	Over mineral fertiliser	Over control	Over mineral fertiliser
1	No fertiliser (control)	295	360	293	316	–	–	100	–
2	Mineral fertilisers	612	465	462	513	197	–	162.34	100
3	Manure	710	589	480	593	277	80	187.66	115.60

Source: compiled by the authors

At the same time, manure, having resulted in an average of 596 fruits across all three replicates, surpassed mineral fertilisers in this yield component. The increase in this case was 80 fruits, or 15.50%. Relative to the control, the additional yield in terms of fruit number was even more substantial, reaching 280 fruits, or 88.61%. This indicates that manure, while slightly inferior to mineral fertilisers in terms of individual fruit weight, significantly compensated for this by increasing the number of fruits, thereby contributing to a higher overall cucumber yield.

The figures for the total number of fruits per unit area from the experimental plots appear even more distinct (Table 4). Fertilised plots yielded between 54.12

and 76.10 more fruits compared to the control area. The difference in fruit yield between the mineral fertiliser and manure treatments is quite substantial, reaching nearly 22 fruits per square metre, which underscores the advantage of applying manure to cucumbers in greenhouse operations.

Table 4. Number of fruits per square metre, pcs, experiment 1

No.	Treatment	Number of fruits by replicates				Increase			
						pcs		%	
		I	II	III	Average	Over control	Over mineral fertiliser	Over control	Over mineral fertiliser
1	No fertiliser (control)	81.04	98.90	80.89	86.81	–	–	100	–
2	Mineral fertilisers	168.13	127.75	126.92	140.93	54.12	–	162.34	100
3	Manure	195.06	161.81	131.87	162.91	76.10	21.98	187.66	115.60

Source: compiled by the authors

The results of the second experiment, where all three main treatment variants were combined with a nanohumic substance, indicated that this physiological stimulant exerted a discernible positive influence on cucumber yield formation (Table 5). For instance, while mineral fertilisers without nanohumic substance increased the yield mass per square metre by 1 kg, representing 114.7% relative to the control, treatment with nanohumic substance resulted in an additional yield of 1.40 kg, or 121.2% more than the nanohumic substance treatment without fertilisers.

Simultaneously, a substantial increase in cucumber productivity was ensured by manure, both in combination with nanohumic substance and without it. The increased cucumber yield in the former case amounted to 5.05 kg/m^2, equivalent to 176.5% over the baseline (presumably the control without fertiliser or nanohumic substance), and 4.40 kg/m^2, or 164.2%, in the latter case (manure without nanohumic substance compared to the control without fertiliser or nanohumic substance). Overall, the use of nanohumic substance proved most effective on native greenhouse soil when it was fortified with manure containing macro- and micronutrients, and favourably influenced the soil's agrophysical properties. The adequate supply of carbon dioxide, resulting from the decomposition of fresh manure, likely played a significant role in this process.

Table 5. Cucumber yield recording per 1 m^2 of cultivated area, experiment 2

No.	Treatment	Yield by replication				Increase	
						kg	%
		I	II	III	Average	Over control	Over control
1	No fertiliser, no nanohumic substance (control)	6.70	–	6.67	6.80	–	100
2	No fertiliser with nanohumic substance (control)	6.55	–	6.65	6.60	–	100
3	Mineral fertilisers without nanohumic substance	7.60	8.00	–	7.80	1.00	114.7
4	Mineral fertilisers with nanohumic substance	7.70	8.20	–	8.00	1.40	121.2
5	Manure without nanohumic substance	–	10.50	11.90	11.20	4.40	164.7
6	Manure with nanohumic substance	–	11.20	12.10	11.65	5.05	176.5

Source: compiled by the authors

Pre-planting application of mineral fertilisers at a dose of $N_{150}P_{150}K_{150}$ prior to cultivation ensured maximum yield in the experiment, with an increase of 1.61 kg/m^2 or 13.3% compared to the control treatment. A systematic increase in the dose of mineral fertilisers applied during pre-planting cultivation did not significantly influence the growth in crop productivity. The average yield of cucumber fruits under protected cultivation (2021-2022) in the control treatment (without fertiliser application) was 11.85 kg/m^2. The highest cucumber yield in the experiment was obtained with the application of $N_{200}P_{200}K_{200}$ mineral fertilisers in spring prior to pre-planting cultivation. The yield exceeded the control treatment by 1.73 kg/m² or 14.6%. The final data on cucumber yield based on the experimental results are presented in Figure 1.

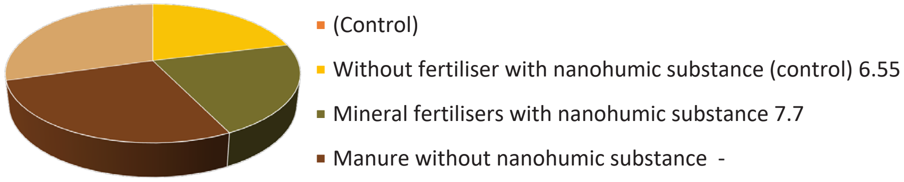

Figure 1. Cucumber yield with the use of mineral fertilisers

Source: compiled by the authors

As A. Kuramshin (2011) posits, the substrate is a significant factor that largely determines the yield of vegetable crops. Various types of substrates are used in protected cultivation, including perlite, peat, rock wool, expanded clay aggregate, and others. When selecting a substrate, facility managers consider its cost, delivery expenses, and disposal requirements. In practice, using a questionable substrate without knowledge of its physicochemical properties or intended use, and without guidance on working with it, leads to operational difficulties (Autko, 2007). This often results in reduced yield or plant death. According to A. Kuramshin (2011), cultivating cucumbers under protected conditions, facilitates the production of ecologically safe produce: the heavy metal content in the produce for individual elements is more than 10 times below the maximum permissible concentration, and nitrates are up to 2.5 times lower. When growing cucumber plants in the third light zone during the winter-spring period in a greenhouse, it is recommended to apply organo-mineral fertiliser at a base rate of 1,250 kg/ha ($N_{29}P_{29}K_{33}$) in conjunction with simple mineral fertilisers ($N_{90}P_{120}K_{150}$) to increase yield and improve fruit quality (Yakovleva, 2003). In the opinion of R. Bulavintsev (2017), the development of greenhouse enterprises in the Russian Federation will facilitate significant import substitution, enhance the quality and competitiveness of vegetable produce, and expand the assortment of crops grown under protected cultivation.

I. Pigorev & N. Dolgopolova (2018) observe that in greenhouse environments, where agrocenosis is particularly susceptible to attacks from parasitic mycobiota due to the favourable microclimate and limited range of cultivated plants, the disruption of any factor contributes to a loss of ecological stability. This, in turn, leads to plant diseases and reduced yields. To maintain stability and control the spread of harmful organisms, it is necessary to implement an integrated protection system encompassing prophylactic, agrotechnical, breeding and genetic, chemical, and biological methods. A. Sergeeva (2020) found that to increase cucumber yields under protected cultivation and enhance produce quality, it is essential to apply complex feeding regimes combining root and foliar fertiliser application. This approach can achieve a significant increase in both yield and the proportion of standard produce. M. Selivanova *et al*. (2013) emphasise that optimising the mineral nutrition of plants, using both root and foliar feeding and combining mineral and organic fertilisers, is crucial for increasing cucumber yields in protected cultivation and meeting consumer demand for vegetable produce. They highlight that despite the effectiveness of individual fertiliser types, their combined application yields the greatest economic benefit, substantially increasing both productivity and profitability of production.

Conclusions

The experimental results demonstrate the feasibility of achieving satisfactory yields in the region's native soil without the use of imported bulk substrate, provided there is adequate mineral or organic (manure) fertilisation for spring-summer cucumber cultivation. It was established that in field soil, the application of mineral fertilisers at a rate of 25 g nitrogen, 35 g phosphorus, and 70 g potassium per square metre resulted in a nearly twofold increase in cucumber yield compared to the control, reaching 14.88 kg per unit area. Incorporating manure at a rate of 15 kg per m² led to a further yield increase of 1.5 kg per square metre compared to the mineral fertiliser treatment. This represented more than double the yield of the control and a 10.08% increase over the yield achieved with mineral fertilisers alone.

In this instance, the crop's productivity was primarily determined by an 18.31% increase in individual fruit weight and a 62.34% increase in the number of harvested fruits. Conversely, in the manure treatment, the main factor contributing to the increased yield was the number of harvested cucumbers, which reached 187.66% of the control yield per m². This exceeded the yield from the mineral fertiliser treatment by 80 fruits per plot or 22 fruits per unit area. Although it should be emphasised that the weight of individual fruits here was 10.84 g heavier than the control, it was 5.44 g lighter than with the mineral fertiliser treatment. As for the effect of the physiological stimulant – nanohumate – its application generally had a beneficial influence on cucumber growth and development, which is evident from the increased yield observed in conjunction with fertilisers. Moreover, this effect was more pronounced when manure was used as the primary nutrient source for the cucumbers. Thus, manure can serve as a viable alternative to mineral fertilisers for introducing organic farming practices and cultivating cucumbers in greenhouse settings, particularly in the native field soils of the grey soil type prevalent in Kyrgyzstan. For a more comprehensive understanding of the impact of organic and mineral fertilisers on cucumber yield under greenhouse conditions, a promising avenue for further research involves investigating the dynamics of soil microbial composition and fruit quality under the long-term application of these fertilisers.

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Conflict of Interest

None.

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Аннотация. Заманбап айыл чарбасында жер семирткичтерди колдонууну оптималдаштыруу бадыраңдын түшүмдүүлүгүн жогорулатуунун негизги фактору болуп саналат. Салттуу органикалык жер семирткич катары кык жана минералдык жер семирткичтер жана наногуматтар сыяктуу заманбап айыл чарба продукциялары өсүмдүктөрдү керектүү азыктар менен камсыз кылууда маанилүү роль ойнойт. Бул иштин максаты салттуу органикалык жер семирткичтин (кык) өзүнчө да, ошондой эле наногумат жана минералдык жер семирткичтер менен айкалыштырып колдонууда күнөскана шарттарында бадыраң өсүмдүктөрүнүн натыйжалуулугун салыштырып талдоо болгон. Бул салыштыруу бадыраңдын максималдуу түшүмдүүлүгүнө жетүү үчүн уруктандыруунун оптималдуу стратегияларын аныктоого мүмкүндүк берди. Изилдөө Абсолют бадыраң гибридинин жардамы менен күнөскана шарттарында жүргүзүлгөн. Эксперименттин жүрүшүндө жер семирткичтердин ар кандай комбинациялары, анын ичинде кык, минералдык жер семирткичтер жана наногуматтар колдонулуп, андан кийин алардын мөмө-жемиштердин түшүмдүүлүгүнө жана сапатына тийгизген таасирине талдоо жүргүзүлдү. Жер семирткичтердин бүткүл комплексинин – минералдык жана кыкты өзүнчө жана наногумат менен айкалыштыруу – бадыраңдын өндүрүмдүүлүгүнө оң таасири аныкталган. Бир жемиштин салмагы минералдык жер семирткичтерге салыштырмалуу азыраак болгону менен кык колдонуунун фонунда бадыраңдын түшүмдүүлүгүнүн өзгөчө олуттуу өсүшү байкалды. Бирок, мөмө-жемиштердин саны бир чарчы метрге минералдык жер семирткичтер менен болгон варианттан бир топ ашып кетти, анын эсебинен жогорку түшүм түзүлдү. Ошентип, минералдык жер семирткичтерди колдонуу бадыраңдын түшүмдүүлүгүн бир чарчы метрден 14,88 килограммга чейин жогорулатты, бул контролдук көрсөткүчтөн эки эсе көп. Кыкты колдонууда түшүмдүүлүк 1 чарчы метрден 16,38 килограммга чейин өскөн, бул минералдык жер семирткичтерди колдонууга караганда 10,08 %га жана контролдук көрсөткүчтөн 2,2 эсеге жогору. Бул иштин натыйжаларын күнөскана чарбалары жана фермерлер бадыраңды жер семирткичтүү системаларды оптималдаштыруу үчүн пайдалана алышат, бул продукциянын түшүмүн жана сапатын жогорулатат

Негизги сөздөр: күнөскана чарбасы; органикалык жер семирткич; минералдык жер семирткич; наногумат; бадыраңдын өндүрүмдүүлүгү; өсүмдүк структурасы; салмак

Эффективность навоза в условиях закрытого грунта

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Аннотация. В условиях современного сельского хозяйства оптимизация использования удобрений является ключевым фактором для повышения урожайности огурцов. Навоз, как традиционное органическое удобрение, и современные агротехнические средства, такие как минеральные удобрения и наногуматы, играют важную роль в обеспечении растений необходимыми питательными веществами. Целью данной работы был сравнительный анализ эффективности традиционного органического удобрения (навоза) при его использовании как отдельно, так и в сочетании с наногуматом и минеральными удобрениями на посевах огурцов в условиях тепличного хозяйствования. Такое сравнение позволило определить оптимальные стратегии удобрения для достижения максимальной урожайности огурцов. Исследование проводилось в тепличных условиях с использованием гибрида огурца Абсолют. В ходе эксперимента применялись различные комбинации удобрений, включая навоз, минеральные удобрения и наногуматы, с последующим анализом их влияния на урожайность и качество плодов. Установлено положительное влияние всего набора удобрений – как минеральных, так и навоза в отдельности и в сочетании их с наногуматом – на продуктивные показатели огурца. Особенно существенный рост урожая огурцов наблюдался на фоне применения навоза, хотя масса одного плода при этом была меньше по сравнению с минеральными удобрениями. Однако количество плодов на квадратный метр существенно превышало вариант с минеральными удобрениями, за счет чего формировался более высокий урожай. Так, применение минеральных удобрений увеличило урожай огурцов до 14,88 кг на квадратный метр, что в два раза превысило контрольный показатель. При использовании навоза урожайность возросла до 16,38 кг на квадратный метр, что на 10,08 % больше, чем при использовании минеральных удобрений, и в 2,2 раза выше контрольного показателя. Результаты данной работы могут быть использованы тепличными хозяйствами и фермерами для оптимизации систем удобрения огурцов, что позволит повысить урожайность и качество продукции

Ключевые слова: тепличное хозяйство; органическое удобрение; минеральное удобрение; наногумат; продуктивность огурца; структура урожая; масса

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Evaluation of potato cultivars for resistance to diseases and pests under the high-altitude conditions of the Gornyi Altai testing site

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Abstract. The relevance of this study lies in the need to identify potato cultivars with the highest resistance to diseases and pests under the unique high-altitude conditions of the Gornyi Altai, contributing to improved crop yield stability. This study aimed to assess the resistance of early maturing potato cultivars – Belukha, Gorets, Suvenir Gornogo Altaya, and Snegir – to diseases and pests under the conditions of the high-altitude testing site in the Gornyi Altai. The research was conducted in 2023 in the village of Aktash, Ulagansky District, Altai Republic, Russia. The main findings and conclusions concerned the following aspect: the level of resistance to diseases and pests in each cultivar was influenced by various factors, including climatic conditions, soil composition, and the presence of pathogens and pests at the testing site. The study employed field trials, phytopathological analysis, and statistical data processing methods to assess the resistance of various potato cultivars. The presence and severity of plant infection by phytopathogens such as late blight and common scab, as well as damage caused by the Colorado potato beetle and other pests, were analysed. It was established that all cultivars exhibited complete resistance to late blight, common scab, and dry rot, indicating a high level of adaptation to the regional conditions. However, the cultivar Suvenir Gornogo Altaya showed minor infection by soft rot, with a damage level of 0.2%. The productivity of the studied cultivars ranged from 1,120 g per plant (Snegir) to 1,870 g per plant (Belukha). The findings support the recommendation of these cultivars for cultivation in the high-altitude conditions of the Altai Republic, with the aim of minimising crop losses. The practical value of the study lies in the potential use of its results to recommend well-adapted potato cultivars to farmers working in similar climatic conditions, thereby reducing crop losses and plant protection costs

Keywords: genotype; Gorets; Belukha; Suvenir Gornogo Altaya; late blight; common scab

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Introduction

The topic of potato cultivar resistance to diseases and pests in high-altitude testing sites, such as Gornyi Altai, is of significant importance. The climatic conditions of mountainous regions differ considerably from lowland areas, creating unique ecological niches and, consequently, specific agricultural challenges. In this context, selecting suitable potato cultivars that exhibit resistance to local pathogens and pests becomes a priority for agronomists and farmers working in these highaltitude conditions. This research emphasises the need for potato cultivars adapted to the specific environmental conditions of the Altai Republic's high-altitude testing sites. It highlights the importance of timely cultivar replacement and renewal, along with a structured plan for providing the region's population with healthy seed material (Okasheva *et al.*, 2023a; 2023b). Therefore, evaluating the disease and pest resistance of potato cultivars Belukha, Gorets, Suvenir Gornogo Altaya, and Snegir in the highaltitude Gornyi Altai region (Aktash Village, Ulagansky District) is a crucial aspect for agricultural producers and researchers. Special attention was also given to the harmful insects that affect potatoes, as they can cause substantial crop damage.

Long-term research by S. Krasnikov *et al.* (2023) identified common potato diseases found in the Altai Republic: late blight, common scab, and dry and soft rots. These diseases were mainly observed in lowland areas, where potato infection rates ranged from 0.7%-3% of total plantings. Air temperatures in these lowlands remained more stable throughout the summer compared to the highlands, where daytime temperatures reached +30°C and nighttime frosts dipped to −4°C. This extreme temperature fluctuation likely explains the absence of potato pests in the highland regions.

Late blight is a widespread and serious potato disease caused by microorganisms from the *Phytophthora* genus. These organisms can induce root and leaf necrosis, as well as stem and flower bud rot (Chizhik *et al.*, 2024). As noted by N. Zoteyeva *et al.* (2024), late blight can lead to significant yield losses if its progression is not prevented or controlled. Common scab is caused by the *Leptosphaeria maculans* fungus, which attacks the plant's leaves and stems. Initial symptoms include dark spots on the leaves, which expand and cause extensive leaf damage. The disease can then spread to the stems and roots, hindering plant development and reducing potato yields (Bethke & Jansky, 2021).

Dry and soft rots are diseases caused by various types of fungi, including *Alternaria*, *Fusarium*, and *Rhizoctonia*. Dry rots affect dry parts of the plant, such as stems, leaves, and roots, forming grey-brown or brown spots and lesions (Bomok & Pikovskyi, 2019). Soft rots, on the other hand, typically affect plants in wet weather conditions, forming grey-green or grey-brown lesions on leaves and stems. A significant amount of research focuses on studying the resistance of various potato cultivars to these pathogens. For example, the research of M. Anoumaa *et al.* (2022) emphasises the importance of using cultivars that exhibit resistance to late blight, one of the most destructive potato diseases. Their research results showed that some cultivars, when adapted to high mountain conditions, do not lose their protective properties, making them promising for use in such regions.

Research highlights that potato resistance to late blight is a key area of study. For example, L. Weng *et al.* (2024) explored the genetic mechanisms of resistance to this disease, identifying markers that facilitate the breeding of resistant cultivars. T. Adekanmbi *et al.* (2023) examined the impact of changing climatic conditions across various ecological sites on potato quality and yield, which is crucial in today's world. The authors emphasise that in mountainous environments, where agroclimatic factors can change rapidly, cultivars with multi-component resistance are needed. Another study by D. Griffin *et al.* (2022) investigates potato cultivars for their ability to withstand complex infections, i.e., combinations of multiple diseases. A. García-Serquén *et al.* (2024) demonstrate that in the high-altitude regions of the Peruvian Andes, different soil management techniques are commonly used, especially for growing potatoes on mountain slopes. These methods help mitigate the effects of nighttime frosts, which are more pronounced than in lowland areas.

This study aimed to assess the level of resistance to major diseases (late blight, common scab, dry and soft rots) and pests in selected potato cultivars under high-altitude conditions in the Gornyi Altai testing site. The research objectives were as follows: to examine three early-maturing potato cultivars (with four replications) in the village of Aktash, Ulagansky District of the Altai Republic, using the locally adapted cultivar Snegir as a control; and to compare the resistance of the cultivars Belukha, Gorets and Suvenir Gornogo Altaya to common diseases prevalent in the region.

Materials and Methods

The study materials consisted of early-maturing potato cultivars developed by the Gorno-Altaisk State University: Belukha, Gorets, and Suvenir Gornogo Altaya (cultivar authors: T. Streltsova, S. Krasnikov), with the adapted cultivar Snegir used as a control. The planting of the experimental cultivars took place on 8 June 2023 at the high-altitude site in Aktash, Ulagansky District, Altai Republic, on a plot belonging to B. Kozhamiarov. The planting date was selected due to the high amount of precipitation and the location's distance from Gorno-Altaysk (365 kilometres). The planting was done according to the following scheme: 90×30 cm spacing, with a planting depth of 10 cm, in two rows of

60 plants, and four replications. The arrangement was randomised, with cultivar-specific weeding, phytosanitary care, timely harvesting and other research stages performed. The results are presented both before and after storage. The tests were conducted following the Guidelines for Ecological Testing of Potato Varieties (Karmanov *et al.*, 1982), Research Methods for Protecting Potatoes from Diseases, Pests, Weeds, and Immunity (Volovik *et al.*, 1995), and the Field Experiment Methodology by B. Dospekhov (1985). All procedures were carried out in compliance with the Convention on Biological Diversity (1992).

The research methodology encompassed physiological and genetic selection, alongside direct observation of plant interactions with various pathogens and pests. Agronomic analysis methods were used to evaluate the results. Yield was assessed in kilograms per hectare, and the size and quality of tubers and disease resistance were analysed. Statistical methods were also employed to determine the significance of differences between cultivars. The studied cultivars (Fig. 1) are known for their productivity and ability to withstand diverse weather conditions and diseases, making them popular among the local population.

Figure 1. Studied potato cultivars

Note: the photo shows the potato cultivars Belukha, Gorets, and Suvenir Gornogo Altaya

Source: authors' photo

The soil in the Aktash area is known for its fertility and loamy composition, providing good aeration and moisture retention. During the study, no organic fertilisers or mineral complexes were applied to the soil. The trials were conducted on a natural soil background. Standard agricultural equipment, including a tractor for ploughing, was used, with all other tasks performed manually. The climatic conditions in Aktash during the experiment featured a moderately warm summer with temperatures ranging from 15°C to 25°C, which is favourable for potato growth. Precipitation was moderate (Table 1), with periods of increased humidity, supporting consistent plant growth.

Table 1. Precipitation and average air temperature in 2023 in the village of Aktash

Aktash testing site (month)	Average air temperature, °C	Precipitation, mm
May	11.3	31.2
June	28.6	11.9
July	17.9	74.7
August	18.9	58.3
September	17.3	42.4

Source: developed by the authors based on research

After harvesting, the potatoes were stored in a purpose-built storage facility with controlled temperatures between 2°C and 4°C and air humidity of approximately 85%-90%. The storage was equipped with a ventilation system to prevent condensation and maintain optimal storage conditions. However, during early spring, a roof leak occurred in the storage facility. Two sacks of the Suvenir Gornogo Altaya cultivar were directly exposed to water, leading to rapid tuber decay. When the potatoes became wet, they became more susceptible to diseases such as soft and dry rot. The excessive moisture and constant dampness created ideal conditions for the growth of mould fungi. Even if the external appearance of the potatoes did not change immediately, their internal structure was compromised by the excess moisture, deteriorating the product's quality. This ultimately reduced the nutritional value and flavour of the cultivar.

Results and Discussion

The study of the Gorets, Belukha, and Suvenir Gornogo Altaya potato cultivars, with Snegir as a control, revealed that regardless of the precipitation and air temperatures experienced in the high-altitude testing site of Aktash, Ulagansky District, Altai Republic, in 2023, the tested cultivars exhibited resistance to diseases and pests. No pests were observed, likely due to the low nighttime air temperatures in the highlands. Only the Suvenir Gornogo Altaya cultivar showed a 0.2% infection rate with soft rot, attributed to storage conditions (Table 2). Considering the site's distance from Gorno-Altaisk, mechanical damage to the tubers of the tested cultivars was expected, but none was found. As the harvest occurred during dry weather in the sandy soil of the highlands, all tubers were clean, large and yielded more than the control cultivar.

Table 2. Disease resistance of studied genotypes

No.	Cultivars	Potato diseases, %			
		Late blight	Common scab	Dry rot	Soft rot
1	Belukha	0	0	0	0
2	Gorets	0	0	0	0
3	Suvenir Gornogo Altaya	0	0	0	0.2
4	Snegir	0	0	0	0

Source: developed by the authors based on research

The study found a lack of Colorado potato beetles and other potato pests in the high-altitude Gornyi Altai region. This absence can be attributed to several factors related to the unique climatic and ecological conditions of the area. The high-altitude climate is characterised by cold temperatures and a short growing season. Colorado potato beetles and many other insect pests actively reproduce and develop in warm climates. The cold temperatures in the mountains may limit their life cycle and survival capabilities. Additionally, at high altitudes (above sea level), atmospheric pressure decreases, affecting insect respiration and potentially hindering their existence. The reduced oxygen levels and lower temperatures further contribute to their inability to thrive.

The productivity levels in the highlands were 1,120 g/plant (Snegir cultivar), 1,340 g/plant (Suvenir Gornogo Altaya), 1,570 g/plant (Gorets), and 1,870 g/plant (Belukha). These results indicate that the studied potato cultivars demonstrate higher resistance and productivity in highaltitude conditions, enabling stable yields even in challenging climates. A comprehensive approach, including breeding, improved agricultural practices, and effective resource management, is crucial for successful potato cultivation in mountainous regions.

Indian researchers V. Bhardwaj *et al.* (2022) identified 1,253 locations across India for testing potato cultivars with a cumulative positive temperature sum of 70 days. They conducted similar studies on potato cultivars at these test sites, considering meteorological conditions. While the Aktash site experiences significant negative nighttime temperatures (−4°C), India, conversely, has high nighttime temperatures. This difference is crucial to consider when studying potatoes in the context of changing climates.

Research conducted in the Himalayas by A. Choudhary *et al.* (2021) examined the combination of genetically resistant cultivars with integrated crop management methods. The results demonstrated that using organic protection methods and selecting resistant cultivars can significantly reduce crop losses from diseases without substantially increasing costs. Consistent with these findings, the current study identified resistant potato cultivars – Gorets, Belukha, and Suvenir Gornogo Altaya – that are ideally suited for cultivation in the high-altitude environment of Gornyi Altai.

The studies of W. Pérez *et al.* (2022) and C. Patarroyo *et al.* (2024) examined the resistance characteristics of various potato cultivars to late blight, one of the most destructive diseases, in the mountainous regions of Peru and Colombia. Similarly, T. Dey *et al.* (2018) conducted research in India. M. Gastelo *et al.* (2024) carried out field trials that demonstrated that local cultivars, bred using traditional knowledge, exhibited higher resistance compared to commercial cultivars. The studied potato cultivars in the Gornyi Altai region proved to be highly productive and diseaseresistant.

W. Fry (2020) emphasises that *Phytophthora infestans* populations, the causative agent of late blight, in different regions of the world, are primarily represented by several clonal lines, whose dominance can be temporary and variable. The migration of exotic strains with new phenotypic characteristics poses a significant threat, as they may be resistant to traditional disease control methods and cause substantial damage. J. Arcos-Pineda *et al.* (2024) studied the adaptive properties of various potato cultivars in the high-altitude conditions of the Andes. Similar to the Gornyi Altai conditions, researchers found that cultivars with shorter growing seasons are better adapted to mountain environments, where growing seasons are shorter. P. Bagchi *et al.* (2024) highlight the importance of selecting cultivars resistant to the low nighttime temperatures and high UV radiation characteristic of mountainous regions.

Authors J. González-Jiménez *et al.* (2023) developed an effective model simulating potato crop losses due to late blight. This model accounts for the dynamic interaction between disease development and crop growth, utilising available meteorological data. Despite the complexity of these interactions, the authors successfully created a relatively simple model that closely correlates with real-world crop loss data. Furthermore, the model can predict the impact of climate change (temperature increases) on both potato development and late blight, suggesting that this increase may be more detrimental to the pathogen than to the crop.

Therefore, the authors of this study recommend the following key measures to prevent and control potato diseases in the Altai Republic:

- use resistant potato cultivars such as Gorets, Belukha, and Suvenir Gornogo Altaya, which have genetic resistance to major diseases;
- apply preventive treatments with fungicides to prevent fungal development and maintain plant health in the lower-altitude regions of the Gornyi Altai, where infected tubers were previously found;
- employ appropriate sanitation and field-cleaning methods to avoid the spread of diseases from previous crops;
- proper fertilisation and plant nutrition will strengthen their immune system and reduce susceptibility to diseases.

It is important to note that potato diseases can be caused by microorganisms other than fungi, such as viruses and bacteria. Therefore, for accurate diagnosis and effective disease treatment, laboratory analysis is necessary to determine the specific cause of the disease.

Conclusions

The results of evaluating the disease and pest resistance of potato cultivars in the high-altitude testing site of Gornyi Altai (Aktash Village, Ulagansky District, Altai Republic) can assist producers and experts in making informed decisions about selecting optimal potato cultivars for cultivation in the Gornyi Altai conditions. The Belukha cultivar exhibits high resistance to the major diseases and pests encountered at the testing site. This may be attributed to its genetic potential and ability to adapt to adverse conditions. The Gorets cultivar also demonstrates high resistance to the studied diseases and pests. The Suvenir Gornogo Altaya cultivar displays mixed results regarding disease and pest resistance. Some aspects of resistance were high, while others raised concerns related to the optimal storage of the cultivar. The findings of this research can be used to develop strategies for improving disease and pest resistance in cultivated potato cultivars within the Gornyi Altai region.

The studied cultivars demonstrated resistance to late blight regardless of meteorological conditions and the testing site. The evaluation of the Belukha, Gorets, and Suvenir Gornogo Altaya potato cultivars at the Gornyi Altai testing site (Aktash Village, Ulagansky District) indicates that the high-altitude environment influences the level of disease and pest resistance in different potato cultivars. Factors determining resistance levels include climatic conditions, soil composition, and the absence of pathogens and pests at the testing site. To protect potatoes from pests and preserve yields, a comprehensive approach is necessary. This approach should encompass preventative measures such as selecting healthy seeds, implementing proper soil preparation and cultivation techniques, and utilising biological control methods.

Studies in this field demonstrate a variety of approaches to evaluating potato cultivar resistance. They highlight the interconnectedness of biodiversity, regional climatic features, and agronomic practices. This data forms the basis for further research and the development of recommendations for selecting potato cultivars best suited for cultivation in high-altitude conditions. The experiment showed that all cultivars exhibited high yields and resistance to local conditions, confirming their suitability for cultivation in the temperate continental climate of the Ulagansky district. Evaluating the disease and pest resistance of potato cultivars such as Belukha, Gorets, Suvenir Gornogo Altaya, and Snegir in the high-altitude testing site of Gornyi Altai is an important area of research. High-altitude regions have specific climatic conditions that can affect the development of both cultivated plants and pathogens. Prospects for further research include developing biological control methods and studying the impact of specific high-altitude climatic conditions on potato development and resistance. These studies will contribute to increasing the yield and resilience of potato cultivars in Gornyi Altai and promoting the development of the agricultural sector in this unique climatic zone.

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Conflict of Interest

None.

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Алтай тоолорунун бийик тоолуу полигонунун шарттарында илдеттерге жана зыянкечтерге туруштук берүү үчүн картошканын сортторун баалоо

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Аннотация. Иштин актуалдуулугу Алтай тоолорунун уникалдуу шарттарында илдеттерге жана зыянкечтерге эң туруктуу картошка сортторун аныктоо зарылдыгында турат, бул түшүмдүн туруктуулугун жогорулатууга өбөлгө түзөт. Иштин максаты Тоолуу Алтай полигонунун шарттарында Белуха, Горец, Тоолуу Алтай сувенири жана Снегирдин алгачкы сортторунун илдеттерине жана зыянкечтерине туруштук берүү деңгээлин аныктоо болгон. Изилдөө 2023 – жылы Россиянын Алтай Республикасы Улаган районундагы Акташ айылында жүргүзүлгөн. Изилдөөнүн негизги табылгалары жана тыянактары төмөнкү аспектиге байланыштуу: картошканын ар бир сортундагы ооруларга жана зыянкечтерге туруштук берүү деңгээли климаттык шарттар, топурактын курамы жана полигондо патогендер менен зыянкечтердин болушу сыяктуу ар кандай факторлор менен аныкталат. Изилдөө картошканын ар кандай сортторунун туруктуулугун баалоо үчүн талаа сыноосунун, фитопатологиялык анализдин жана статистикалык маалыматтарды иштеп чыгуунун ыкмаларын колдонгон. Фитопатогендер, мисалы, фитофтора жана кадимки котур сыяктуу өсүмдүктөрдүн катышуусу жана даражасы, ошондой эле Колорадо коңузу жана башка зыянкечтер келтирген зыяндуулар талданды. Бардык сорттор кеч күйүүгө, кадимки котурга жана кургак чирикке толук туруштук берери аныкталган, бул сорттордун аймактын шарттарына жогорку ыңгайлашуусун көрсөтүп турат. Бирок, Алтай тоосундагы Сувенир сорту 0,2 % бузулуу деңгээли менен нымдуу чириктер менен бир аз бузулганын көрсөттү, ал эми изилденген сорттордун өнүмдүүлүк көрсөткүчү 1120 г бадал (Снегирь сорту) 1870 г бадал (Белуха сорту) сортун түздү. Алынган маалыматтар түшүмдүн коромжулугун азайтуу үчүн ушул сортторду Алтай Республикасынын бийик тоолуу шарттарында өстүрүүгө сунуш кылууга мүмкүндүк берет. Иштин практикалык мааниси окшош климаттык шарттарда иштеген фермерлерге ылайыкташтырылган картошка сортторун сунуштоо үчүн изилдөөлөрдүн натыйжаларын колдонуу мүмкүнчүлүгү болуп саналат, бул өсүмдүктөрдү коргоо үчүн продукциянын жоготууларын жана чыгымдарын азайтууга мүмкүндүк берет

Негизги сөздөр: генотип; Тоо; Белуха; Алтай тоосундагы Сувенир; кеч Жара; кадимки котур

Оценка сортов картофеля на устойчивость к болезням и вредителям в условиях высокогорного полигона Горного Алтая

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Аннотация. Актуальность работы заключается в необходимости выявления сортов картофеля, наиболее устойчивых к болезням и вредителям в уникальных условиях высокогорья Горного Алтая, что способствует повышению стабильности урожая. Цель работы состояла в том, чтобы определить уровень устойчивости к болезням и вредителям ранних сортов картофеля Белуха, Горец, Сувенир Горного Алтая и Снегирь в условиях высокогорного полигона Горного Алтая. Исследование проходило в 2023 году в с. Акташ Улаганского района Республики Алтай, Россия. Основные находки и выводы исследования касаются следующего аспекта: уровень устойчивости к болезням и вредителям у каждого сорта картофеля определяется различными факторами, такими как климатические условия, почвенный состав и наличие патогенов и вредителей на полигоне. В ходе исследования применялись методы полевых испытаний, фитопатологического анализа и статистической обработки данных для оценки устойчивости различных сортов картофеля. Было проанализировано наличие и степень поражения растений фитопатогенами, такими как фитофтора и парша обыкновенная, а также повреждения, наносимые колорадским жуком и другими вредителями. Установлено, что все сорта проявляют полную устойчивость к фитофторозу, парше обыкновенной и сухим гнилям, что говорит о высокой адаптированности этих сортов к условиям региона. Однако, сорт Сувенир Горного Алтая показал незначительное поражение мокрыми гнилями с уровнем поражения 0,2 %, а показатели продуктивности изучаемых сортов составил от 1120 г/куст (сорт Снегирь) до 1870 г/куст (сорт Белуха). Полученные данные позволяют рекомендовать к выращиванию в высокогорных условиях Республики Алтай данные сорта для минимизации потерь урожая. Практическая ценность работы состоит в возможности использовать результаты исследований для рекомендации адаптированных сортов картофеля фермерам, работающим в аналогичных климатических условиях, что позволит снизить потери продукции и затраты на защиту растений

Ключевые слова: генотип; Горец; Белуха; Сувенир Горного Алтая; фитофтороз; парша обыкновенная

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Morphostructural characteristics of secondary immunogenesis organs in wild boars

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Abstract. To analyse the involvement of immune cells in the pathogenesis of diseases of various aetiologies, and to inform therapeutic and preventive interventions, it is essential to understand the normal morphology of the immune system organs and tissues. This study presented the findings of a morphological investigation of the secondary (peripheral) immune system organs in the Asian wild boar subspecies (*Sus scrofa nigripes*) inhabiting the forest-steppe region of the Moskva District, Chüy Region, Kyrgyz Republic. This research aimed to identify the general morphological and functional features of the lymphoid structures of the spleen, mesenteric lymph nodes, and haemolymph nodes in healthy animals. Study materials were collected from three sexually mature wild boars. Anatomical and histological methods were employed to achieve the study aim. Anatomical methods were used to determine the syntopy, shape, colour, and consistency of these organs. Histological studies were carried out using standard techniques: haematoxylin and eosin staining was employed to examine the general structural organisation of the organs, while Van Gieson's method was used to differentiate muscular and connective tissue

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elements. Light microscopy was used to analyse the stromal and parenchymal structure, cellular composition, and morphofunctional state of lymphoid formations. The study established the morphofunctional condition and morphological characteristics of the spleen, lymph nodes, and haemolymph nodes in sexually mature Asian wild boar subspecies. The findings represented the morphological norm for the secondary immune system organs of this subspecies. These results may serve as a reference framework for future experimental and applied research in the morphology and immunology of organs and tissues in wild boars, both under normal conditions and in pathological states. The data may also be of practical use to veterinary specialists and biologists engaged in functional, ecological, and comparative morphology of organs in domestic and wild animals

Keywords: spleen; lymph nodes; haemolymph nodes; trabeculae; organ parenchyma; lymphoid follicles; lymphocytes

Introduction

The Asian wild boar subspecies (*Sus scrofa nigripes*) is one of the largest wild animals inhabiting the mountainous steppe territories of the Kyrgyz Republic and serves as a primary target for sport hunting among commercial species. According to data from the National Statistical Committee of the Kyrgyz Republic (n.d.), the population of these animals showed steady growth between 2019 and 2023, reaching 3,089 individuals in 2023. The wild boar (*Sus scrofa*) is recognised as one of the world's most widely distributed omnivorous mammals, present on all continents except Antarctica (Markov *et al*., 2022). Despite its extensive range, there is currently a lack of comprehensive scientific studies focusing on the morphological and functional characteristics of both the primary and secondary organs of its immune system under normal conditions. Furthermore, it should be noted that this topic remains relatively understudied in current scientific practice. The available literature presents only isolated studies on this subject: for instance, A. Panphilof *et al.* (2005) investigated the cytoarchitecture of mesenteric lymph nodes; Y. Bozkurt *et al.* (2019) conducted an analysis of the histological and immunohistochemical characteristics of abdominal and thoracic lymph nodes; and E. Chirkova *et al.* (2023) examined the anatomical structure of the heart and spleen in this species. A. Marunchyn *et al.* (2023) studied the clinical manifestations of splenic tumour lesions and associated structural changes.

It is recognised that the wild boar is the direct ancestor and close relative of all known breeds of domestic pigs (Getmantseva *et al*., 2020). Unlike other domesticated animals, pigs have undergone the fewest genetic alterations. Compared to their wild counterparts, they are frequently utilised as subjects in biomedical and bio-veterinary experiments (Lunney *et al*., 2021). Scientists in the field of porcine immunomorphology have achieved significant progress, leading to the accumulation of extensive data regarding the morphology and morphofunctional state of lymphoid organs and tissues under normal conditions and various pathological states. Information concerning these investigations is detailed in the article by R. Pabst (2020). Numerous high-quality studies have been conducted on the morphology and morphofunctional state of secondary lymphoid organs and tissues in domestic pigs. For instance, age-related changes in mucosa-associated lymphoid tissue (MALT) of the conjunctiva in pigs were investigated by A. Irgashev *et al.* (2020). They established that conjunctiva-associated lymphoid tissue in pigs contains all the necessary structures and cells required for an immune response and the protection of parocular tissues of the eye. In addition, V. Grigoryev *et al.* (2023) examined the histogenesis and functional development of the thymus and lymph nodes in piglets during the prenatal period. It was revealed that the thymus, as a central organ of the immune system, begins to form in pig foetuses from the 30th day of embryonic development, while the lymph nodes, acting as sites of lymphoid haematopoiesis and components of the peripheral immune system, attain morphofunctional maturity by the 70th day. T. Chuluunbaatar *et al.* (2023) studied the anatomical and histological characteristics of lymphoid tissue associated with the reproductive organs, specifically in the region of the vaginal vestibule, in healthy, non-pregnant, adult goats and pigs.

Secondary organs of the immune system in animals are recognised to include the spleen, lymph nodes, and haemolymph nodes (Ghosh & Stumhofer, 2021; Pan *et al*., 2023; Cruz de Casas *et al*., 2024). The spleen is a crucial component of the immune system, responsible for filtering blood to maintain immune homeostasis (Wei *et al*., 2022). As noted by G. Crane *et al.* (2021), the unique morphological organisation of this organ facilitates a key role in the integration of the circulatory, reticuloendothelial, and immune systems. The organ filters ageing erythrocytes, immune complexes (antigen-antibody), apoptotic bodies, damaged cells, and other elements circulating within the blood. The histological structure of the spleen reflects its functional diversity and complexity. As a specialised lymphoid organ, the spleen plays a significant role in both innate and adaptive immune responses. Populations of innate immune cells, including B cells, natural killer cells (NK cells), and macrophages, are located within different functional zones of the organ (Aliyu *et al*., 2021).

Lymph nodes are compact, highly organised structures of the secondary lymphoid organs, playing a key role in coordinating innate and adaptive immune responses to exogenous antigens, including vaccine components (Cakala-Jakimowicz *et al.*, 2021). To perform this function, specialised zones are formed within the nodes, integrating blood and lymphatic vessels and facilitating the directed migration of immune cells. Specifically, according to L. Dubreil *et al.* (2022), B cells are directed to lymphoid follicles, where they undergo selection and maturation of clones producing high-affinity antibodies against antigens.

Haemolymph nodes are small, soft, dark red lymphoid organs found in mammals. They are typically located along the vertebral column, abdominal aorta, and within the perirenal adipose tissue, functioning as secondary organs of haematopoiesis and immunogenesis. They are involved in the destruction of aged erythrocytes, processes of erythropoiesis, erythrophagocytosis, and the activation of immune cells, thus contributing to the body's immune response (Arbaev *et al.*, 2019). According to M. Yamada *et al.* (2025), haemolymph nodes represent a unique immune organ, distinct from conventional lymph nodes and the spleen.

Investigating the morphology of these organs in wild boars is significant for both fundamental science and the applied aspects of veterinary medicine and epidemiology. Such a study allows for assessing population health status, identifying the impact of environmental factors and pathogenic agents, and developing measures for animal conservation and the control of infectious diseases. Furthermore, analysis of the morphological features of these organs in wild boars provides insights into the state of their immune system and adaptation mechanisms in a changing environment. This study aimed to examine the morphological and functional characteristics of the lymphoid structures within the spleen, mesenteric lymph nodes, and haemolymph nodes in sexually mature individuals of the Asian wild boar subspecies.

Materials and Methods

The subject of this study was the Asian wild boar subspecies, inhabiting the mountainous steppe zone of the Moskva District, Chüy Region, Kyrgyz Republic. Research materials comprised the spleen, mesenteric lymph nodes, and haemolymph nodes, which were collected during post-mortem examination (necropsy). Biological material was obtained through the licensed harvesting of animals for scientific purposes, carried out under permission issued by the Department of Protection and Rational Use of Natural Resources of the State Agency for Environmental Protection and Forestry under the Government of the Kyrgyz Republic. The harvesting was conducted in the autumn of 2024, adhering to the principles of humane animal treatment (European Convention..., 1986) and following the Hunting Rules in the Territory of the Kyrgyz Republic (2003).

The study group consisted of three individuals: two males and one female. Animal age was determined based on age-related changes in the skull and dental system, following the methodology described by P. Kozlo (1973). The first boar was approximately four years of age, and the second was approximately five years of age. The age of the female corresponded to indicators characteristic of four-year-old individuals. The mass of the animal carcasses was not determined due to the absence of weighing procedures. Immediately after harvesting, a post-mortem examination of the animals was performed in the field, followed by a detailed pathological inspection of the organs, during which no macroscopically visible changes were observed. During the visual inspection, the syntopy, shape, colour, and consistency of the organs were assessed. For histological analysis, tissue samples were fixed directly on-site in a 10% aqueous solution of neutral buffered formalin for 24 hours.

Under laboratory conditions, standard histological processing of organ fragments was conducted, including dehydration, embedding in paraffin, and the preparation of paraffin blocks. Tissue samples, fixed in a 10% aqueous solution of neutral formalin, were initially washed in running water for 24 hours before being sequentially dehydrated in increasing concentrations of ethanol (50%, 60%, 70%, 80%, 90%, 96% I, and 96% II). Each dehydration step lasted for 24 hours. Residual ethanol was removed using chemically pure xylene over a period of three hours, after which the samples were infiltrated with paraffin. Finally, paraffin blocks were prepared and mounted onto wooden holders.

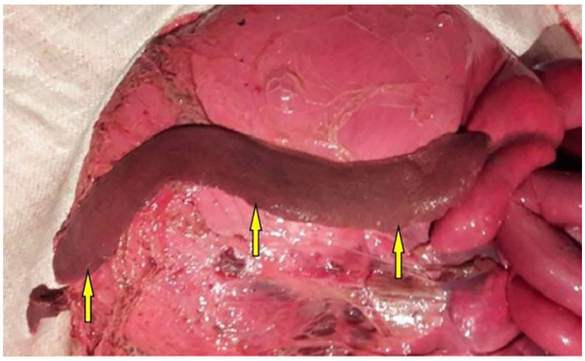
Serial sections, 4-5 μm thick, were cut from the paraffin blocks using a pfm Slide 4004M sledge microtome (Germany). Sections were floated onto a water bath heated to 37°C, then transferred to glass slides using a dissecting needle and subsequently dried on a specialised hot plate. Histological sections were stained with haematoxylin and eosin for general structural description and assessment of cellular composition, and Van Gieson's method was applied for the identification of muscular and connective tissue elements.

Microscopic examination of the histological sections was performed using a MicroOptix MX 100 binocular microscope (Austria), and imaging of tissue structures was carried out using a ToupCam UCMOS01300KPA camera (China), specifically designed for light microscopy. All aforementioned histological procedures were performed manually under standard conditions in the histological laboratory of the Department of Veterinary and Sanitary Expertise, Histology and Pathology at the Kyrgyz National Agrarian University named after K.I. Skryabin. The research was conducted in compliance with established methodological recommendations and requirements applicable to such investigations, following the methodology detailed in the guide by G. Merkulov (1969).

Results and Discussion

The study was conducted on the spleen, mesenteric lymph nodes, and haemolymph nodes of Asian wild boars (Fig. 1a). Upon external examination, all harvested animals were found to be in good body condition, possessing elastic skin, a dense undercoat, and a firmly attached hair coat. No macroscopically visible pathological changes were observed in the organs and tissues during necropsy. The anatomical investigation established that the wild boar spleen is an unpaired parenchymatous organ. It was situated in the left hypochondrium, adjacent to the greater curvature of the stomach. The dorsal pole of the spleen contacted the left kidney and partially the pancreas, while the ventral pole reached the umbilical region and bordered the liver. The parietal surface of the organ lay adjacent to the diaphragm, and the visceral surface featured a ridge through which the splenic hilus passed. The spleen exhibited an elastic consistency, a dark red colour, and an elongated, flattened shape with slightly rounded margins (Fig. 1b). These findings are consistent with the results of studies by E. Chirkova *et al.* (2023) investigated the location of the wild boar spleen. Furthermore, the syntopy of the wild boar spleen demonstrates similarity to the anatomical position of the pig spleen, as supported by data presented by H. Kaur (2019).

a



b

Figure 1. Asian wild boar subspecies after harvesting (a) and macroscopic appearance of the spleen (b), indicated by arrows

Source: authors' photo

Upon sectioning the spleen, the stroma and pulp were discernible. Small, greyish-white punctate formations were observed on the surface of the pulp. Microscopic examination revealed that the spleen of the Asian wild boar subspecies was encased in a dense connective tissue capsule, comprising a serous membrane. Large connective tissue trabeculae extended inwards from the capsule into the organ parenchyma, containing blood vessels – arteries and veins. Collagen fibres and a small number of smooth muscle cells were present within the capsule and trabeculae. Collagen fibres were distinctly evident in the capsule and trabeculae, and to a lesser extent around the walls of the blood vessels. Similar morphological features are described by N. Shringi *et al.* (2018) in their study of the spleen of the White Yorkshire pig (*Sus scrofa*), indicating structural similarity between the subspecies.

The organ parenchyma comprised white pulp and red pulp. The white pulp included lymphoid follicles and the periarterial lymphoid sheath, populated by corresponding populations of T and B cells, which defined them as the T and B zones, respectively. The T zone was represented by a diffuse infiltrate of T cells surrounding the central artery. The B zone consisted of lymphoid follicles situated adjacent to the T zone and containing B cells. Lymphoid follicles were characterised by the eccentric positioning of the central arteries. Findings from studies by B. Steiniger (2015) and R. Asaro & P. Cabrales (2021) confirm that the white pulp of the human spleen exhibits a similar organisation. Lymphoid follicles are located at varying distances from the commencement of the periarterial lymphoid sheath and are found both in the region where the artery branches from the trabecula and in its distal branching areas. However, according to L. da Fonseca Filho *et al.* (2023), the central artery within the white pulp of the brown-throated sloth spleen is centrally located within the germinal centres of the lymphoid follicles.

Lymphoid follicles within the spleen of the Asian wild boar subspecies displayed diverse shapes, including both round and oval forms. Functionally, they were categorised into three groups: newly formed follicles, resting follicles, and actively functioning follicles. Newly formed follicles were typically characterised by small size, indistinct boundaries, and a loose cellular structure (Fig. 2a). This appearance was attributed to their developmental stage and the absence of the morphological maturity characteristic of fully functional lymphoid structures. In contrast, resting lymphoid follicles (lacking a germinal centre) generally exhibited a round or oval shape, a compact arrangement of cells, and relatively small dimensions (Fig. 2b). However, these structures were observed relatively infrequently and in limited numbers within the spleen parenchyma of the Asian wild boar subspecies.

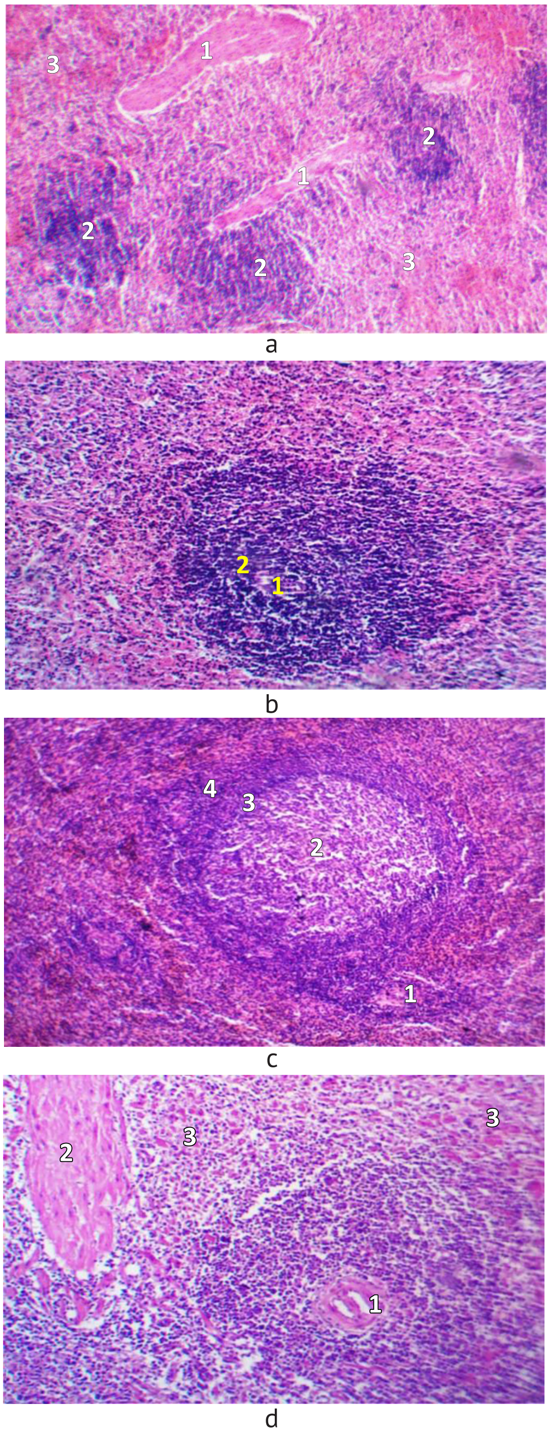


Figure 2. Microscopic appearance of the spleen parenchyma of the Asian wild boar subspecies (haematoxylin-eosin staining)

Note: a. Newly formed lymphoid follicles: 1 – trabeculae, 2 – white pulp, 3 – red pulp. Magnification x40. b. Resting lymphoid follicles: 1 – central artery, 2 – densely packed lymphocytes around the central artery. Magnification x100. c. Actively functioning lymphoid follicles: 1 – central artery, 2 – light (germinal) centre, 3 – mantle zone, 4 – marginal zone, 5 – red pulp. Magnification x100. d. Primary lymphoid follicles with loose cell arrangement: 1 – central artery, 2 – trabecula, 3 – red pulp. Magnification x100

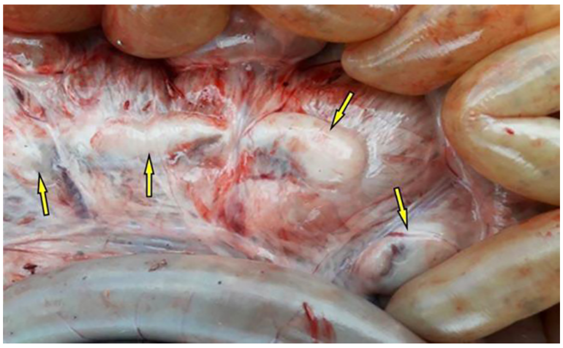
Source: authors' photo

Within an actively functioning lymphoid follicle, a germinal centre was observed – a lighter region containing proliferating young cells – while the peripheral, darker portion comprised mature immunocompetent cells, including lymphocytes, monocytes, macrophages, and plasma cells. A well-defined marginal zone was distinctly evident, situated around the periphery of the follicle and enclosing the T and B zones. This zone served as a transitional area between the white and red pulp (Fig. 2c). According to R. Riedel *et al.* (2020) and G. Victora & M. Nussenzweig (2022), the formation of the lymphoid follicle germinal centre is contingent upon B cell activation in response to antigenic stimulation. Furthermore, the findings obtained by the authors of this article align with data from N. Fedorovskaya *et al.* (2020), who established that the functional activity of lymphoid follicles is determined by the developmental stage of their germinal centre. An increase in germinal centre size indicated an active phase of the immune response, whereas its decrease pointed to structural regression. Thus, the observed morphological features of the lymphoid follicles reflected the dynamics of the immune response and the degree of activation of splenic cellular elements contingent upon the nature of antigenic exposure.

The red pulp of the spleen was comprised of splenic sinuses and cords, containing a significant number of blood vessels. It was located between the capsule, trabeculae, and the lymphoid tissue of the white pulp. Its stroma was formed by reticular tissue, which included lymphocytes, macrophages, plasma cells, and erythrocytes. The morphological characteristics of the wild boar spleen's red pulp were consistent with data obtained in studies by R. Gnanadevi *et al.* (2019) investigating the spleen of sheep and goats, as well as H. Kaur (2019) studying the spleen of pigs.

Accumulations of lymphocytes, capable of forming new (primary) lymphoid follicles of the white pulp, were observed in certain areas of the red pulp (Fig. 2d). This finding was consistent with data presented by J. Kranich & N. Krautler (2016). Their study demonstrated that a significant portion of the red pulp lacks terminal capillaries and does not perform a filtering function. These areas consisted of aggregates of B and T cells, along with mononuclear phagocytes, at which sites lymphoid follicles could subsequently develop.

Based on the findings, the mesenteric lymph nodes of the Asian wild boar subspecies were determined to have an oval or elongated shape, a dense consistency, and a greyish-yellow colour. These nodes were arranged in a chain within the mesentery of the small intestine, between the loops of the colon, and in the short mesentery of the rectum (Fig. 3a). Microscopic examination revealed that the lymph nodes were externally enclosed by a well-developed connective tissue capsule. Wide trabeculae extended inwards from the well-developed capsule into the organ, forming a branched structure within the cortical zone of the node. The internal framework of the lymph node was constituted by the stroma, which consisted of reticular connective tissue. The capsule and trabeculae comprised a dense network of collagen fibres, which were revealed as bright red structures when stained by Van Gieson's method (Fig. 3b). Collagen fibres were also present within the walls of blood vessels, albeit in limited quantities. Similar data were reported by A. Kalita *et al.* (2014), who indicated that the capsule and trabeculae of both the cortex and medulla of lymph nodes in Mizo local pig (Zo Vawk) primarily consisted of collagen fibres, with a lesser proportion of elastic fibres. The content of elastic fibres was notably higher in the blood vessels situated within the capsule and trabeculae. Furthermore, studies by Y. Bozkurt *et al.* (2019) demonstrated that the capsule and trabeculae of the wild boar lymph node were analogous to those of the domestic pig. They contained both collagen and elastic fibres and also included smooth muscle cells and fibroblasts.



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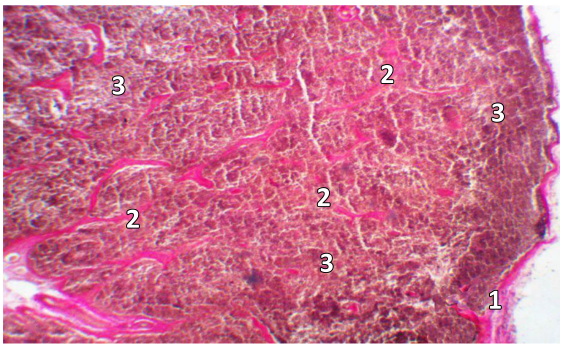


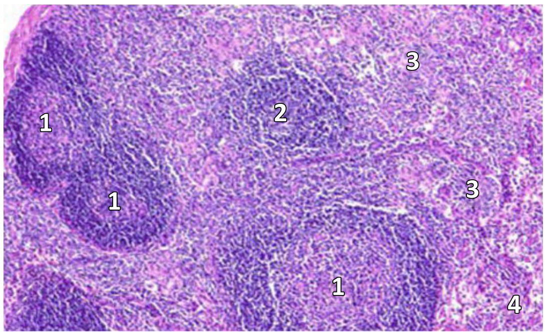
b

Figure 3. Macroscopic and microscopic appearance of the mesenteric lymph nodes of the Asian wild boar subspecies

Note: a. Mesenteric lymph nodes (indicated by arrows). b. Microscopic appearance of the lymph node cortex: 1 – organ capsule, 2 – branched trabeculae, 3 – organ parenchyma. Collagen fibres appear bright red in the capsule and trabeculae. Van Gieson's staining, magnification x40

Source: authors' photo

The organ parenchyma primarily comprised lymphocytes at various stages of maturation and functional activity. Within its structure, three main zones were discernible: the cortex, the paracortical region, and the medulla. The cortex was characterised by a high density of lymphocytes and was subdivided into the outer cortex and the paracortical zone. Lymphoid follicles were located in the outer cortex and were subdivided into primary (resting follicles) and secondary (actively functioning follicles). Secondary follicles predominated among them, distinguished by a distinctly evident light (germinal) centre, along with mantle and marginal zones. The germinal centre contained large lymphocytes (lymphoblasts) and was encircled by a layer of densely packed small (mature) lymphocytes (Fig. 4a). Similar morphological organisation has been noted in other animal species, including sheep (Rahmoun *et al*., 2020) and camels (Fares *et al*., 2023).



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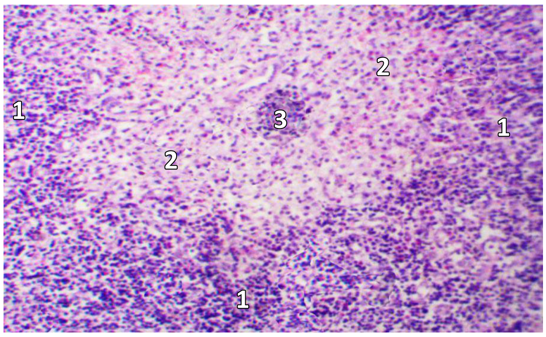


b

Figure 4. Microscopic appearance of the mesenteric lymph nodes of the Asian wild boar subspecies

Note: haematoxylin-eosin staining, magnification: a – x40, b – x100. a. Regions of the organ cortex: 1 – actively functioning lymphoid follicles, 2 – resting lymphoid follicles, 3 – paracortical zone, 4 – medulla. b. Region of the medulla surrounded by paracortical zones: 1 – paracortical zone, 2 – medulla, 3 – primary lymphoid follicle

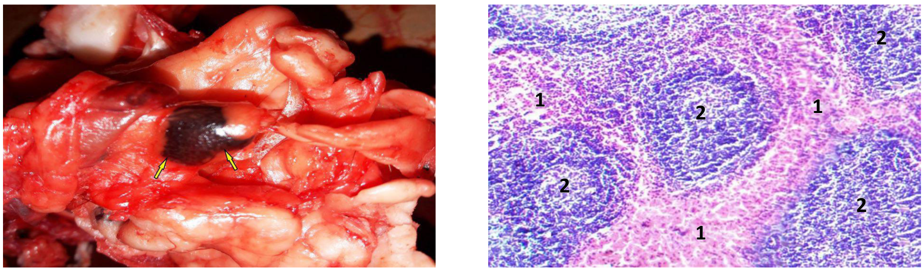
Source: authors' photo

The paracortical zone of the lymph node was situated between the outer cortex and the medulla. It primarily consisted of diffusely distributed lymphocytes and surrounded both primary and secondary lymphoid follicles. In addition to lymphocytes, the cellular composition of the paracortical zone included dendritic cells and reticular fibroblasts. According to the study by G. Slack (2016), this region was considered the T zone of the lymph node, as it was predominated by mature

T cells, as well as varying numbers of large transformed immunoblasts, which could be either T or B cells. T cells, upon exposure to antigens, were activated, proliferated, and differentiated into effector cells or memory cells (Notarbartolo & Abrignani, 2022).

In the medulla, numerous reticular cells with associated reticular fibres were observed, interspersed with lymphocytes, plasma cells, and macrophages. Primary lymphoid follicles, lacking a distinctly defined separation zone, were identified in this region (Fig. 4b). Their number was significantly lower compared to the cortex. The cellular composition was predominantly represented by small lymphocytes, macrophages, and plasma cells. These findings were consistent with data presented by A. Panphilof *et al.* (2005), additionally noted that the main cell type in wild boar lymph nodes comprises lymphocytes, reticular cells are second in prevalence, and mast cells are present throughout all zones of the lymph node.

Haemolymph nodes identified in the wild boar were primarily located within the abdominal cavity along the abdominal aorta, in the perirenal adipose tissue, and deep within the omentum (Fig. 5a). They presented as formations of varying size, exhibiting a round-oval shape, ranging from dark red to brown in colour, with an elastic consistency. Similar haemolymph nodes have been described in humans (Pototskaya & Lapsar, 2016) and in the water deer (Artemeva, 2018). Upon sectioning, the parenchyma of the nodes was saturated with blood, while in certain areas, greyish-white inclusions and connective tissue strands were observed. Microscopic examination established that the haemolymph node was covered by a capsule consisting of fibrous connective tissue. Connective tissue trabeculae extended inwards from the capsule into the organ, dividing the parenchyma into separate regions. According to data from K. Arbaev *et al.* (2019), in the wild boar, the trabeculae in the haemolymph nodes not only possessed significant width but were also welldeveloped. A small number of smooth muscle cells and a significant quantity of collagen fibres were found in the capsule and trabeculae, which corresponded to data from T. Kannan *et al.* (2019).



a b

Figure 5. Macroscopic and microscopic appearance of the haemolymph node of the Asian wild boar subspecies
Note: a. Haemolymph nodes deep within the omentum (indicated by arrows). b. Microscopic appearance of the middle zone of the haemolymph node: 1 – accumulation of erythrocytes in the parenchyma, 2 – lymphoid follicles in different morphofunctional states. Magnification x200
Source: authors' photo

The organ parenchyma was subdivided into zones containing a mixture of blood and lymph, thus confirming the presence of haemolymph within the afferent vessels and sinuses. Beneath the capsule lay a wide subcapsular sinus, which was continuously connected to the trabecular sinuses. A significant number of erythrocytes were observed within the subcapsular sinus and peritrabecular spaces, imparting the node its characteristic red hue. According to studies by M. Zidan & R. Pabst (2004), haemolymph nodes contained subcapsular sinus, trabecular and medullary blood sinuses, indicative of their involvement in blood circulation and filtration. Accumulations of erythrocytes were observed throughout the entire parenchyma of the node, among which regions featuring a local concentration of lymphocytes were encountered. These lymphoid accumulations formed both follicles and diffusely distributed zones within the interfollicular space (Fig. 5b). Secondary lymphoid follicles, separated by blood sinuses, were predominantly observed. They were in an active functional state, evidenced by the presence of well-developed germinal centres. A mantle zone was identified around the periphery of the germinal centres. The cellular composition included small, medium, and large lymphocytes, macrophages, and plasma cells. These findings indicated that haemolymph nodes functioned as lymphoid organs. According to data from C. Park *et al.* (2001), haemolymph nodes likely perform functions related to haematopoiesis, blood filtration, and immune responses. However, the precise mechanisms underlying the functioning of this organ remain insufficiently studied (Boes & Durham, 2017). Consequently, the morphological characteristics of the secondary organs of immunogenesis presented in this study for the Asian wild boar subspecies serve as baseline data and reflect their functional activity in a healthy state.

Conclusions

Morphostructural analysis revealed that the spleen, mesenteric lymph nodes, and haemolymph nodes of the Asian wild boar subspecies possess characteristic anatomical, histological, and cellular features. The spleen exhibits an organisation typical of a parenchymatous organ, with a clear demarcation between the white and red pulp. Its lymphoid follicles are present at various stages of maturation, indicative of active immune processes. The red pulp, comprised of reticular tissue and an extensive vascular network, confirms its role in blood filtration and the destruction of erythrocytes.

Mesenteric lymph nodes feature a well-developed capsule and trabeculae containing collagen fibres. Their structure includes distinct cortical and medullary zones, as well as a paracortical region containing diffuse lymphoid tissue. The predominance of secondary lymphoid follicles with germinal centres signifies active antigenic stimulation. Haemolymph nodes are characterised by a prominent sinusoidal system saturated with erythrocytes, indicating their involvement in blood filtration and the destruction of aged erythrocytes. The active state of lymphoid follicles further confirms their role in the immune response and haematopoiesis.

Further studies should encompass age-related and seasonal variations in the morphofunctional state of these organs, and include a comparative analysis with domestic pigs to elucidate evolutionary differences in immune system organisation. These findings are of importance for veterinary medicine, ecology, and animal husbandry, potentially contributing to the development of strategies for controlling infectious diseases in wild animal populations.

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Conflict of Interest

The authors declare that there is no conflict of interest in this study.

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Жапайы камандардагы иммуногенездин экинчилик органдарынын морфоструктуралык мүнөздөмөсү

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Аннотация. Ар кандай этиологиядагы ылаңдардын патогенезинде иммундук клеткалардын катышуусун талдоо жана аны дарылоо жана алдын алуу иштеринде колдонуу үчүн иммундук системанын органдарынын жана ткандарынын нормадагы морфологиясын билүү зарыл. Бул иште, Кыргыз Республикасынын Чүй облусунун Москва районунун тоо-талаа аймактарын жердеген азиялык түрчөдөгү жапайы камандардын (*Sus scrofa nigripes*) экинчилик (четки) иммундук органдарынын морфологиялык изилдөөлөрүнүн жыйынтыктары берилген. Изилдөөнүн максаты болуп дени сак жаныбарлардын көк боорунун, мезентериалдык лимфа түйүндөрүнүн жана гемолимфа түйүндөрүнүн лимфоиддик түзүмдөрүнүн жалпы морфологиялык жана функциялык өзгөчөлүктөрүн аныктап көрсөтүү саналат. Изилдөөнүн материалы жыныстык жактан жетилген үч баш жапайы камандан алынган. Коюлган максатка жетүү үчүн анатомиялык жана гистологиялык изилдөө ыкмалары пайдаланылган. Анатомиялык ыкмалар аркылуу органдардын синтопиясы, формасы, түсү жана консистенциясы аныкталган. Гистологиялык изилдөөлөр жалпы кабыл алынган ыкмалар боюнча жүргүзүлгөн: органдын жалпы түзүмдүк уюмдуулугун аныктоо үчүн гематоксилин жана эозин боёктору, ал эми булчуң жана тутумдаштыргыч ткандын элементтерин айырмалоо үчүн Ван-Гизон ыкмасы колдонулган. Жарык микроскобунун жардамында органдардын стромалык жана паренхималык түзүмдөрү, клеткалык курамы жана лимфоиддик пайда болуулардын морфофункциялык абалдары талданган. Изилдөөлөрдүн жыйынтыгында жыныстык жактан жетилген азиялык түрчөдөгү жапайы камандардын көк боорунун, лимфа жана гемолимфа түйүндөрүнүн морфологиялык өзгөчөлүктөрү жана морфофункциялык абалы аныкталды. Азиялык түрчөдөгү жапайы камандардын иммундук системасынын экинчилик органдары боюнча алынган маалыматтар морфологиялык норманы өзүнө камтыйт. Жыйынтыктар, жапайы камандардын органдары менен ткандарынын нормадагы жана патологиялык абалдардагы морфологиясы жана иммунологиясы боюнча мындан аркы эксперименталдык жана колдонмо мүнөздөгү иштерди жүргүзүү үчүн нормативдик негиз катары сунушталат. Ошондой эле бакма жана жапайы жаныбарлардын органдарынын функциялык, экологиялык жана салыштырмалуу морфологиясы боюнча алектенген биологдордун жана ветеринардык дарыгерлердин илимий жана практикалык ишмердүүлүгүндө колдонулушу мүмкүн

Негизги сөздөр: көк боор; лимфа түйүндөрү; гемолимфа түйүндөрү; трабекулалар; органдын паренхимасы; лимфоиддик фолликулдар; лимфоциттер

Морфоструктурная характеристика вторичных органов иммуногенеза у диких кабанов

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Аннотация. Чтобы проанализировать участие иммунных клеток в патогенезе болезней различной этиологии и использовать в лечебных и профилактических работах, необходимо знать нормальную морфологию органов и тканей иммунной системы. В данной работе представлены результаты морфологического исследования вторичных (периферических) органов иммунной системы дикого кабана азиатского подвида (*Sus scrofa nigripes*), обитающих в горностепной местности Московского района Чуйской области Кыргызской Республики. Целью исследования было выявление общих морфологических и функциональных особенностей лимфоидных структур селезенки, мезентериальных лимфатических узлов и гемолимфатических узлов у здоровых животных. Материалы исследования были отобраны от трех голов половозрелых диких кабанов. Для достижения поставленной цели использованы анатомические и гистологические методы исследований. Анатомическими методами были определены синтопия, форма, цвет и консистенция данных органов. Гистологические исследования проводили по общепринятым методикам: для выяснения общей структурной организации органа окрашивали гематоксилином и эозином, а для дифференцировки мышечных и соединительнотканных элементов использовали метод Ван-Гизона. С помощью светового микроскопа анализировали стромальную и паренхиматозную структуру, клеточный состав и морфофункциональное состояние лимфоидных образований. В результате исследований были установлены морфофункциональное состояние и морфологические особенности селезенки, лимфатических и гемолимфатических узлов у дикого кабана азиатского подвида в половозрелой стадии. Полученные данные о вторичных органах иммунной системы кабана азиатского подвида представляют собой морфологическую норму. Результаты могут быть рекомендованы как нормативная основа для дальнейших экспериментальных и прикладных разработок морфологии, иммунологии органов и тканей диких кабанов в норме и при патологических состояниях. Также будут использованы в исследованиях и практической работе ветеринарных врачей и биологов, занимающихся функциональной, экологической и сравнительной морфологией органов домашних и диких животных

Ключевые слова: селезенка; лимфатические узлы; гемолимфатические узлы; трабекулы; паренхима органа; лимфоидные фолликулы; лимфоциты

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Mathematical modelling of moisture and heat transfer processes in soils for crop irrigation optimisation

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Abstract. The relevance of this study is conditioned by the need to develop scientifically sound methods to optimise the processes of moisture and heat transfer in soils, which will increase the efficiency of water resources use and improve crop yields. Under the conditions of global climatic changes and increasing deficit of water resources, effective management of crop irrigation becomes one of the key tasks of agronomy. The purpose of the present study was to create mathematical models describing the processes of moisture and heat transfer in soils to be applied to optimise irrigation regimes. The study highlighted the significance of integrating mathematical modelling into practical activities to achieve sustainable development of the agronomy sector. Convective diffusion processes in soils attract the attention of scientific researchers, as it is associated with the broad penetration of mathematical research methods in various fields of sciences. The great spread of surface irrigation methods necessitates the creation of mathematical models and techniques for their solution, revealing the principal regularities of both filtration and purely hydrodynamic processes. The study presented the key physical and mathematical regularities

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underlying the processes of moisture transfer and heat transfer in soil, as well as their interaction. The principal result of the study was a plant and its optimal development, which is of final economic interest, and the object of the study was soils, for which mechanical and mathematical models of the joint movement of moisture and heat with their different characteristics were developed. This study investigated the non-stationary convective diffusion equation. Based on the small perturbation method, the considered equation was represented as a linear equation and its solution was found in the automodel form and two classes of solutions were determined. The findings of this study may be useful for agronomists, engineers, and agricultural specialists seeking to implement modern water management technologies and improve the efficiency of agricultural production

Keywords: convective diffusion equation; hypergeometric Gauss equation; diffusion coefficient; Kummer's transformations; filtration; nonstationary equation

Introduction

The relevance of the subject is driven by the growing demands for efficient use of water resources in agriculture, especially in the context of climate change and increasing global population. Optimisation of irrigation is a key factor for increasing crop yields and sustainability, which requires a thorough understanding of soil processes. Mathematical modelling allows not only predicting the behaviour of moisture and heat in soils but also developing adaptive irrigation strategies that account for the specifics of various crops and climatic conditions. This contributes to more rational water use, cost reduction, and increased agricultural productivity, which is crucial for food security.

V. Díaz-González *et al.* (2022) performed numerical simulations of the proposed model to represent soil moisture content and plant growth dynamics and their consistency with the results of mathematical analysis. Furthermore, a concrete calibration was considered for field data obtained from a wheat experiment, and then these parameters were used to test the proposed model, resulting in an error in the estimation of soil moisture content of about 6%. D. Vishwakarma *et al.* (2023) argued that this simple model, which only requires soil, irrigation, and modelling parameters, is a valuable and practical tool for irrigation design. In this case, the net yield profitability increases markedly compared to the conventional method. It was also shown that the optimum irrigation scheduling solution strongly depends on the particular hydraulic properties of the soil at a given field site (Fontanet *et al.*, 2022).

The experimental findings of Z. Zhai *et al.* (2021) showed that the recommended irrigation rate is compared with the local experience of cultivation technology to obtain a decision accuracy of 81.7%. The irrigation and fertiliser management plan obtained from the intelligent decision-making system provides higher plant height during the growth period than that of locally grown crops. I. Lakhiar *et al.* (2024) concluded that the future of precision irrigation and water conservation systems looks bright due to the need for efficient irrigation water management systems, technological advancements, and increased environmental awareness. As water scarcity is exacerbated by climate change and population growth, precision irrigation and water conservation systems are poised to play a crucial role in optimising and modernising water use, improving water use efficiency and reducing adverse environmental impacts, thereby ensuring sustainable agricultural development.

S. Jaiswal & M. Ballal (2020) presented an automated irrigation controller based on real-time fuzzy inference implemented in LabVIEW, which utilises data from sensor network and transmitted using GSM/GPRS module. An efficient and sustainable irrigation mechanism results in reduced water losses and increased crop yields. O. Novikov *et al.* (2021) proved that the development of irrigation requires a systematic approach with mandatory scientific support on the terms of public-private partnership and can increase revenues to the state budget.

Tremendous attention in reclamation and intensification of agriculture is paid to improving the efficiency of irrigated land use, creation of progressive irrigation methods, improvement of irrigation techniques and technology, significant saving of water reserves, preservation of existing agricultural lands. The purpose of the present study was to develop and apply mathematical models for the analysis and optimisation of moisture and heat transport processes in soils, which will improve water resources management in agriculture.

Materials and Methods

Mathematical modelling was the principal method employed in the present study, which helped to create abstract models describing the processes of moisture and heat transfer in soil. Comparative analysis was used to compare various irrigation methods and their effects on crop growth, which can help in selecting the best approach. Using the systemic approach, processes were considered in the context of the entire agro-ecosystem, including interactions between soil, plants, and the atmosphere. These methods enabled a deeper understanding of soil processes and the optimisation of irrigation systems to improve agricultural efficiency.

Groundwater always contains a certain amount of dissolved salts. A certain amount of salts are in the soil, in the solid phase, can be sorbed on soil particles, be dispersed within soil pores, and appear as a result of irrigation (Hakami *et al.*, 2024). When groundwater rises, moisture approaches the soil surface at a fairly close distance, intense evaporation takes place, and salts are carried to the upper parts of the soil and to the soil surface. At the same time, soil fertility decreases and after a certain period the utilised land may become infertile (Li *et al.*, 2025). Therefore, methods of investigating the water-salt regime of soils and subsoils are essential for land reclamation (Bajpai & Kaushal, 2020). Both small and large portions of water, food, heat, etc., are equally bad for the plant.

Thus, the movement of salts in soils is driven by their migration with solutes. This process of salt transfer in soils, in the absence of chemical reaction and sorption, is described by the following equation (1):

$$m_0\frac{\partial C}{\partial t}=\frac{\partial}{\partial x}\left(D(C)\frac{\partial C}{\partial x}\right)+ \\ +\frac{\partial}{\partial y}\left(D(C)\cdot\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(D(C)\frac{\partial C}{\partial z}\right)-\mathrm{div}(\mathrm{vC}), \quad (1)$$

where C (x, y, z, t) is the salt concentration in the liquid, v is the filtration speed, m_0 is the active porosity of soil, which characterises the active volume of the pore space, D (C) is the diffusion coefficient, which in the general case is a function of the salt concentration in the liquid (Derbie *et al.*, 2024). It was previously proposed that the soil was assumed to be homogeneous, isotropic, and therefore the diffusion coefficient and filtration rate components were considered constant in the first approximation (Henri & Diamantopoulos, 2023). In this case, equation (1) had the following form:

$$m_0\frac{\partial C}{\partial t}=D_0\left[\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2}+\frac{\partial^2 C}{\partial z^2}\right]- \\ -U_0\frac{\partial C}{\partial x}-V_0\frac{\partial C}{\partial y}-W_0\frac{\partial C}{\partial z}\quad , \quad (2)$$

while the following initial-boundary conditions were set:

a. At the initial moment $t=t_0$, $C\ (x, y, x, t_0)=P_0\ (x, y, z)$ (3)

b. At the boundary $C\ (x, y, x, t_0)=Q_0\ (x_0, y_0, z_0, t)$. (4)

Next, a new function was introduced:

$$C\ (x, y, x, t_0)=exp\xi_0\cdot Q\ (x, y, x, t),\ \xi_0= \\ =a_0\ x+b_0\ y+c_0\ z+d_0\ t, \quad (5)$$

and a linear equation of the following form was obtained:

$$Q_\tau=Q_{xx}+Q_{yy}+Q_{zz}, \quad (6)$$

which is an equation for further studies, therewith:

$$a_0=\frac{U_0}{2\mathrm{D}_0},\ \mathrm{b}_0=\frac{V_0}{2\mathrm{D}_0},\ \mathrm{C}_0=\frac{W_0}{2\mathrm{D}_{,0}},$$

$$\mathrm{d}_0=-\frac{U_0^2+V_0^2+W_0^2}{4\mathrm{m}_0 D_0},\ \tau=\frac{D_0}{m_0}\mathrm{t}.$$

The solution of equation (6), invariant relative to the uniparametric similarity transformation group:

$$x\Rightarrow\gamma x, y'\Rightarrow\gamma y, z'\Rightarrow\gamma z, \tau'\Rightarrow\gamma\tau, Q^1\Rightarrow\gamma Q,$$

which must have the following form:

$$Q(\mathrm{x},\mathrm{y},\mathrm{z},\tau_0)=\tau^n\cdot P(\eta_1),\eta_1=\frac{(x^2+y^2+z^2)}{\tau}. \quad (7)$$

By finding all necessary specific derivatives and substituting them into the equation (6) under study, the following ordinary differential equation can be obtained:

$$P''(\eta_1)+\left[\frac{1}{2}+\frac{1}{4}\eta_1\right]P'(\eta_1)-\frac{n}{4}P(\eta_1)=0. \quad (8)$$

Comparing it with an equation of the form

$$xy''+(ax+b)\ y'+(cx+d)y=0, \quad (9)$$

it is possible to write one of the solutions as follows:

$$y=x^{-b/2}\cdot e^{-ax/2}\cdot F\left(\frac{2d-ab}{2\sqrt{a^2-4c}}\right), \\ \frac{1}{2}(b-1);\ x\sqrt{a^2-4c} \quad (10)$$

i.e., one of the specific solutions of equation (8) takes the following form:

$$P(\eta_1)=\eta_1{}^{-1.4}\cdot e^{-\eta_1/8}\cdot F\left(-\frac{4\mathrm{n}+1}{4},-\frac{1}{4};\frac{1}{4}\eta_1\right), \quad (11)$$

where $a=\frac{1}{4}$, $b=\frac{1}{2}$, $c=0$, $d=-\frac{\kappa}{4}$.

The last solution can be written as a polynomial at $\kappa=(4n-1)/4$. The solution of the studied equation (6), in general form, is written as follows $\eta_1=\frac{(x^2+y^2+z^2)}{\frac{D_0}{m_0}t,}$.

$$C\ (x, y, z, t)=exp\,\eta_1\cdot\left(\frac{D_0}{m_0}t\right)^n\cdot \\ \cdot\left[\eta_1{}^{-1/4}\right]\cdot exp\,\eta_1\cdot F\left(-\frac{4n+1}{4},\frac{1}{4},\frac{1}{4}\eta_1\right). \quad (12)$$

If a new variable $\eta=-\eta 1/4$ is introduced, then defining the first and second derivatives P_1', P_1'' and substituting into (8), the following expression is obtained:

$$\eta\ \mathrm{P}''(\eta)+\left[\frac{1}{2}-\eta\right]\cdot P_1'(\eta)+\mathrm{nP}_1(\eta)=0, \quad (13)$$

which is a degenerate hypergeometric Gauss equation and has two linearly independent solutions:

$$P_1(\eta)=C_1F_1\left(-n,\frac{1}{2};\eta\right)+C_2\eta^{1/2}F_2\left(-\eta+\frac{1}{2},\ \frac{3}{2};\eta\right). \quad (14)$$

It is known that both linearly independent solutions simultaneously cannot be written as an algebraic polynomial. The first solution has the form of a polynomial when $n=1, 2, 3\ldots K$, and the second when $n=\frac{3/2,5/2,\ldots\ (2\kappa+1)}{2}$.

Results and Discussion

Some exact solutions can be written for the first solution of equation (6) considering the planned solution (7)

$$Q(x, y, z, \tau) = C_1 (2\tau + \eta^2), \quad at\ n = 1,$$

$$Q(x, y, z, \tau) = C_1 (12\tau^2 + 12\tau\eta + \eta^4), \quad at\ n = 2,$$

$$Q(x, y, z, \tau) = C_1 (120\tau^3 + 180\tau^2\eta + 30\tau\eta^4 + \eta^6), \quad at\ n = 3,$$

$$Q(x, y, z, \tau) = C_1 (a_0\tau^k + a_1\tau^{k-1}\eta + \cdots a_{n-1}\tau\eta^{2n-2} + a_n\eta^{2n}), \ at\ n = k. \quad (15)$$

For the second linearly independent solution of equation (6), there will be other expressions $Q(x, y, z, \tau) = C_2\eta(6\tau + \eta^2)$, $at\ n = 3/2$,

$$Q(x, y, z, \tau) = C_2\eta\,(60\tau^2 + 20\tau\eta^2 + \eta^4),\ at\ n = {}^5/_2,$$

$$Q(x, y, z, \tau) = C_2\eta\,(80\tau^3 + 420\tau^2\eta^2 + 42\tau\eta^4 + \eta^6),\ at\ n = 7/2$$

$$Q(x, y, z, \tau) = C_2\dot{\eta} \times \left(b_0\tau^{k-1/2} + b_1\tau^{k-3/2}\eta^2 + \cdots b_{n-1}\tau\eta^{2k-3/2} + b_n\eta^{2k+1/2}\right),\ at\ n = n + 1/2 \quad (16)$$

Thus, the authors of this study developed two classes of specific automodel solutions for equation (6), which have many different solutions at varying n values. Using Kummer's transformations, one can find other classes of specific solutions (Kamke, 1977).

A different solution of equation (6) was also considered, based on the group properties of differential equations, where the invariance of the equation under study relative to the transformation group of independent and dependent variables was observed (Singh *et al.*, 2020). Based on the above, the solution of equation (6) can be found in the following form:

$$Q(x, y, z, \tau) = (x + y + z)^2 \cdot f(\xi_1), \text{ where } \xi_1 = \frac{\tau}{(x+y+z)^2} \quad (17)$$

By finding all the necessary specific derivatives and substituting them into the equation, an ordinary differential equation of the second order can be obtained

$$\xi_1^2 f_0''(\xi_1) - \left[\frac{1}{12} + \left(n - \frac{3}{2}\right)\xi_1\right] f'(\xi_1) + \frac{n(n-1)}{4} f(\xi_1) = 0. \quad (18)$$

With the introduction of the new function

$$f'(\xi_1) = e^{\xi} \cdot \xi^{\nu} f_0(\xi), \text{ where } \xi = \xi_1^{-1}, \quad (19)$$

the following equation will be obtained:

$$\xi^2 f_0''(\xi) + \left[\frac{25}{12}\xi^2 + \left(2\nu + \frac{1}{2} + n\right)\xi\right] f_0'(\xi) + \left[\frac{13}{12}\xi^2 + \left(n + \frac{1}{2} + \frac{25}{12}\nu\right)\xi\right] \cdot f_0(\xi) + \left[\frac{n(n-1)}{4} + \left(n - \frac{1}{2}\right)\nu + \nu^2\right] f_0(\xi) = 0. \quad (20)$$

Assuming that the square bracket of the last term of the resulting equation is zero, this is possible at $v_1 = -n/2$ and $v_2 = (1 - n)/2$" and so for each value of v the following two equations will be called degenerate hypergeometric Gauss equations:

$$\Xi f_0'' + \left[\frac{1}{2} + \frac{25}{12}\xi\right] f_0' + \left[\frac{13}{12}\xi - \frac{n-12}{24}\right] f_0 = 0, \text{ at } \nu_1 = -\frac{n}{2} \quad (21)$$

$$\xi f_0'' + \left[\frac{3}{2} + \frac{25}{12}\xi\right] f_0' + \left[\frac{13}{12}\xi - \frac{n-37}{24}\right] f_0 = 0, \text{ at } \nu_1 = -\frac{n-1}{2}. \quad (22)$$

In the vicinity of the singular point $\xi = 0$, both linearly independent solutions of equation (21) will be written as follows:

$$f_0(\xi) = exp\left(-\frac{13}{12}\xi\right) \cdot \left[C_1 F\left(\frac{n+1}{2}, \frac{1}{2}; \frac{\xi}{12}\right) + C_2\xi^{1/2} F\left(\frac{n+2}{2}, \frac{3}{2}; \frac{\xi}{12}\right)\right] \quad ,(23)$$

where C_1, C_2 are integration constants.

The general solution of equation (6), considering the solution of (17, 19), will take the following form:

$$Q(x, y, z, \tau) = \tau^{n/2} \cdot exp(-\xi/12) \cdot \left[C_1 F\left(\frac{n+1}{2}, \frac{1}{2}; \frac{\xi}{12}\right) + C_2\xi^{1/2} \cdot F\left(\frac{n+2}{2}, \frac{3}{2}; \frac{\xi}{12}\right)\right] (24)$$

Thus, the required function for equation (21) will finally be written as follows:

$$N(x, y, z, t) = exp\,(a_0x + b_0y + c_0z - d_0t) \cdot \left(\frac{D_0}{m_0}t\right)^{n/2} \cdot exp\left(\frac{m_0(x+y+z)^2}{D_0 + 12t}\right) \cdot \left\{ \begin{array}{l} C_1 F\left[\frac{n+1}{2}, \frac{1}{2}; \frac{m_0}{12D_0} \cdot \left(\frac{x+y+z}{t}\right)^2\right] + \\ + C_2\left(\frac{m_0}{12D_0}\frac{(x+y+z)^2}{t}\right)^{1/2} F\left[\frac{n+2}{2}, \frac{3}{2}; \frac{m_0}{12D_0}\frac{(x+y+z)^2}{t}\right] \end{array} \right\} \quad (25)$$

The general solution for equation (22) will take the following form:

$$f_0(\xi) = exp\left(-\frac{13}{12}\xi\right) \cdot \left[C_1 F\left(\frac{n+2}{2}, \frac{3}{2}; \frac{\xi}{12}\right) + C_2\xi^{-1/2} F\left(\frac{n+1}{2}, \frac{1}{2}; \frac{\xi}{12}\right)\right], \quad (26)$$

then for equation (6) itself, the solution will be written as follows:

$$Q(x,y,z,\tau)=\left(\frac{m_0}{D_0}\tau\right)^{\frac{n-1}{2}}(x,y,z,\tau)exp\left(-\frac{\xi}{12}\right)\cdot$$
$$\cdot\left[C_1F\left(\frac{n+2}{2},\frac{3}{2};\frac{\xi}{12}\right)+C_2\xi^{-1/2}F\left(\frac{n+1}{2},\frac{1}{2};\frac{\xi}{12}\right)\right] \quad (27)$$

and considering expression (5), ultimately there is

$$\mathrm{C}(x,y,z,t)=exp\,(a_0x+b_0y+c_0z-d_0t)\cdot$$
$$\cdot t^{\frac{n-1}{2}}(x+y+z)\cdot exp\left(-\frac{m_0}{12D_0}\frac{(x+y+z)^2}{t}\right)\cdot$$
$$\cdot\left[C_1F\left(\frac{n+2}{2},\frac{3}{2};\frac{m_0}{12D_0}\frac{(x+y+z)^2}{t}\right)+C_2\left(\frac{m_0}{12D_0}\frac{(x+y+z)^2}{t}\right)^{-1/2}\cdot\right.$$
$$\left.\cdot F\left(\frac{n+1}{2},\frac{1}{2};\frac{m_0}{12D_0}\frac{(x+y+z)^2}{t}\right)\right] \quad (28)$$

Next, the analysis will be made when each specific solution of the degenerate hypergeometric Gaussian function can be represented in the form of an algebraic expression. The first specific solution of expression (23) is represented in the form of a polynomial when $n=-2k+1$, and the second at $n=-2k-2$.

Hence, it can be observed that at the same values of the automodelling index, the specific solutions cannot be simultaneously written in algebraic polynomials. Some exact solutions of equation (6) will be defined, for the first specific solution:

$$C(x,y,z,t)=exp\,(a_0x+b_0y+c_0z-d_0t)\cdot$$
$$\cdot\left(\frac{D_0}{m_0}t\right)^{-1/2}\cdot exp\left(-\frac{m_0(x+y+z)^2}{12D_0t}\right) \quad (29)$$

$$\mathrm{C}(x,y,z,t)=$$
$$=exp\,(a_0x+b_0y+\mathrm{c}_0z-d_0t)\cdot\left(\frac{D_0}{m_0}t\right)^{-3/2}\cdot$$
$$\cdot\ exp\left(-\frac{m_0(x+y+z)^2}{12D_0t}\right)\cdot\left[1-\frac{m_0(x''+y+z)^2}{6D_0\cdot t}\right] \quad (30)$$

Next, two solutions at $n=-2$ and $n=-4$ will be written out for the second specific solution:

$$C(x,y,z,t)=C_2\left(\frac{D_0}{m_0}t\right)^{3/2}\cdot$$
$$\cdot(x+y+z)\ exp\ \cdot$$
$$\cdot\left[(a_0x+b_0y+c_0z+d_0t)-\frac{m_0(x+y+z)^2}{12D_0t}\right] \quad (31)$$

$$C(x,y,z,t)=C_2\left(\frac{D_0}{m_0}t\right)^{5/2}\cdot(x+y+z)\ exp\cdot$$
$$\cdot\left[(a_0x+b_0y+c_0z-d_0t)-\frac{m_0(x+y+z)^2}{12D_0t}\right]\cdot$$
$$\cdot\left[1-\frac{m_0(x+y+z)^2}{18D_0t}\right] \quad (32)$$

The authors of the present study defined a class of exact solutions of equation (2,6), and the analysis of the obtained solutions convinced specialists that the number of summands obtained by polynomials increases with decreasing of the automodelling index n. The integration constants C_1, C_2 are determined from the explicit setting of the initial boundary conditions (3, 4). The principal result of the study was the optimum development of various crops in the field, which is of final economic interest, and the object of the study was soil, for which mechanical and mathematical models of the joint movement of moisture, heat, and various concentrations of salts with different characteristics were developed.

Based on the principles of geochemical hydrodynamics and the results of its application in the field of irrigation and land drainage, the study investigated and outlined the methodology for calculating the salt regime of soils (Rachinskaya *et al.*, 1963). According to this, the equation of convective diffusion and mass transfer during water filtration in soils was analysed analytically (Sagyndykova & Tuganbaev, 2014), and methods of calculation of these processes were proposed. In irrigated areas, a significant problem is the prevention of salinisation of fertile lands that were abandoned due to the rise of saline groundwater and other types of salinisation (Phogat, 2012). According to W. Guo *et al.* (2001), salinisation of naturally saline lands, which after desalinisation become suitable for farming, continues to be relevant.

Therefore, measures preventing soil salinisation, forecasting, and correct calculations of the consequences of land irrigation are of paramount significance. M. Hagage *et al.* (2024) pointed out that the application of reclamation measures substantially affects the natural hydrochemical regime of the upper part of the soil, which can cause severe environmental consequences. Therefore, the development of sound methods for predicting hydrochemical processes in soils, aeration zone soils, and groundwater is critical (Zhai *et al.*, 2021). The prediction should explain why the same intervention, in some conditions gives a strong effect, while in other conditions turns out to be suboptimal and sometimes harmful. According to H. Li & Z. Luo (2011), the correct forecast is based on the methods of geochemical hydrodynamics, which combines the principles of filtration theory, diffusion, chemical kinetics, and modern mathematics.

A. Kostyakov (1960) attempted to uncover the mechanism of salt movement in soil and to show quantitative interaction of factors. The researcher used the equation to calculate the increase of groundwater salinity where U is the rate of groundwater evaporation, C is the salt concentration, v is the diffusion coefficient, x is the coordinate directed downwards, t is time, $n=0$; 0.5;1. This equation is derived from the equality in the equilibrium case of two salt fluxes (convective and diffusive) in an arbitrary soil section parallel to the free surface. However, the theoretical dependence obtained from this equation cannot claim to be general at least because it is obtained based on hypotheses with certain assumptions. Assumptions that it is possible to find a single dependence for the entire zone of salt transfer, regardless of the soil structure and the nature of the moisture regime in it, do not correspond to reality.

L. Rex (1968) offered analytical solutions of the system of two equations for the case of steady and unsteady groundwater regime, which allow making forecasts of soil salt regime under irrigation. However, in practice, both progressive rise of groundwater table in case of irrigation and its marked decrease in case of evaporation take place. The process is non-stationary. Furthermore, the models of the above researchers, when considering salt and moisture migration in soil under natural conditions and under irrigation, did not account for horizontal movement of groundwater flow and did not determine the relationship between existing water-salt regimes of soils and groundwater flow. At the same time, groundwater velocity and salinity substantially influence the distribution of salt concentrations in soil (Xun *et al.*, 2022). Notably, consideration of solely the vertical movement of soil moisture leads to the necessity of setting a concentration value at some depth, which is factually an uncertain variable.

Conclusions

The mathematical model of uniform soil hydration was theoretically substantiated, spatial mechanical and mathematical model of heat and moisture transfer and salt migration in different soils was developed and their approximate analytical solutions under initial boundary conditions with different physical and mechanical properties of soil were obtained. Since in the Kyrgyz Republic surface irrigation is applicable for any agricultural crop and is the most widespread, it comes with both advantages and disadvantages. In this regard, quantitative hydrodynamic studies on the selection of the principal elements of irrigation technology, theoretical study of the processes of heat, moisture, and salt transfer in the soil, to create the best conditions for plant development are significant.

Irrigation is an essential factor for increasing crop yields, especially under varying climate conditions. Modelling of moisture and heat transfer processes helps to better understand the interaction between soil, water, and plants. The study described the mathematical models used to simulate moisture and heat transport processes. These models account for soil physicochemical properties, climatic conditions, and plant needs. The models allow predicting the distribution of moisture and temperature in the soil, which contributes to more efficient irrigation scheduling. The findings showed how different irrigation regimes affect soil conditions and plant growth.

Based on the data obtained, it is possible to develop recommendations for optimising irrigation regimes, which reduces water losses and improves conditions for crop growth. Agronomists and farmers can use the findings of this study to make more informed decisions in irrigation management, which can lead to improved agricultural sustainability. These findings highlight the significance of mathematical modelling in agronomy and its contribution to sustainable agriculture. Therewith, there is a need for further research to improve models and account for other factors such as climate change and soil characteristics.

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Conflict of Interest

The authors of this study declare no conflict of interest.

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Айыл чарба өсүмдүктөрүн сугарууну оптималдаштыруу үчүн жер кыртышындагы ным жана жылуулук өткөрүү процесстерин математикалык моделдөө

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Аннотация. Бул иштин актуалдуулугу жер кыртышындагы ным жана жылуулук берүү процесстерин оптималдаштыруунун илимий жактан негизделген ыкмаларын иштеп чыгуу зарылдыгы менен шартталган, бул суу ресурстарын пайдалануунун натыйжалуулугун жогорулатууга жана түшүмдүүлүктү жакшыртууга мүмкүндүк берет. Глобалдык климаттык өзгөрүүлөрдүн жана суу ресурстарынын өсүп бараткан тартыштыгынын шартында айыл чарба өсүмдүктөрүн сугарууну натыйжалуу башкаруу – агрономиянын негизги милдеттеринин бири болуп калууда. Бул иштин максаты сугат режимдерин оптималдаштыруу үчүн жер кыртышындагы нымдуулук жана жылуулук берүү процесстерин сүрөттөгөн математикалык моделдерди түзүү болгон. Макалада агросектордун туруктуу өнүгүүсүнө жетишүү үчүн математикалык моделдөөнү практикалык иш-аракетке интеграциялоонун маанилүүлүгү баса белгиленген. Жер кыртышындагы конвективдүү диффузия процесстери илимий изилдөөчүлөрдүн көңүлүн бурат, анткени бул илимдин ар кандай тармактарына математикалык изилдөө ыкмаларынын кеңири жайылышына байланыштуу. Жер үстүндөгү сугат режимдеринин кеңири жайылышы чыпкалоо жана гидродинамикалык процесстердин негизги үлгүлөрүн ачып бере турган математикалык моделдерди, аларды чечүү ыкмаларын түзүү зарылдыгын шарттайт. Макалада топурактагы ным жана жылуулук берүү процесстеринин, ошондой эле алардын өз ара аракеттенүүсүнүн негизги физикалык жана математикалык мыйзам ченемдүүлүктөрү келтирилген. Изилдөөнүн негизги натыйжасы өсүмдүк жана анын оптималдуу өнүгүшү болгон, ал акыркы экономикалык кызыгууну жаратат, ал эми изилдөө объектиси ар кандай мүнөздөмөлөрү менен нымдуулуктун жана жылуулуктун биргелешкен кыймылынын механикалык-математикалык моделдери иштелип чыккан жер кыртышы болгон. Бул жерде конвективдүү диффузиянын стационардык эмес теңдемеси изилденген. Чакан толкундоолор ыкмасынын негизинде, каралып жаткан теңдеме сызыктуу деп көрсөтүлөт жана анын чыгарылышы автомодельдик түрдө табылып, чыгарылыштардын эки классы аныкталат. Изилдөөнүн натыйжалары агрономдор, инженерлер жана айыл чарба адистери үчүн

пайдалуу болушу мүмкүн, алар заманбап суу ресурстарын башкаруу технологияларын киргизүүгө жана агроөнөр жай өндүрүшүнүн натыйжалуулугун жогорулатууга умтулушат

Негизги сөздөр: конвективдүү диффузия теңдемеси; Гаусстун гипергеометриялык теңдемеси; диффузия коэффициенти; Куммердин өзгөртүүсү; чыпкалоо; стационардык эмес теңдеме

Математическое моделирование процессов влаго- и теплопереноса в почвогрунтах для оптимизации орошения сельскохозяйственных культур

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Аннотация. Актуальность данной работы обусловлена необходимостью разработки научно обоснованных методов оптимизации процессов влаго- и теплопереноса в почвогрунтах, что позволит повысить эффективность использования водных ресурсов и улучшить урожайность. В условиях глобальных климатических изменений и нарастающего дефицита водных ресурсов эффективное управление орошением сельскохозяйственных культур становится одной из ключевых задач агрономии. Целью данной работы было создание математических моделей, описывающих процессы влаго- и теплопереноса в почвах, с целью их применения для оптимизации режимов орошения. В статье подчеркнута важность интеграции математического моделирования в практическую деятельность для достижения устойчивого развития агросектора. Процессы конвективной диффузии в почвогрунтах привлекают внимание научных исследователей, так как это связано с широким проникновением математических методов исследования в различные области наук. Большое распространение поверхностных способов орошения диктует необходимость создания математических моделей и методик их решения, позволяющих выявить основные закономерности как фильтрационных, так и чисто гидродинамических процессов. В работе представлены основные физические и математические закономерности, лежащие в основе процессов влагопереноса и теплопередачи в почве, а также их взаимодействия. Главным результатом исследования было растение и его оптимальное развитие, которое представляет итоговый экономический интерес, а объектом исследования были почвогрунты, для которых разработаны механико-математические модели совместного передвижения влаги и тепла с различными их характеристиками. В работе было исследовано нестационарное уравнение конвективной диффузии. На основании метода малых возмущений, рассматриваемое уравнение представлено как линейное, и его решение найдено в автомодельном виде и определены два класса решений. Результаты исследования могут быть полезны для агрономов, инженеров и специалистов в области сельского хозяйства, стремящихся к внедрению современных технологий управления водными ресурсами и повышению эффективности агропроизводства

Ключевые слова: уравнение конвективной диффузии; гипергеометрическое уравнение Гаусса; коэффициент диффузии; преобразования Куммера; фильтрация; нестационарное уравнение

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Weed vegetation in fields of post-harvest green manure crops and their use as green fertilisers

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Abstract. Perennial weed species predominate in the fields sown with post-harvest green manure crops, surpassing the number of annual weeds. These are mainly represented by persistent and difficult-to-eradicate rhizomatous and root-sprouting noxious weeds. This study aimed to analyse the significance of the agroclimatic potential of the central part of the Chüy Valley in Kyrgyzstan, along with the provision of uninterrupted irrigation of fields during the introduction of post-harvest green manure crops into agricultural production, under conditions where weed growth and development are stimulated on irrigated arable land. The study examined weed vegetation in fields sown with intermediate post-harvest green manure crops (white mustard, oilseed radish, white sweet clover, spring barley, and lacy phacelia) following the harvest of spring wheat. The subsequent incorporation of phytomass into the soil was carried out to serve as a green fertiliser and to analyse its effect on the phytosanitary condition of the soil. The findings confirmed that when green manure crops are incorporated as green fertiliser, weed plants are destroyed in masse; that is, the green biomass of weeds undergoes mineralisation in the arable layer and thereby serves as a source of green fertiliser. The agrotechnological approach of suppressing weed growth in agricultural crop fields through the integration of intermediate post-harvest green manure agrocenoses – white mustard, oilseed radish, white sweet clover, spring barley, and lacy phacelia – into the cropping structure, without the need for additional arable land, reflects a high level of cultivation practice in the irrigated farming systems of the Kyrgyz Republic. These green manure crops are sown after the harvest of spring wheat (the first ten-day period of July) on irrigated fields with typical sierozem soils. This practice fully meets the key principles of environmentally sustainable organic farming. The targeted use of plant phytomass (both intermediate post-harvest green manure crops and weed vegetation) as green fertiliser possesses significant biological potential for reducing greenhouse gas emissions from agricultural production. It also supports carbon sequestration (CO2 capture) in the organic matter of soils and contributes to the resilience of agroecosystems in the face of climate change, thus playing a crucial role in climate change mitigation

Keywords: green manure crops; weeds; damage; climate; soil fertility; arable land

Introduction

Despite the long-standing efforts of farmers to control weed infestation in agricultural crop fields, a high degree of weed contamination persists. Weeds are natural competitors of cultivated plants, and their

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presence negatively affects the development conditions of agrocenoses. Weeds not only reduce crop yields and increase production costs but also diminish the quality of agricultural produce. As noted by S. Shevchenko *et al*. (2023), protecting agrocenoses from weed invasion, reducing their density, and eliminating them altogether represent significant untapped potential for increasing agricultural output. Weeds compete with crops for essential resources such as water, light, nutrients, and space, resulting in lower yields and poorer quality of produce. This competition is especially critical under conditions of limited resources in irrigated arable land and the need to ensure sustainable food production. Losses caused by weed overgrowth directly affect the income of farming enterprises and the availability of food on the domestic market. Furthermore, they have a detrimental impact on the socio-economic well-being of rural populations (Junaid & Gokce, 2024). Thus, weed control remains a key agrotechnological component in ensuring national food security.

Existing methods of weed control – preventive, agrotechnical, and chemical – each offer certain benefits, and their combined application enhances both the cost-effectiveness and efficiency of weed management (Gao & Su, 2024). However, as noted by I. Shuvar & H. Korpita (2023), excessive use of herbicides can lead to significant environmental pollution, changes in the species composition of weed flora, and reduced sensitivity of many species to chemical treatments. This highlights the relevance of ongoing research into weed vegetation, shifts in species composition, and the use of both traditional and environmentally sustainable methods of weed control. According to M. Vasileiou *et al.* (2024), the scientific justification and adoption of new, ecologically safe technologies and methods for controlling weed vegetation – aimed at reducing weed infestation and ensuring the production of environmentally friendly crops – represent an important scientific and practical challenge with considerable national economic significance. This issue is particularly pressing in the context of growing concern over environmental quality and the resilience of agriculture in the face of global climate change.

Scientific research has demonstrated that the use of green manure crops as fertilisers – when combined with technogenic factors for soil fertility restoration and the latest advances in agricultural production – has a multifaceted positive impact on the agroecosystem. This includes improvements in agroecological, phytosanitary, energy-efficient, and economic aspects of crop production (Lei *et al.*, 2022).

Agrotechnologies involving the introduction of intermediate green manuring, which make full use of the region's bioclimatic potential and renewable carbon sources, not only reduce anthropogenic pressure on arable land but also support the controlled germination of weed vegetation. This, in turn, creates favourable conditions for targeted and effective weed control at early stages of development. In developed countries, green manuring is widely used as an agrotechnical practice to restore soil fertility, improve the phytosanitary condition of arable land, and accelerate the growth of the agricultural sector. This contributes to an increase in the production of environmentally friendly food through the implementation of organic farming systems. Therefore, among the range of agrotechnical measures for controlling both perennial and annual weed species, one of the most pressing tasks in the protection of agricultural crops is the integration of intermediate post-harvest green manure crops into irrigated farming systems. This approach has proven effective in reducing weed populations on irrigated arable land (Chicouène, 2020). This has become possible with the advancement of the agroecosystem-based approach to biological farming, which promotes integrated and sustainable management of the crop production sector. It places emphasis on natural mechanisms for regulating biodiversity and restoring soil fertility. One of the key tools in this progressive direction is the agrotechnology of green manuring, which involves cultivating specific crops for incorporation into the soil with the aim of comprehensive improvement – including phytosanitary conditions and weed suppression (Karabaev *et al.*, 2023). The present research aimed to study weed vegetation in fields sown with intermediate post-harvest green manure crops under irrigated conditions on typical sierozem soils in the central part of the Chüy Valley, Kyrgyz Republic.

Materials and Methods

The research focused on the study of weed vegetation in fields sown with intermediate post-harvest green manure crops – white mustard, oilseed radish, white sweet clover, spring barley, and lacy phacelia following the harvest of spring wheat. These green manure crops were sown after the harvest of spring wheat on irrigated typical sierozem soils in the central part of the Chüy Valley, Kyrgyz Republic, and were used as green fertilisers. Field experiments examining weed presence in plots with post-harvest green manure crops, sown following spring wheat, were conducted during the growing seasons of 2019-2021. Observations were made from the third ten-day period of July to the second ten-day period of October. The experimental design was as follows:

1*. Control + Potato – 50% NPK

2*. Green manure (annual white sweet clover) + Potato – 50% NPK

3*. Green manure (white mustard) + Potato – 50% NPK

4*. Green manure (oilseed radish) + Potato – 50% NPK

5*. Green manure (lacy phacelia) + Potato – 50% NPK

6*. Green manure (barley) + Potato – 50% NPK,

where * is the control and all treatment variants were conducted against an agrochemical background of

50% NPK, equivalent to N = 120 kg/ha of active substance, P = 90 kg/ha, and K = 90 kg/ha.

The study was conducted following the research of H. Vetter (1959), E. Schieder & W. Breunig (1978), and A. Berdnikov (1990), who noted that the combined application of green and mineral fertilisers is more effective than their separate use. Furthermore, research by B. Sotnikov (2004) demonstrated that incorporating green manure crops together with straw, against a background of mineral fertilisation (ranging from 50 to 200 kg/ha of active substance), within a crop rotation involving green manure fallow, increased the nutritional value of maize silage by 0.02-0.03 feed units compared with conventional fallow systems. In the present experiment, the preceding crop was spring wheat, harvested in the third ten-day period of July. The agroclimatic potential of the central part of the Chüy Valley allows for the successful sowing of post-harvest green manure crops under conditions of irrigation using sprinkler systems.

The methodology for fieldwork on the experimental plot, as well as laboratory analysis of plant and soil samples, was based on standard procedures accepted in the Kyrgyz Republic (Kachinsky, 1925; Grishina & Samoilova, 1971; Levin, 1973). Weed infestation levels and species composition in the post-harvest green manure crop plots were assessed in late September, prior to the incorporation of the green manure crops. A quantitative method was used, employing a 1 m^2 frame with four replications for each treatment (Samsonov *et al.*, 2006; Fetyukhin *et al.*, 2018). All weed species present within the plots were recorded and identified. In cases where species identification proved difficult, herbarium specimens were collected and later identified under appropriate conditions using specialised literature (Fetyukhin *et al.*, 2018). The study was carried out by ethical standards for plant research and complied with international bioethics regulations (Convention on Biological Diversity, 1992). The species composition and biological groups of the weeds were also determined concurrently.

Results and Discussion

Prerequisites for improving the phytosanitary condition of arable land

The irrigated arable land of northern typical sierozem soils at the experimental site is considered fertile, characterised by a high standard of irrigated farming practices. In the 1960s, large-scale land reclamation was carried out in this area, and a reliable irrigation system using sprinkler units has since been operating effectively to support agricultural crop production. Under such favourable agrotechnical conditions, and when following recommended cultivation practices, it is possible to achieve target yields within agrocenoses. However, even under these conditions, weed infestation remains a significant issue in irrigated fields. This presents one of the most serious agrotechnical and economic challenges for agricultural production, as weeds reduce crop yields, may act as vectors for pests and diseases, and diminish the quality of crop products (Borodin & Tarushkin, 1987).

As a result of non-compliance with recommended farming systems in Kyrgyzstan, agricultural crops are often affected by moderate to severe weed infestation, posing a serious risk of widespread proliferation of persistent perennial rhizomatous and root-suckering weeds. However, the current level of scientific research addressing the phytosanitary challenges of farming systems does not fully meet the requirements of ecologically balanced, soil-conserving and energy-efficient agriculture, nor does it align with the realities of a diverse agricultural sector. The phytosanitary condition of irrigated arable land plays a crucial role in determining the overall effectiveness of agricultural production and the resilience of agroecosystems to the challenges of global climate change. In turn, this directly affects the health of agrocenoses, animals, and humans. Therefore, a comprehensive approach to agricultural management is essential in order to control weed infestation. In this context, the development of new environmentally friendly weed control methods is of increasing importance. Among these, the agrotechnical practice of using post-harvest green manure crops (intermediate green manuring) represents a highly relevant and sustainable strategy for the protection of irrigated farmland.

Intermediate post-harvest green manuring within the framework of innovative irrigated farming represents a promising agrotechnical approach based on the rational use of bioclimatic potential and land resources. This method enables the production of an additional yield of green phytomass from each hectare of irrigated arable land during the second half of summer and early autumn. The phytomass of green manure crops is used as a green fertiliser, meaning that the cultivation of intermediate post-harvest green manures does not require the allocation of additional irrigated land – a critical advantage in the context of limited agricultural land resources. These crops serve as an additional renewable source of "green" organic fertilisers, helping to replenish the reserves of organic matter in irrigated soils, which are often depleted due to excessive exploitation and the neglect of scientifically based agricultural practices.

Currently, the use of irrigated arable land in the Kyrgyz Republic is largely driven by the intensive exploitation of the soil's fertility potential, frequently in violation of scientifically recommended farming systems. This has led to a decline in soil fertility and reduced crop yields (Karabaev *et al.*, 2024). Over the years, the consistent removal of large quantities of nutrients from the soil with crop harvests, without adequate replenishment, has resulted in a noticeable decline in organic matter levels and the loss of valuable agrophysical and agrochemical properties of arable land.

The loss of soil fertility in irrigated agriculture poses a serious threat to the food security of the Kyrgyz Republic, which is directly linked to the rational and careful management of soil resources. This challenge has become increasingly pressing, as numerous issues have accumulated in the country's agricultural sector in this regard. Addressing these problems requires the support of innovative scientific research focused on the nation's land resources. A key priority is the collection of data and materials concerning the current state of soil fertility, using an agro-soil information system tailored to agricultural land (Golozubov *et al.*, 2024). In the near future, this information is expected to be used strategically in the development of policy measures aimed at strengthening food security and improving nutritional outcomes for the population. It will also serve the needs of all stakeholders within the agricultural sector of the national economy.

Influence of agroclimatic potential on plant development

The meteorological conditions of the region, along with anthropogenic factors, can significantly influence the spread of weeds on arable land by altering their distribution, population density, and competition with cultivated crops. Table 1 presents the average long-term meteorological indicators for the central part of the Chüy Valley in the Kyrgyz Republic.

Table 1. Average long-term meteorological indicators for the central part of the Chüy Valley in the Kyrgyz Republic

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual average
Air temperature, °C												
-5.1	-2.8	3.8	11.5	16.9	20.3	23.9	21.9	16.7	9.9	1.4	-4.1	9.5
Soil surface temperature, °C												
-8.5	-4.7	4.0	13.7	21.0	26.5	30.2	27.2	19.5	10.2	1.0	-5.0	11.2
Precipitation, mm												
22.2	25.0	49.0	64.0	59.5	37.2	17.7	11.7	14.7	35.7	37.2	25.7	400.0
Relative air humidity, %												
75.2	76.7	74.7	65.0	60.0	55.0	51.2	51.7	54.0	62.2	72.7	75.7	64.5

Source: developed by the authors

The agroclimatic potential of the study region, following the harvest of spring wheat in the third ten-day period of July, enables the cultivation of post-harvest green manure crops under irrigation (via sprinkler systems). These conditions also promote the emergence of weed vegetation. This is evidenced by the climatic data of the central Chüy Valley, where both air temperature and soil thermal regime are favourable for the development of post-harvest green manure crops as well as weed species (Table 1).

During the growing season of post-harvest green manure crops, the weather remains relatively dry. Air humidity averages 51.7% in August and 54.0% in September, while precipitation levels are low – only 11.7 mm in August and 14.7 mm in September. A notable increase is observed only in October, reaching 35.7 mm. The above-mentioned air temperature indicators contribute to soil drying: in August, absolute soil moisture is 13.1 mm, in September it drops to 9.5 mm, and by October falls further to 6.8 mm. Even the higher rainfall in October does not significantly improve soil moisture levels. These meteorological data, along with anthropogenic influences, indicate that the successful cultivation of post-harvest green manure crops is not feasible without regular irrigation.

The key method for optimising the water regime in the hot summer climate of the Chüy Valley is scheduled irrigation, which ensures an optimal soil moisture balance and enables the cultivation of post-harvest green manure crops. Given the high daytime air temperatures during the summer, irrigation of such crops plays an important agrotechnical role in supporting sustainable and productive farming practices. Changes in soil temperature regimes under the influence of irrigation have a positive effect on both soil formation processes and plant development, including the emergence of weed vegetation. Optimal regulation of the water regime – through sprinkler irrigation – on fields sown with post-harvest green manure crops enhances the solubility of soil nutrients by acting as a solvent for chemical compounds, thereby increasing nutrient availability for plants. It also stimulates soil microbiological activity. This process promotes the mineralisation of crop residues from the preceding spring wheat (straw and roots), which in turn improves the nutrient status of the soil. The freshwater used by sprinkler systems is characterised by a neutral pH of 7.

Against this background of favourable agrometeorological conditions and the introduction of innovative agrotechnical practices in irrigated farming, an optimal balance of water, nutrients, and air in the soil is achieved in the experimental plots. This creates a sound basis for the advanced cultivation of post-harvest green manure crops. Such a combination of natural and anthropogenic factors in the cultivation of intermediate green manures is essential for achieving the desired outcomes in the adoption of green fertiliser practices in agricultural production.

Components of weed vegetation in green manure crop stands

As noted in the articles of B. Sotnikov (2004), K. Dovban (2009), and L. Frolova & M. Novikov (2018), the introduction of intermediate green manure crops into agricultural production is one of the key ecologically sound agrotechnical practices for restoring soil organic matter. These crops also serve a phytosanitary function on arable land. Although intermediate post-harvest green manures are effective in suppressing weed growth and development, weed species are still found within these stands. The important question is how these weeds may affect the phytosanitary condition of the fields for subsequent crops in the rotation. The species composition of the weed vegetation recorded in the authors' third-year trial is presented in Table 2.

Table 2. Species composition of weed vegetation by treatment (third year of the trial)

Weeds	Treatments of post-harvest green manure crops					
	Control	White mustard	White sweet clover	Spring barley	Pacy phacelia	Oilseed radish
Volunteer wheat						
	7	2	3	3	2	3
Perennial weeds						
Couch grass	4	3	3	2	3	2
Field bindweed	5	2	2	3	2	3
Field sow-thistle	6	3	3	2	3	2
Bermuda grass	4	1	2	3	2	1
Russian knapweed	5	2	3	3	3	3
Wintercress	3	1	1	2	2	2
Annual weeds						
White goosefoot	5	1	2	3	2	1
Bristle grasses	7	1	1	2	1	1
Redroot pigweed	8	2	3	3	2	2
Field pennycress	5	1	1	2	1	1
Cockspur	4	1	2	2	2	2
Corncockles	3	1	1	2	1	1

Source: developed by the authors

As shown in Table 2, the fields under intermediate post-harvest green manure crops are predominantly infested with persistent and aggressive rhizomatous and root-sprouting perennial weeds. These are among the most harmful species in agriculture, as their ability to reproduce vegetatively enables them to spread rapidly and regenerate even after partial removal of the above ground biomass. Such weeds cause substantial damage to agricultural production by reducing yields, impairing crop quality, and negatively affecting the overall economic efficiency of farming. Managing rhizomatous and root-sprouting weeds requires additional investment in herbicides, mechanical cultivation, and other agrotechnical measures.

An analysis of the weed composition across the experimental variants revealed the presence of highly persistent perennial weeds, such as couch grass (*Elytrígia répens*), field bindweed (*Convolvulus arvensis*), field sow-thistle (*Sonchus arvensis*), Bermuda grass (*Cýnodon dáctylon*), Russian knapweed (*Rhaponticum repens*), wintercress (*Barbaréa vulgáris*). Among these, rootsprouting perennials – field sow-thistle (*Sónchus arvénsis*), field bindweed (*Convōlvulus arvēnsis*), Russian knapweed (*Rhaponticum repens*) – were found alongside rhizomatous species such as couch grass (*Elytrígia répen*) and Bermuda grass (*Cýnodon dáctylon*). Wintercress (*Barbaréa vulgáris*) reproduces both by seed and root suckers. These species belong to a category of particularly difficult-to-eradicate weeds. Root-sprouting weeds are capable of propagating not only by seed but also through root suckers or underground shoots. They spread rapidly across irrigated arable land, forming dense infestations and competing aggressively with cultivated crops for essential resources.

The cultivation of agricultural crops presents significant challenges in controlling perennial weeds that propagate via root suckers and rhizomes. The resilience of these weeds is largely due to their extensive and well-developed root systems. These species are particularly problematic because they spread underground, often to considerable depths, and can remain viable in the soil for many years (Samsonov *et al*., 2006; Mazirov & Korchagin, 2009). Under adverse environmental conditions, their vitality is maintained in a dormant state – an important biological characteristic of these weeds. Their vegetative propagation organs include reproductive roots, root suckers, rhizomes, bulbs, tubers, and surface runners. Even within a single growing season, these structures can produce several, or even dozens, of new daughter plants.

During weed control measures and root pruning, the above-ground parts of the plants may die off, yet a vast number of vertical and horizontal roots and rhizomes remain in the soil, retaining their viability for many years. Under favourable conditions, these weeds can regenerate even after remaining dormant in the soil for three to four years. Furthermore, they are capable of both vegetative reproduction and propagation by seed, with seeds remaining viable in the soil for five years or more and germinating when conditions become favourable (Spiridonov, 1997). These hardy and persistent species germinate en masse on irrigated arable land, depriving crops of essential nutrients, suppressing seedlings, and blocking access to sunlight, thereby reducing the productivity of agrocenoses. Their control requires significant labour and financial resources, ultimately increasing the cost of agricultural production.

The harmfulness of perennial weeds is determined not only by their abundance and species composition but also by the sensitivity of cultivated plants to their presence, which varies depending on the crop's growth stage. In the studies by Yu. Fadeev & K. Novozhilov (1984) and M. Sokolov & E. Litvishko (1993), particular attention is given to biological methods of weed control among agronomic practices. In this context, the introduction of intermediate post-harvest green manure crops into the cropping systems of agrocenoses can provoke a mass emergence of weed vegetation. However, intermediate green manures such as white mustard, oilseed radish, white sweet clover, spring barley, and lacy phacelia exhibit vigorous growth during the summer months, forming a dense above-ground phytomass that effectively suppresses weed growth and development.

Phenological observations of weed growth and development under different green manure crop treatments revealed that these plants can successfully suppress even the most persistent perennial weeds. This occurs due to several factors:

- the green manure crops actively utilise both anthropogenic and natural resources – irrigation water, sunlight, and soil nutrients – which reduces the availability of these essential growth factors for weeds;
- the green manures rapidly develop under the favourable meteorological conditions of the study region, forming dense cover that shades the soil and limits light penetration, thereby inhibiting the germination and growth of light-dependent weed species.

However, as shown in Table 2, weed species were still present across the experimental treatments. This can be attributed to their adaptability, reproductive capacity, and resilience to adverse conditions. Such traits allow weeds to compete effectively with cultivated crops, making them a persistent challenge in agricultural production. The primary weed-suppressing function of intermediate post-harvest green manure crops lies in their incorporation into the soil during autumn ploughing, at which point both the green manure and accompanying weeds serve as green fertilisers. Importantly, prior to this ploughing, the weeds do not have time to reach the seeding stage, meaning the seed bank in irrigated fields with ordinary sierozem soils is not replenished. Following autumn ploughing, during the mineralisation process of plant residues (including green manure crops and weeds), the vegetative organs of the most aggressive perennial weeds lose viability in both autumn and spring. These residues are decomposed by soil microorganisms, which actively proliferate in the phytomass of green manure crops and accompanying weed vegetation.

The green phytomass of post-harvest green manure crops, when incorporated into arable soil in its fresh state, contains 77.6%-83.1% moisture. At this stage, it also features a narrow carbon-to-nitrogen ratio, which promotes microbial activity in the soil. In addition, the total biomass of weeds, when combined with the phytomass of the green manure crops, serves as green fertiliser. This contributes to the enrichment of organic matter in irrigated arable soils and improves the soil's nutrient regime. Such targeted use of plant phytomass (both green manure crops and accompanying weeds) as green fertiliser holds significant potential for reducing greenhouse gas emissions associated with agricultural practices. It also supports the sequestration of carbon in the soil's organic matter and enhances the resilience of agroecosystems to climate change.

As demonstrated by the research findings, the cultivation technologies of intermediate postharvest green manure crops – such as white mustard, oilseed radish, white sweet clover, spring barley, and lacy phacelia – on irrigated fields of ordinary sierozem soils in the Chüy Valley of Kyrgyzstan contribute to a reduction in the prevalence of perennial weeds. These ecologically and economically viable agrotechnologies for weed suppression in crop fields, through the introduction of intermediate green manure crops, reflect a high standard of irrigated farming practice. Therefore, the full range of measures and approaches for weed control – including the integration of intermediate post-harvest green manure crops into crop rotation – vegetation remains highly relevant.

Conclusions

The integrated effect of post-harvest green manure crops used as green fertilisers is reflected both in their function as organic fertilisers and in their ability to suppress weed growth during the growing season. Emerging weeds are subsequently destroyed during autumn ploughing while still in their green state. As the plant residues (both green manure crops and weeds) decompose through mineralisation in autumn and spring, the vegetative organs of persistent perennial weeds lose their viability. This contributes to a reduction in weed populations and prevents the replenishment of the soil seed bank. The scientific justification and practical implementation of new, environmentally safe technologies, methods, and means of weed control through the cultivation of post-harvest green manure crops help reduce weed infestation on irrigated arable land in the Kyrgyz Republic. This approach also represents a cost-effective means of producing ecologically clean agricultural yields, which is of significant national economic importance. The use of postharvest green manure crops for weed control in crop fields serves as an indicator of advanced irrigated farming practices, promoting the sustainable use of soil resources and minimising the environmental footprint of agricultural production.

The use of post-harvest green manure crops contributes not only to the improvement of the phytosanitary condition of arable land but also to the enhancement of soil fertility through the enrichment of organic matter and the improvement of agrophysical properties. This is particularly relevant in the context of soil degradation caused by intensive land use, and it supports the longterm sustainability of agroecosystems. The inclusion of post-harvest green manure crops in crop rotation systems also promotes soil carbon sequestration, playing a significant role in mitigating the effects of climate change. This approach aligns with global initiatives aimed at reducing greenhouse gas emissions and strengthening the environmental resilience of the agricultural sector in the Kyrgyz Republic. Further development of weed control methods should be based on an understanding of ecological changes resulting from the characteristics of farming systems, their components, and the pathways of agricultural intensification. This calls for in-depth research into the interaction between green manure crops and weed vegetation under various agroclimatic conditions, as well as the development of adapted agrotechnologies tailored to regional specifics.

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Conflict of Interest

The authors declare no conflict of interest.

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Орто мезгилдеги сидераттардын талааларындагы отоо чөптөр жана аларды жашыл жер семирткич катары пайдалануу

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Аннотация. Жаздык буудайдын түшүмү жыйналгандан кийин орто мезгилде өстүрүлгөн жашыл жер семирткич түрүндө өстүрүлгөн сидераттар жайгаштырылган сугат айдоо талааларында көп жылдык отоо чөптөрдүн саны бир жылдык отоо чөптөрдүн санына караганда басымдуулук кылат жана алар өтө зыяндуу отоо чөптөр катары мүнөздөлөт. Изилдөөнүн максаты болуп, Кыргызстандын Чүй өрөөнүнүн Борбордук бөлүгүнүн агроклиматтык потенциалынын орто мезгилде өстүрүлгөн сидераттарды айыл чарба өндүрүшүнө киргизүүдөгү ролун жана антропогендик фактор – талааларды үзгүлтүксүз жамгырлатып сугаруунун маанилүүлүгүн аныктоо каралган. Изилдөө жүргүзүүдө, сугат айдоодо жашыл жер семирткич түрүндө жаздык буудайдан кийин орто мезгилде өстүрүлгөн сидераттардын (ак горчица, майлуу турп, ак таттуу беде, жазгы арпа, фацелия) талаасында отоо чөптөрдүн санынын азайышы тастыкталды жана алардын жашыл массасы сидераттар менен чогуу, күзүндө жерге айдалганда жок кылынып, жашыл жер семирткичтин ролун аткарары аныкталды. Сугат айдоо аянттарынын структурасына орто мезгилде өстүрүлгөн жашыл жер семирткич түрүндө пайдаланган сидераттар жайгаштырылганда отоо чөптөрдү жок кылуунун экологиялык жактан таза агротехнологиясы ишке киргизилет. Өсүмдүк биомассасын (сидерат жана отоо чөптөр) жашыл жер семирткич катары максаттуу пайдалануу багытындагы жүргүзүлгөн иштер айыл чарба өндүрүшүндө парник газдарынын эмиссиясын азайтуу багытында зор потенциалга ээ жана топурактын органикалык заттарында көмүртекти секвестрлөө процессине жардам берүү менен агроэкосистеманын климаттын глобалдуу өзгөрүшүнө туруктуулугун жогорулатып, климаттын глобалдык өзгөрүшүнүн кесепеттерин жумшартат

Негизги сөздөр: сидерат өсүмдүк; отоо чөп; зыян; климат; түшүмдүүлүк; айдоо жер

Сорная растительность на полях пожнивных сидератов и их использование в качестве зеленых удобрений

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Аннотация. Многолетние сорные растения на посевах промежуточных пожнивных сидератов превалируют над численностью малолетних сорняков, и они представлены трудно искореняемыми корневищными и корнеотпрысковыми злостными сорняками. Цель работы состояла в том, чтобы проанализировать значение агроклиматического потенциала Центральной части Чуйской долины Кыргызстана и обеспечение бесперебойного орошения полей при внедрении в аграрное производство пожнивных сидеральных культур, когда на орошаемой пашне провоцируется рост и развитие сорняков. В процессе работы изучалась сорная растительность на посевах промежуточных пожнивных сидератов (горчица белая, редька масличная, донник белый, ячмень яровой, фацелия рябинколистная) после уборки яровой пшеницы, с последующей запашкой фитомассы для использования в качестве зеленых удобрений и анализа их влияния на фитосанитарное состояние почвы. Исследование подтвердило, что при использовании сидератов на зеленое удобрение они массово уничтожаются, т.е. зеленая масса сорняков минерализуются в пашне, тем самым они используются в качестве зеленых удобрений. Агротехнология уничтожения сорных растений на посевах сельскохозяйственных культур внедрением в структуру посевных площадей агроценозов промежуточных пожнивных сидератов – горчицы белой, редьки масличной, донника белого, ячменя ярового, фацелии рябинколистной, которые размещаются после уборки урожая яровой пшеницы (первая декада июля) на орошаемых полях обыкновенных сероземов и не занимают дополнительной площади пашни, является показателем высокой культуры системы орошаемого земледелия Кыргызской Республики и отвечает основным требованиям экологического ведения органического сельского хозяйства. Целенаправленное использование фитомассы растений (промежуточные пожнивные сидераты и сорная растительность) в качестве зеленых удобрений обладает огромным биологическим потенциалом по сокращению атмосферных выбросов парниковых газов в сельскохозяйственном производстве и помогает процессу связывания углерода (секвестрация углекислого газа – CO_2) в составе органического вещества почвы, а также формирует устойчивость агроэкосистемы к изменению климата, соответственно, играет большую роль в смягчении последствий изменения климата

Ключевые слова: сидеральная растительность; сорняки; вред; климат; плодородие; пашня

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Climate change in Kyrgyzstan and its impact on the emergence of biogeocoenotic pathologies in animals

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Abstract. Biogeocoenotic pathology refers to the widespread occurrence of disease not only in animals but also in humans and plants. Such conditions arise as a result of adverse changes in the environment. In this context, the timely investigation of the ecosystem of the Chüy Region of Kyrgyzstan as an aetiological factor, along with early detection of pathologies in cattle resulting from these changes, has become particularly important. This study aimed to examine biogeocoenotic pathology in Alatau breed cows in the Chüy Region, to carry out monitoring based on the "soil plant animal" system concerning the content of biogenic macro- and micronutrients as well as toxic metals, and to develop recommendations for establishing an innovative ecological centre to support ecosystem optimisation in Kyrgyzstan The experimental study involved Alatau cows in the second half of gestation, with soil and plants used as key environmental components. The soil, plants and animal blood samples were analysed using an atomic emission spectrophotometer. At the same time, key metabolic indicators in the experimental and control groups of cows were assessed using standardised and unified methods. Analysis of soil, forage plants and blood from cows kept in environmentally disadvantaged areas of the Chüy Region revealed a

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significant imbalance in the levels of macronutrients, micronutrients and heavy (toxic) metals. This imbalance in the biochemical trophic chain has disrupted the circulation of substances within the specific biogeocoenosis of the Chüy zone, a phenomenon linked to ecological degradation – particularly in areas where major industrial enterprises are concentrated. To support timely ecosystem monitoring in Kyrgyzstan, the authors have proposed the establishment of an innovative scientific and educational ecological centre focused on protecting the health of humans and animals. The findings of this study may be applied in medicine, agriculture, veterinary science, ecology, and within both academic and research institutions

Keywords: cow; soil; plant; blood; innovative scientific and educational ecological centre; toxic metals

Introduction

Kyrgyzstan is a developing mountainous country, with mountains covering up to 95% of its total territory. The country stretches approximately 900 km from east to west and 410 km from north to south, lying between 39° and 43° N latitude. Its total area is nearly 200,000 square kilometres. The climate is sharply continental, with extreme temperature fluctuations – from as low as -53.6°C in winter to as high as +44°C in summer. Annual precipitation ranges from 150 to 650 mm. Snow cover can vary from 4 to 200 cm, while permafrost occupies around 34% of the country's territory. Solar radiation levels reach between 136 and 161 kcal/cm^2. Kyrgyzstan possesses extensive natural pastures – around 9.2 million hectares, or 86% of all agricultural land. However, over 60% of these pastures have experienced various forms of degradation (Oruzbayeva, 1982). At the 29th Conference of the Parties to the United Nations Framework Convention on Climate Change, attended by around 100 heads of state and government, the President of the Kyrgyz Republic, S. Japarov, stated that glaciers in Kyrgyzstan are melting at an unprecedented rate. Over the past 50 to 70 years, the total glacier area has decreased by 16% due to climate change within the country (United Nations Climate Change Conference, 2024). Speaking at the international conference Global Mountain Dialogue for Sustainable Development: Towards the Bishkek +25 Summit on 24 April 2025, President S. Japarov once again drew the international community's attention to climate change, extreme weather events, natural disasters, accelerated ecosystem degradation, and glacier melt in mountainous regions (S. Japarov spoke..., 2025).

The main causes of these changes include global warming, loss of biodiversity, ozone layer depletion, air and water pollution, accumulation of industrial and domestic waste, and greenhouse gas emissions, among others (Essack, 2018; Eskew *et al.*, 2020). In Kyrgyzstan, these issues ultimately lead to climate change and the emergence of new pathologies affecting not only plants and animals but also humans. Biogeocoenotic pathology is a field that studies mass diseases in animals arising from adverse environmental changes within ecosystems (biogeocoenoses). It views animal diseases as closely linked to shifts in environmental conditions – such as climate change, ecotoxicants, radioactive metals, and toxic gases – in ecosystems altered by human activity. These diseases, along with the resulting decline in the quality of livestock products, pose a threat not only to animal health but also to human health (Elenshleger, 2016; Moskalchuk, 2021).

In this context, Kyrgyzstan endorsed the agreement on the seventeen Sustainable Development Goals (SDGs) to be achieved by 2030, adopted in Paris in 2015 (The 17 Goals, 2015). This document was signed by nearly 200 countries, including Kyrgyzstan. Industrial cities such as Bishkek, Kant, Tokmok, and Kara-Balta have particularly polluted atmospheres, contaminated by emissions of heavy metals and toxic mixtures of smoke, fog and dust (smog). According to reputable international organisations, air quality in Bishkek is among the most hazardous, with an Air Quality Index (AQI) rating of 229. The average annual concentration of PM 2.5 is approximately 153.5 μg/m^3, significantly exceeding both national and international hygienic standards by as much as 3.6 times (United Nations, 2022; IQAir, n.d.). Certain heavy metals, such as lead, mercury and arsenic, are classified as highly hazardous substances. Once deposited in the bones, they lead to gradual degeneration and accumulate in parenchymal organs such as the liver, kidneys and heart. These toxicants can reduce the immune system's responsiveness, contribute to chronic neurological disorders and, in some cases, cause cancer (Skugoreva *et al.*, 2016; Pourret & Hursthouse, 2019).

The ecological issue of biogeocoenotic pathology in animals should be addressed through a comprehensive approach aimed at improving environmental conditions, involving experts from a range of fields, including ecology, toxicology, technology, agrochemistry, land reclamation, medicine and veterinary science. To investigate this problem in Kyrgyzstan in a holistic manner, the authors of this article set the aim of studying climate change in the Chüy zone – an area with high levels of atmospheric pollution caused by transport and industrial emissions. The study involved monitoring the "soil-plant-animal" system for macronutrients, micronutrients and heavy metals; identifying biogeocoenotic pathologies in Alatau breed cows; and developing proposals for the establishment of an innovative ecological centre dedicated to safeguarding the health of both humans and animals.

Materials and Methods

The experimental studies were conducted between October 2018 and July 2022 within a specific biogeocoenosis – the Chüy zone of Kyrgyzstan – at farms most affected by anthropogenic influences: Vetka AC, Chabrets Farm, and Kyrgyz IFIBS. These sites are located within 3 kilometres of the country's main North-South highway, as well as near major industrial cities such as Bishkek, Kant and Kara-Balta The experiment involved Alatau breed cows in the second half of gestation (10 animals in total), divided into experimental (5 cows) and control (5 cows) groups. The animals were selected based on average body weight and external conformation measurements. They were kept in open feeding and exercise areas under identical feeding conditions. During the autumn and winter months, the live weight of the cows ranged on average from 361 to 368 kg.

The content of macronutrients, micronutrients and heavy metals in the "soil-plant (forage)animal (blood)" system was analysed using atomic emission spectrophotometry (ICP-AES OPTIMA 5300 DV and ICP-MS Elan DRS). Sampling of experimental and control specimens, including soil and forage plants, was carried out following GOST 17.4.1.02-83 (1985), GOST 17.4.3.01-2017 (2017), and SanPiN 42-123-4089-86 (1986). Blood samples were collected following the recommendations of the I. Kondrakhin *et al.* (1985). For morphobiochemical analysis, blood from both experimental and control cows was drawn in the morning before feeding. The parameters measured included erythrocyte and leukocyte counts, haemoglobin, glucose, lymphocytes, total protein, carotene, phosphorus and calcium levels, using standardised and unified methodologies (Kondrakhin *et al.*, 1985). All results were meticulously recorded and documented in a specially bound laboratory journal. The data were processed using MS Excel software on a TRUCRED computer, and statistical analysis was conducted using Student's t-test, with significance thresholds of $P \leqslant 0.05$ and $P \leqslant 0.5$. The experiment was conducted following the ethical standards outlined in the Code of Practice for the Housing and Care of Animals Bred, Supplied or Used for Scientific Purposes (2014).

Results and Discussion

The results of the experimental study indicated that the primary cause of biogeocoenotic pathologies in cows is an imbalance of specific biogenic macro- and micronutrients, as well as heavy metals, in soil and forage. Similar conclusions have been drawn by other researchers, including V. Baturin *et al.* (1998) and M. Wrzecińska *et al.* (2021), who reported that environmental contamination by toxic waste is one of the key factors contributing to the development of biogeocoenotic pathologies in animals. S. Mukhacheva & V. Bezel (2015) further asserted that ecotoxicants (particularly heavy metals) affect not only the mother but also the foetus, within the "mother-placenta-foetus-offspring" system. This finding is supported by the research of R. Nogoibaeva *et al.* (2020). The results of the comparative analysis of macro- and micronutrient content in soil, forage and the blood of experimental cows are presented in Figures 1, 2, and 3.

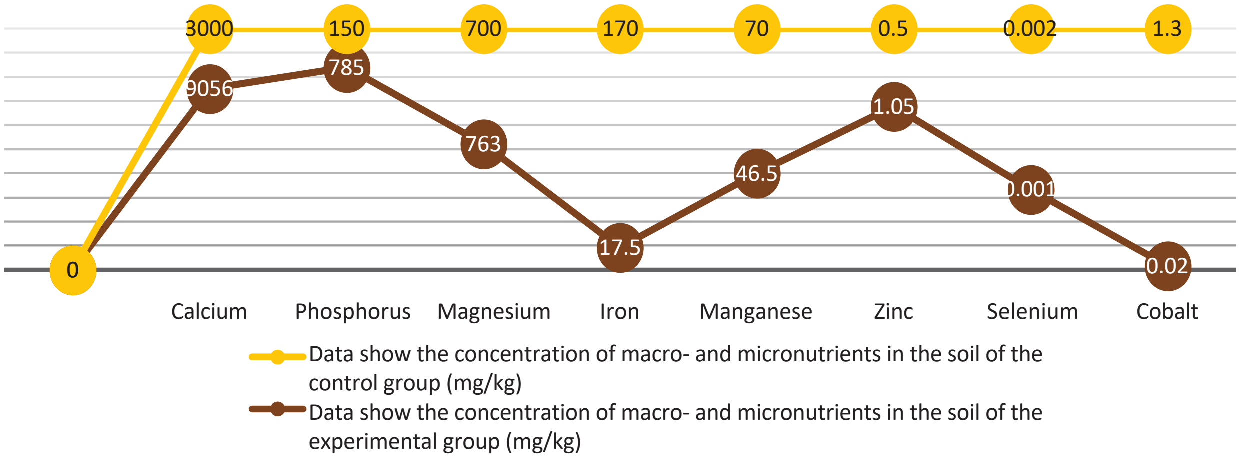

Figure 1. Content of macro- and micronutrients in the soil from the environment of experimental cows
Source: developed by the authors based on original research

Based on the data in Figure 1, it can be assumed that the levels of certain macro- and micronutrients in the soil of the environmentally compromised biogeocoenosis differ significantly from baseline values. For example, the concentrations of manganese, iron, cobalt, and selenium are considerably lower, whereas the levels of calcium, phosphorus, and magnesium are higher than the threshold concentrations. Figure 2 presents data on the macro- and micronutrient content in forage.

The concentrations of calcium and magnesium in the forage increased by 24.2% and 39.3%, respectively, compared with standard levels. However, other essential elements – phosphorus, iron, manganese, zinc, selenium, and cobalt – were significantly lower than those found in the control samples within this biogeocoenosis. Figure 3 presents data on the macro- and micronutrient content in the blood of the experimental cows.

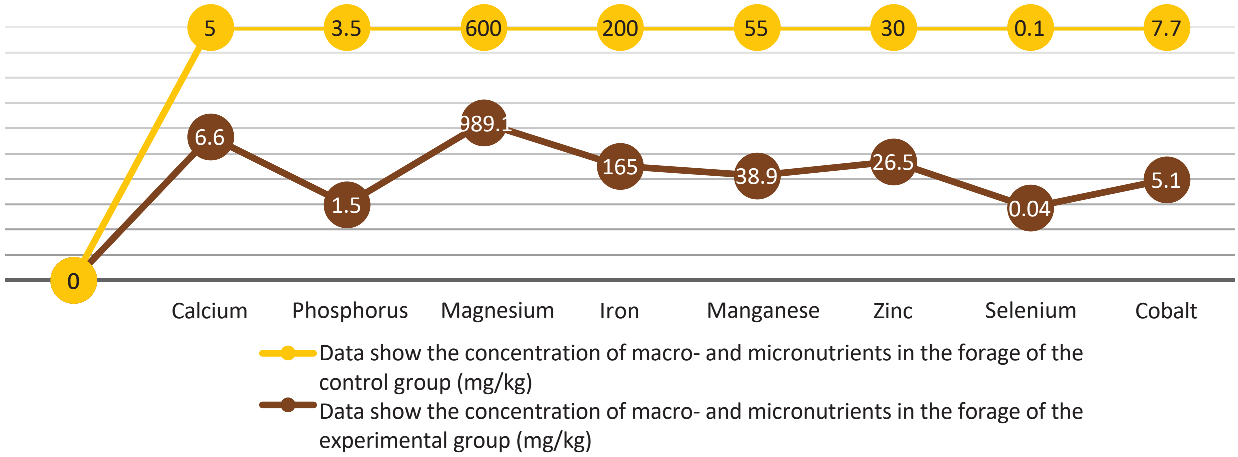

Figure 2. Content of macro- and micronutrients in the forage consumed by experimental cows
Source: developed by the authors based on original research

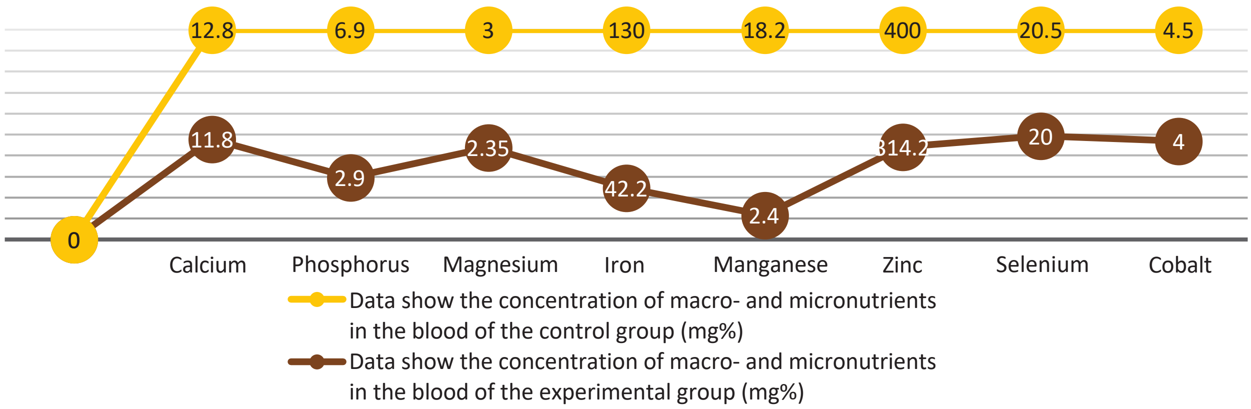

Figure 3. Content of macro- and micronutrients in the blood of the experimental cows
Source: developed by the authors based on original research

In the blood of the experimental cows, the total calcium level was at the lower limit of the physiological norm, while the phosphorus concentration decreased to 2.9 mg% compared with 6.9 mg% in the control group. This suggests a potential disruption in the calcium-to-phosphorus ratio (optimal ratio: 2:1). Furthermore, analysis of micronutrient levels in the blood indicates that nearly all values were significantly lower than those in the control group, pointing to impaired metabolism in the experimental cows (Urazaev, 2000; Elenshleger, 2003).

As noted by A. Sindreva (2012), E. Skorykh (2014), and G. Samoilenko *et al.* (2018), an imbalance of certain essential micronutrients in the "soil-plant-animal" system can lead to metabolic disorders in animals. Within the framework of this study, the authors examined the presence of toxic elements such as lead, mercury, cadmium, nickel, and arsenic in the soil, forage, and blood of the experimental cows. Similar studies were conducted in Kazakhstan by A. Farmer & A. Farmer (2000). According to the present findings, the average concentrations of heavy metals in the soil and forage did not exceed the maximum permissible levels. Only the concentration of arsenic in the soil exceeded the MPL by 0.1 mg/kg, while in plants it reached a peak value of 0.3 mg/kg compared to 0.25 mg/kg in the control samples. In the blood, no exceedance of the maximum permissible concentrations was observed for lead, mercury, cadmium, or nickel. However, the concentration of arsenic was found to be eight times higher, at 0.40 mg/L versus 0.05 mg/L in the control animals. The harmful effects of arsenic on both human and animal health have been reported by T. Abdulmutalimova *et al.* (2019).

Thus, the imbalance of macro- and micronutrients and heavy metals acts as an ecological factor in the "soil-forage-animal" system, affecting animal health (Gortázar *et al.*, 2007; Duskaev *et al.*, 2014; Gertman *et al.*, 2020). The results of the comparative analysis of the morphobiochemical composition of the blood in the experimental cows are presented in Figure 4.

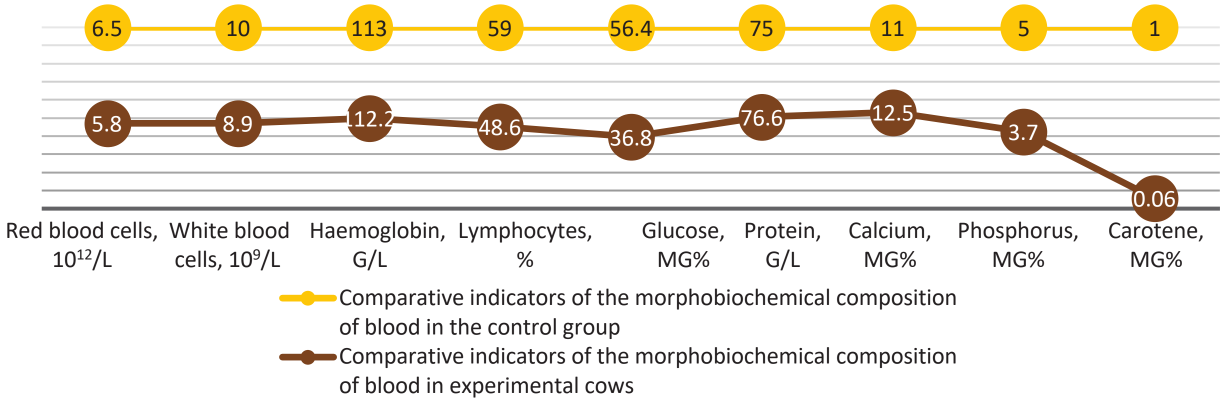

Figure 4. Comparative indicators of the morphobiochemical composition of blood in experimental cows
Source: developed by the authors based on original research

Based on the data presented in Figure 4, the number of erythrocytes decreased by 10.7%, white blood cells by 21.3%, haemoglobin by 12.0%, and lymphocytes by 17.6% ($P \leqslant 0.05$). Significant changes were also observed in glucose concentration (a decrease of 13.3%). Conversely, the level of calcium increased by 12.0%, while the levels of phosphorus, total protein, and carotene decreased by 19.2%, 6.5%, and 4.4%, respectively ($P \leqslant 0.05$). These findings are consistent with the results of previous studies by I. Shkuratova (2000), I. Donnik *et al*. (2012), and M. Nogoibaev *et al*. (2023).

The authors of this study concluded that, in order to optimise the ecosystem in Kyrgyzstan, it is essential to establish an innovative scientific-educational ecological centre for the protection of human and animal health. This centre should integrate existing, independently operating institutions into a unified, modern research and training hub capable of addressing key issues related to ecosystem optimisation in Kyrgyzstan. Its core mission would be the timely assessment of climatic and biogeocenotic (ecosystem) conditions, as well as the early detection of climate change. The centre is envisioned as a creative community of highly qualified specialists and researchers, founded on shared professional interests and committed to the humanistic values of education and science. In the long term, the effective operation of this innovative centre will require the training and involvement of highly skilled biogeocenologists.

Conclusions

In the environmentally compromised areas of the Chüy Region of Kyrgyzstan, an imbalance in the levels of macro- and micronutrients, as well as toxic elements, has been identified in the soil, forage plants, and the blood of Alatau breed cows used in the study. It was established that the quantities of essential macro- and micronutrients within the biogeochemical trophic food chain in the Chüy area differ significantly from baseline values, particularly in the calcium-to-phosphorus ratio. The average concentrations of toxic elements such as lead, mercury, cadmium, and nickel in the "soil-forageblood" system did not exceed the maximum permissible levels, except arsenic, which reached 0.40 mg/L compared to 0.05 mg/L in the control animals.

To ensure appropriate responses and early warning of ecosystem changes, it is necessary to establish an innovative scientific-educational ecological centre in Kyrgyzstan dedicated to the protection of human and animal health. Looking ahead, the authors of this study aim to continue indepth research on this issue across the country and on other animal species. As Kyrgyzstan is a highland country, climate change has become one of the most significant and persistent factors contributing to the emergence of various biogeocenotic pathologies in animals. While the climatic conditions of lowland regions have been thoroughly studied, the effects of climate change in other areas – such as Naryn, Issyk-Kul, Osh and Talas – remain insufficiently explored. In this regard, comprehensive climate research (including air and water conditions, temperature changes, wind speed, and other variables) is planned in the aforementioned regions of Kyrgyzstan. The authors also intend to carry out integrated monitoring of greenhouse gases, radionuclides, and other toxic substances within the "soil-water-air-plants-animals" system, and to investigate the decline in the quality of livestock and crop production. Experimental studies will include the manifestation of biogeocenotic pathologies in other animal species, such as sheep, goats, and their young. The practical value of this study lies in its status as the first comprehensive investigation into climate change in Kyrgyzstan and the levels of macro- and micronutrients and heavy (toxic) metals within the "soilplants (forage)-animals" system under conditions of environmental contamination in the Chüy Region. It also marks the first development and proposed implementation of the INUEC.

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Conflict of Interest
The authors declare no conflict of interest.

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Кыргызстандагы климаттын өзгөрүшү жана анын малдын биогеоценотикалык патологиясынын пайда болушуна тийгизген таасири

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Аннотация. Биогеоценоздук патология – бул жапырт түрдө жаныбарлардын гана эмес, адам менен өсүмдүктөрдүн да оорушу. Бул оорунун пайда болушу айлана-чөйрөдөгү жагымсыз өзгөрүүлөрдүн натыйжасында байкалат. Ушуга байланыштуу Кыргызстандын Чүй зонасынын экосистемасын өз убагында иликтөө, аны этиологиялык фактор катары карап чыгуу, ошондой эле ушул өзгөрүүлөрдүн натыйжасында пайда болгон ири мүйүздүү малдын патологияларын эрте аныктап, алдын алуу өзгөчө актуалдуулукка ээ болууда. Изилдөөнүн максаты – Чүй зонасындагы алатау породасындагы уйлардын биогеоценоздук патологиясын изилдөө, “топурак-өсүмдүк-жаныбар” системасы боюнча алардын курамындагы биогендик макро- жана микроэлементтердин, ошондой эле уулуу металдардын деңгээлин мониторинг кылуу жана Кыргызстандын экосистемасын оптималдаштыруу үчүн инновациялык экологиялык борборду түзүү боюнча сунуштарды иштеп чыгуу болду. Эксперименталдык тажрыйба үчүн стелдин экинчи жарымындагы алатау породасындагы уйлар колдонулду, ал эми айлана-чөйрөнүн негизги компоненти катары топурак менен өсүмдүктөр алынган. Топурак, өсүмдүк жана жаныбарлардын каны атомдук-эмиссиялык спектрофотометр аркылуу изилденди, ал эми тажрыйба жана көзөмөлдөгү уйлардын негизги метаболизм көрсөткүчтөрү бирдиктүү унификацияланган методдор боюнча аныкталды. Чүй облусунун жагымсыз зоналарында жайгашкан тажрыйбадагы уйлардын топурагынын, тоют өсүмдүктөрүнүн жана кандарынын анализинин натыйжасында макро-, микроэлементтер менен оор (уулуу) металлдардын мазмуну боюнча олуттуу дисбаланс аныкталды. Бул биохимиялык трофикалык чынжырдагы дисбаланс белгилүү бир биогеоценоздо – тактап айтканда, Кыргызстандын Чүй зонасында зат алмашуу процессинин бузулушуна алып келген, бул айрыкча ири өнөр жай ишканалары топтолгон райондордогу экологиялык абалдын бузулушу менен байланыштуу. Кыргызстанда экосистеманы өз убагында изилдөө максатында авторлор адам менен жаныбарлардын саламаттыгын коргоо боюнча инновациялык илимий-окуу экологиялык борборду түзүү сунушун иштеп чыгышкан. Бул изилдөөнүн жыйынтыктары медицинада, айыл чарбасында, ветеринардык медицинада, ошондой эле экология тармагында, окуу жана илимий мекемелерде пайдаланылышы мүмкүн

Негизги сөздөр: уй; топурак; өсүмдүк; кан; инновациялык илимий-окуу экологиялык борбор; уулуу металлдар

Изменение климата в Кыргызстане и его влияние на возникновение биогеоценотических патологий у животных

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Аннотация. Биогеоценотическая патология – это массовое заболевание не только животных, но и человека и растений. Данное заболевание проявляется вследствие неблагоприятных изменений в окружающей среде. В этой связи своевременное изучение экосистемы Чуйской зоны Кыргызстана как этиологический фактор, а также раннее предупреждение патологий у крупного рогатого скота, возникающих в результате этих изменений, приобрело особую актуальность. Целью исследования было изучение биогеоценотической патологии коров алатауский породы в Чуйской зоне, проведение мониторинга по системе «почва-растение-животное» на содержание в них биогенных макро- и микроэлементов, а также токсичных металлов, и разработка рекомендаций по созданию инновационного экологического центра для оптимизации экосистемы в Кыргызстане. Для экспериментального опыта использовали коров алатауской породы во второй половине стельности, а как основной компонент окружающей среды брали почву и растения. Почву, растения и кровь животных исследовали с помощью атомно-эмиссионного спектрофотометра, а исследование основных показателей метаболизма у опытных и контрольных коров проводилось по единым унифицированным методикам. В результате анализа почвы, кормовых растений и крови у подопытных коров, которые находились в неблагоприятных зонах Чуйской области, установлен серьезный дисбаланс по содержанию макро-, микроэлементов и тяжелых (токсичных) металлов. Такой дисбаланс в биохимической трофической цепи привел к изменению круговорота веществ в определенном биогеоценозе, т.е. в Чуйской зоне Кыргызстана, что связано с нарушением экологической обстановки, особенно в тех районах, где сосредоточены крупные промышленные предприятия. С целью своевременного изучения экосистемы в Кыргызстане авторами разработаны рекомендации по созданию инновационного научно-учебного экологического центра по охране здоровья человека и животных. Результаты данного исследования могут быть использованы в медицине, сельском хозяйстве, ветеринарной медицине, а также в сфере экологии, в учебных и научных учреждениях

Ключевые слова: корова; почва; растение; кровь; инновационный научно-учебный экологический центр; токсичные металлы

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Results and prospects of wheat breeding in Kyrgyzstan

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Abstract. Wheat plays a crucial role in ensuring food security in the Kyrgyz Republic. Annually, approximately 250,000 hectares are allocated for wheat cultivation, with the area reaching up to 535,000 hectares in certain years (e.g. 1996). Wheat is grown on irrigated, semi-irrigated, and rainfed lands across the country and is used to produce bread and related products. The development and use of initial breeding material at the early stage of breeding programmes is a key factor in improving their effectiveness. This study aimed to evaluate the outcomes of wheat breeding programmes in Kyrgyzstan from 1935 to 2024, focusing on the development of high yielding and well-adapted varieties, and identifying future directions for their enhancement under the conditions of the Kyrgyz Research Institute of Agriculture. It was established that both cultivated and wild platforms are used as initial breeding material. The main methods employed in wheat breeding include the use of natural and hybrid populations, as well as induced mutations and polyploid forms. The use of both intraspecific and distant hybridisation in the breeding activities of the Department of Wheat Breeding and Primary Seed Production has enabled the development of original genetic material. Through individual selection, this material has led to the creation of varieties approved for cultivation in the Kyrgyz Republic, including Lutescens 46, Adyr, and Erythrospermum 13. In global climate change, the development of varieties adapted to local soil and climatic conditions remains a key objective. Individual selection helps to identify forms with increased adaptability, while the adaptive potential of winter wheat is enhanced by genetic recombination. Primary seed production remains a vital factor in the sustainable development of the sector. The Green Evolution of wheat breeding in Kyrgyzstan is associated with the introduction of high-yielding winter and spring wheat varieties possessing valuable agronomic traits. The study highlighted the need for further improvement in breeding programmes to ensure resilient agricultural production under changing climate conditions

Keywords: food; security; irrigation; initial material; the Green revolution; variety; primary seed production

Introduction

Wheat plays a crucial role in ensuring food security in the Kyrgyz Republic. As the main food crop in Kyrgyzstan, wheat occupies between 250,000 and 535,000 hectares in certain years (National Statistical Committee of the Kyrgyz Republic, n.d.). A significant proportion of these wheat crops are situated on non-irrigated or semi-irrigated lands. Increasing grain production and enhancing its economic efficiency are closely tied to the development and implementation of superior, high-yielding varieties (Urazaliev &

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Yesimbekova, 2016) As far back as the 20th century, scientists such as M. Tovstik *et al.* (1983) established that the yield of cereal crops depends by 25%-30% on the correct varietal choice, provided essential agricultural practices and cultivation technologies are adhered to.

The substantial growth in global grain production during the 20th century, exceeding 40%, is attributed to the selective improvement of cereals, with outstanding examples of wheat breeding efforts termed the Green Revolution (Pingali, 2024) Global climate change, manifesting as soil and atmospheric drought, alongside reduced water flow due to the disappearance of certain glaciers within the Kyrgyz Republic, has necessitated the creation of new wheat varieties possessing enhanced heat and drought tolerance Under irrigated conditions, there is a need to develop varieties that efficiently utilise high-input agricultural environments to boost their yield potential (Afanasyeva *et al.*, 2023). This necessitates a local adjustment of breeding programmes. For instance, late spring frosts often lead to erratic grain development and a sharp decline in yields, a problem particularly prevalent in early-maturing wheat varieties. Conversely, a shift in the frost-free period, extending it later into autumn, requires an adjustment of sowing dates, especially for facultative varieties. As the FAO (2016) notes, in the face of climate change, heat and drought resistance will become critical traits for cereal crops. Several countries have already introduced heat-tolerant wheat varieties developed from germplasm stored at CIMMYT (International Maize and Wheat Improvement Center) and the International Center for Agricultural Research in the Dry Areas (ICARDA). The CIMMYT-supported wheat improvement network is actively researching the possibility of developing high-yielding wheat varieties capable of thriving in Kazakhstan's increasingly hot summer seasons.

Research undertaken as part of the "Formation of the Gene Pool of Agricultural Crops for Sustainable and Competitive Development of the Agro-Industrial Complex of the Republic of Kazakhstan" project from 2012-2014 focused on establishing a gene pool adaptive to both biotic and abiotic stresses across Kazakhstan's main agro-climatic zones (Yesimbekova *et al.*, 2015). The intensification of the continental climate, which began in the Don region of Russia in the late 20th century, has continued even more significantly into the 21st century. This primarily leads to a greater amplitude in the manifestation of negative environmental factors, with drought emerging as the foremost concern, according to A. Grabovets & M. Fomenko (2015). In this situation, there is a growing need to create populations with more pronounced genetic variability. They recommend that ecological plasticity should be assessed primarily by the potential productivity of new varieties.

In the Kyrgyz Republic, the primary focus for wheat breeding aimed at drought resistance is the creation of varieties characterised by rapid development during the spring, prior to the onset of summer drought. These varieties are designed to effectively utilise autumn-winter and spring soil moisture reserves. This strategy allows the grain-filling stage to conclude before the summer drought takes hold, a consideration that has guided the breeders (Lyubavina, 1984). Developing and creating an optimal varietal model, adapted for specific soil and climatic conditions, as well as for a broader geographical range, remains a pertinent challenge in winter wheat breeding (Korkhova *et al.*, 2023). The application of reliable quantitative criteria for trait expression, underpinned by a deep understanding of plant morpho-physiology and genetics, enables the prediction of a scientifically sound model for the ideal winter wheat variety for its intended cultivation zone, proving useful for breeders (Krishnappa *et al.*, 2021). Enhancing the adaptive potential of winter wheat varieties is achievable through the genetic mechanism of recombinogenesis. Obtaining unusual recombinations – known as transgressions – and then stabilising them in subsequent generations is currently a key area of focus.

One of the principal threats to food security stems from crop diseases and pests. For wheat, which provides 20% of the world's consumed calories, diseases play a significant role. M. Koyshybaev (2018) notes that in the Central Asian republics, particularly the southern and south-eastern regions of Kazakhstan, yellow rust, septoria, and yellow spot are especially dangerous diseases for winter wheat. During years of epiphytotic yellow rust development in Tajikistan and Uzbekistan, grain losses on untreated fields could reach 30%-40% or more. This disease periodically appears in wheat crops within the Kyrgyz Republic. This necessitates an effective strategy for breeding for disease resistance. Several authors have developed principles and approaches for implementing precise disease control in wheat agro-phytocoenoses (Bespalova *et al.*, 2019). They emphasise that chemical treatments should only be applied when varieties are unable to cope with the disease independently.

The Italian scientist G. Azzi (1922) was the first to clearly articulate the idea of an ecological classification of wheat, characterising varieties based on their geographical distribution. To determine their adaptive potential, new Kyrgyz-bred varieties undergo ecological testing in the conditions of the Issyk-Kul basin (IEBS) and the Naryn zone (NES). For the identification of drought-resistant varieties, breeding material is sown under harsh rainfed conditions in the lowland area of the Chüy Valley (Zhany-Pakhta breeding farm). This study aimed to assess the effectiveness of wheat breeding efforts in Kyrgyzstan between 1935 and 2024, as well as to analyse the outcomes and future prospects of wheat breeding at the Kyrgyz Research Institute of Agriculture. The study employed methods of retrospective analysis of the Institute's breeding programmes from 1935-2024. This included evaluating the effectiveness of using intraspecific and distant hybridisation, individual selection, and genetic recombinogenesis to develop adapted wheat varieties. A review of breeding prospects, considering climatic changes and primary seed production, was also conducted.

Main directions in wheat breeding

In N. Vavilov's (1962) seminal work, Scientific Bases of Wheat Breeding, the practical application of dwarfing in wheat was set as a crucial objective. During the 1960s, this strategic challenge in the microevolution of the genus *Triticum* L. was successfully addressed by the distinguished breeder N.. Borlaug. The highly productive semi-dwarf wheat varieties he developed are intrinsically linked to the Green Revolution – a significant increase in wheat yields achieved through breeding (Dorofeev *et al.*, 1987).

The alteration of plant architecture, notably in the 1930s when the Italian breeder Nazareno Strampelli used the Japanese variety Akakomyghi in crosses to create the short-stemmed winter wheat varieties, Ardito and San Pastore, can be considered the first Green Revolution. A striking example of effective breeding work is the creation of the winter wheat variety Bezostaya 1, a masterpiece of global breeding, by Academician P. Lukyanenko at the Krasnodar Research Institute of Agriculture. This variety, alongside Bezostaya 4, was cultivated in numerous countries worldwide for many years, leading to a doubling of yields through varietal replacement, which can rightly be termed the second Green Revolution (Bespalova, 2001). An analysis of the pedigree of many wheat varieties has revealed that the genetic lineage of Bezostaya 1, Bezostaya 4, Kavkaz, and Aurora flows through over 300 varieties developed worldwide (Rabinovich, 1972) The rapid, dramatic increase in yields in many countries during the early 1960s (particularly in India and Pakistan), achieved through the short-stemmed varieties created in Mexico (CIMMYT) by 1970 Nobel laureate N. Borlaug, became known as the Green Revolution. The origins of scientific breeding in Kyrgyzstan trace back to 1928 with the breeding and seed production department of the Republican Experimental Station. However, its work ceased in 1930, and all materials were transferred to the Central Asian Breeding Centre. Wheat breeding resumed in 1934 at the Frunze Integrated Agricultural Experimental Station, which was subsequently reorganised in 1937 into the Kyrgyz State Breeding Station, and then in 1956 into the Kyrgyz Research Institute of Agriculture. The Kyrgyz Breeding Centre was established there in 1971.

From 1938 onwards, breeding activities also commenced at key field stations in Przhevalsk, Naryn, Nurus, and Uzgen. Pioneers in this field included G. Kuzmin, N. Konovalov, N. Moskvin, I. Ryzhey, V. Lyubimova, V. Nikolayev. In the initial years of this breeding work, varieties were developed using mass and individual selection from existing local varieties. Subsequently, methods of intraspecific and intergeneric hybridisation were employed, followed by single or multiple selections. For example, the first spring-type varieties – Erythrospermum 41, Erythrospermum 14 (authored by M. Linchenko), and Ferrugineum 87 (authored by V. Lyubimova) – were derived through individual and mass selection from local wheat and subsequently regionalised between 1946 and 1954 for the Issyk-Kul and Tian Shan regions. In the late 1940s, new locally bred winter wheat varieties were developed in Kyrgyzstan, including Erythrospermum 9 (I. Ryzhey and V. Nikolayeva), Erythrospermum 72, and Erpitrospermkum 115 (I. Ryzhey). Towards the end of the 1960s, a new rainfed winter wheat variety, Kyrgyzskaya 16, was created by M. Tovstik. During the same period, Kyrgyzskaya 3 (I. Ryzhey, R. Lyubavina) was developed and regionalised in 1960, along with Batkan Krasnaya (N. Bataleva, S. Batalev, V. Kantemirov), regionalised in 1957. Additionally, spring soft wheat varieties were developed at the Osh field station by M. Tovstik (Oshskaya or Taldykskaya) and at the Issyk-Kul experimental station by M. Nesterov (Przhevalskaya 1). In 1965, at the Osh Pedagogical Institute, I. Shuvalov bred the winter durum wheat variety Oshskaya 60. From 1968, a new Kyrgyz-bred variety, Dzhany-Budai (selected from Krasnodarskaya 362), was regionalised. Between 1961 and 1970, almost the entire wheat acreage in Kyrgyzstan (350,000 hectares) was sown with the Bezostaya 1 variety. Among the winter wheat varieties, only Kyrgyzskaya 16, grown under rainfed conditions, managed to withstand the dominance of Bezostaya 1 (Tovstik, 1969). Subsequently, from 1970 to 1980, Kyrgyz breeders extensively used Bezostaya 1 and other sources in hybridisation to develop and submit six new intensive-type varieties for State Trials, four of which were regionalised: Kyrgyzskaya 100, Intensivnaya, Erythrospermum 80, and Frunzenskaya 60. During this same period, spring varieties were also bred and regionalised: Kyrgyzskaya Yubileynaya, a soft, semi-intensive type, and Kyrgyzsky Polukarlik, a durum wheat. At the Przhevalsk irrigated variety testing plot, V. Mishchenko used Bezostaya 1 in hybridisation to create the winter soft wheat variety Przhevalskaya. In 1973, this variety yielded a record harvest of 11.05 tonnes per hectare, the highest in the entire previous history of State Variety Trials in the USSR. From 1975, Przhevalskaya was regionalised for the Issyk-Kul region.

Working as the director of the Main Botanical Garden of the USSR Academy of Sciences, N. Tsitsin utilised distant hybridisation – specifically crossing cultivated plants with wild relatives, such as wheat with couchgrass. This approach yielded a vast diversity of forms, including perennial and annual grain-forage wheat, which exhibited significant biological and morphological differences from all existing wheat species (Golikov, 2020). M. Tovstik, in collaboration with R. Lyubavina at the Kyrgyz Research Institute of Agriculture, incorporated Bezostaya 1 into intergeneric hybridisation with elongated couch grass (*Agropyrum elongatum*) and the Tibetan dwarf wheat Tom Pouce. This effort resulted in large-eared, short-stemmed forms that were subsequently integrated into further breeding programmes. However, the first variety derived from this material, Lutescens 46, despite achieving a record yield of 11.85 tonnes per hectare at the Przhevalsk irrigated State Variety Trial site in 1984, exhibited poor grain quality due to weak gluten. Nevertheless, it was regionalised across all agricultural zones of the republic from 1987 (Udachin & Shakhmedov, 1984).

Among other Kyrgyz-bred varieties, Dzhany-Budai (selected from Krasnodarskaya 362) has been regionalised since 1968. Wheat varieties developed in subsequent years for irrigated conditions – Erythrospermum 13, Tilek, Kyyal, Asyl, Dzhamin, Dank, Araket, Kasiyet, Almira, Melyanopus 223, Vassan and Nazdan – have demonstrated high efficiency and profitability in organised seed-producing, peasant, and other types of farms. The winter wheat variety Bermet was also recommended for use in the Kyrgyz Republic. However, due to its severe susceptibility to yellow rust and a drastic reduction in yield during an epiphytotic outbreak in the early 21st century, its production was discontinued. Conversely, varieties of soft winter wheat with plasticity, adapted for use in both arid, rainfed conditions and irrigated lands, have gained widespread adoption. These include Erythrospermum 760, Adyr, Kayrak, Ralyub, EHOL, and Taazhy (Ministry of Agriculture of the Kyrgyz Republic, 2023).

As of 2025, the older winter wheat varieties Erythrospermum 80 and Frunzenskaya 60 remain approved for use in the Kyrgyz Republic and are recommended for cultivation on both rainfed and irrigated lands. Annually, a significant acreage is dedicated to the facultative wheat variety Intensivnaya, which is recommended for cultivation under both rainfed and irrigated conditions.

Soil and climatic conditions for research in the Kyrgyz Republic

The Kyrgyz Republic is situated in the north-eastern part of Central Asia, nestled between two major mountain systems: the Tian Shan and the Pamir-Alay. Only a tenth of the Republic's total area (198,500 km^2) comprises intermontane pastures and basins, where the majority of agricultural activity is concentrated (Prokhorov, 1979). In some years, the total arable land in the Republic exceeds 1.2 million hectares. The climate of the Kyrgyz Republic is distinctly continental, characterised by significant fluctuations in air temperature, low humidity, moderate atmospheric precipitation, minimal cloud cover, and extensive periods of sunshine (averaging 2,600 hours annually).

The mountainous terrain dictates a pronounced vertical zonation in the distribution of climatic indicators, such as heat, moisture, and temperature. Desert and semi-desert climates prevail in the lowland areas, while the mountains experience steppe, forest-steppe, meadow, and high-altitude tundra climates. The annual moisture regime is divided into two distinct periods: from October to April, moisture accumulates in the soil due to melting snow, as well as late autumn and early spring precipitation; and from late April to September, there is intense moisture depletion due to increased temperatures and strong winds, leading to high evaporation and plant uptake. The average annual relative humidity across Kyrgyzstan ranges from 50% to 70%. The lowest levels are typically recorded between July and September, while the highest values are observed between January and March (Mamytov *et al.*, 1966).

Cereal crops are cultivated across all agricultural zones in Kyrgyzstan. In the low and midmountain valleys, which benefit from extended frost-free periods, both winter and spring cereals, as well as maize, are grown. Higher-altitude valleys, with their shorter frost-free seasons, primarily focus on cereal crops. In certain regions experiencing harsh winters and brief summers, only spring cereals, predominantly barley, are cultivated. Wheat breeding in Kyrgyzstan is conducted for four distinct zones, each presenting varying natural and climatic conditions:

- rainfed conditions in hot and dry lowland valleys, which receive the highest amount of precipitation, mainly in winter and spring, and experience moderately severe, unstable winters. Varieties developed for this zone must be resistant to both soil and atmospheric drought, and exhibit rapid growth and development during the spring months;
- irrigated conditions in lowland valleys, where intensive-type varieties are required. These must respond well to irrigation and fertilisation, and possess high heat tolerance along with improved resistance to lodging and disease;
- mild conditions of the central and eastern Issyk-Kul basin, which call for intensive-type varieties suitable for both rainfed and irrigated systems, with good disease and lodging resistance;
- high-altitude valley conditions with short frost-free periods and cool summers, where varieties must be tolerant to night-time temperature drops.

In the Fergana, Chüy, and Talas valleys, as well as Eastern Issyk-Kul – regions that encompass the majority of the country's wheat-growing areas connection – there is an optimal balance of air temperature, daylight length, and solar radiation. These conditions provide a favourable climatic environment for the development of the agricultural seed production sector. The low atmospheric humidity during the summer (30%-32%), combined with other climatic factors, inhibits the development of plant pathogens. As a result, the produced agricultural seed material tends to be healthy. Furthermore, the sierozem soil and its subtypes, where the main wheat cultivation areas are located, yield high wheat harvests when recommended agricultural practices are followed. Therefore, greater attention should be given to the development of the agricultural seed production sector, including wheat, in Kyrgyzstan. This would open avenues for intensification and make agriculture more profitable, thereby significantly elevating the economic standing (FAO, 2018).

Based on annual precipitation, rainfed lands are conventionally categorised into zones: one classification distinguishes between under-supplied (250-350 mm per year), partially supplied (350-500 mm), and well-supplied (over 500 mm); another uses classifications of 200-300 mm and over 400 mm, respectively (Borzdyko & Simonov, 1935). The highest wheat yields (7-8 tonnes per hectare) are achieved on rainfed lands in the foothills and Eastern Issyk-Kul, where sufficient rainfall (450-800 mm per year) occurs. In the under-supplied rainfed areas of the country's valley regions, with insufficient moisture (200-350 mm per year), yields rarely exceed 1.5-2.5 tonnes per hectare. Furthermore, droughts occurring every 2-3 years frequently negate all efforts made by farmers. Achieving high yields under rainfed conditions is only possible with the use of droughtresistant and heat-tolerant varieties bred by the Kyrgyz Research Institute of Agriculture, such as Erythrospermum 760, Erythrospermum 80, Intensivnaya, and Taazhy.

Research at the Kyrgyz Research Institute of Agriculture

In recent years, the wheat breeding programme at the Kyrgyz Research Institute of Crop Production, which focused on both winter and spring wheat varieties, has primarily employed hybridisation. This involves crossing introduced genetic material obtained from international centres such as CIMMYT-ICARDA, along with local varieties and lines (Pakhomeev *et al.*, 2023). Various crossing types are utilised, including simple, paired, backcross, and saturating. Forced pollination is the standard method. Hybridisation is carried out in field conditions, with the selection of elite spikes, possessing desired characteristics, occurring within the F3 to F5 hybrid populations. The selected progenies are then studied in the first-year breeding nursery. Here, they are rigorously compared against the best-regionalised varieties. Stable lines demonstrating high productivity and resistance to lodging and diseases are advanced to the second-year breeding nursery. Promising lines identified from the second-year nursery are then moved to the control nursery. The final stage of evaluating selected varieties involves preliminary and competitive variety trials. Successful varieties are subsequently submitted for State Variety Trials, based on the results of which they are approved for use. To obtain a patent for a new variety, the Department for the Examination of Agricultural Crops conducts a DUS examination over two years, following which Kyrgyzpatent issues a conclusion on the variety's protectability.

The wheat breeding and primary seed production department at the Kyrgyz Research Institute of Agriculture is currently focused on: "Creating wheat varieties adapted to environmental stress factors for both irrigated and rainfed lands, possessing a high level of economically valuable traits and characteristics, and conducting ecological testing". The considerable diversity of soil and climatic conditions, coupled with sharply defined vertical zonation, dictates two primary directions for wheat breeding in Kyrgyzstan: a) developing highly intensive varieties for irrigated agriculture, aiming for yields of up to 10 tonnes per hectare and above; b) creating varieties adapted to arid rainfed conditions, targeting yields of 3-5 tonnes per hectare and above.

Field experiments and seed production plantings are established on the semi-irrigated lands of the Kyrgyz Experimental Breeding Station, as well as on the rainfed experimental plot at Zhany-Pakhta breeding farm in Sokuluk District, Chüy Region. Ecological testing is also carried out at the Issyk-Kul Experimental Breeding Station and the Naryn Experimental Station. Breeding work follows a comprehensive scheme of the selection process: a study of the germplasm collection; hybridisation; cultivation and selection of hybrid populations (F2-F5); first-year breeding nursery; second-year breeding nursery; control nursery; preliminary trials; competitive variety trials; environmental and production testing; multiplication of promising varieties; submission of advanced lines for State Variety Trials; and submission of new varieties for DUS testing.

The winter soft wheat variety Adyr was developed at the Kyrgyz Research Institute of Agriculture using a hybridisation method. It originated from a cross between the variety Erythrospermum 80 and a line derived from a cross involving a wheat-wheatgrass hybrid [Lutescens 25 x (Bezostaya 1 x wheatgrass hybrid) x Tom Pouce x Polukarlik 49]. It has been approved for use in the Kyrgyz Republic since 2001. This variety exhibits resistance to lodging, is drought-tolerant, and shows resistance to rust pathogens and loose smut. Furthermore, it possesses good baking qualities. Its potential grain yield in rainfed conditions with sufficient precipitation is 6.67 tonnes per hectare, rising to 9.50 tonnes per hectare under irrigated conditions (Table 1).

Table 1. Yield potential and grain quality of wheat varieties bred by the Kyrgyz Research Institute of Agriculture

No.	Variety	Growing conditions	Yield, t/ha	Grain quality				1,000 grain weight, g	Vitreousness, %	Overall baking score, point
				Protein, %	Gluten, %	GDI	Test weight, g/L			
1	Adyr	Irrigated Rainfed	9.5 6.67	14.6	29.0	80	810	48.3 40.0	92.0	4.8
2	Erythrospermum 760	Irrigated Rainfed	9.2 6.35	13.6-14.9	28.4	83	800	37.0 40.0	94.5	4.7

Table 1. Continued

No.	Variety	Growing conditions	Yield, t/ha	Grain quality				1,000 grain weight, g	Vitreousness, %	Overall baking score, point
				Protein, %	Gluten, %	GDI	Test weight, g/L			
3	Kayrak	Irrigated Rainfed	8.35 6.55	12.6-13.2	25.1-28.4	60	790	43.6-45.8	93.0	4.5
4	Ralyub	Irrigated Rainfed	9.02 6.5	13.1	26.6	39	700	40.0	91.0	3.8
5	EHOL	Irrigated Rainfed	8.7 6.45	13.5	28.8	90	810	43.4-47.1	96.0	5.0
6	Intensivnaya	Winter wheat Spring wheat	9.65 6.35	13.4-16.0	28.9-35.5	85	790	36.2-47.6	91.0	4.9
7	Taazhy	Irrigated Rainfed	8.75 6.15	13.8	27.5	85	820	40.0	94.0	4.7

Source: developed by the authors

The winter soft wheat variety Erythrospermum 13 was also developed using material derived from distant hybridisation. This variety originated from a cross of [Red River 68 x Bezostaya 1] x [Bezostaya 1 x A9 elongatum] x Tom Pouce, followed by a single selection in the F2 generation. This variety boasts a potential grain yield of 9.36 tonnes per hectare and exhibits good baking qualities. Its grain contains up to 14.4% protein and 29.9% gluten. It is characterised by moderate susceptibility to brown rust and common bunt but is resistant to loose smut and powdery mildew, and possesses high winter hardiness.

Through individual selection from the introduced Romanian variety F 474 S 82, the winter soft wheat variety Almira was developed. Similarly, the facultative variety Dzhamin was bred from the introduced Yugoslavian variety NS-55-58/VEE. Both these varieties are approved for use within the Kyrgyz Republic. Under a joint project, 20 winter wheat varietal samples obtained from the Kazakh Research Institute of Agriculture and Plant growing underwent trials. During a severe yellow rust epiphytotic in the 2024 season, these samples proved tolerant and delivered high yields, comparable to the standard variety Adyr (6.35 tonnes per hectare). For the 2025 harvest, these varieties have been sown in arid rainfed conditions at the Zhany-Pakhta breeding farm.

Testing of 350 varietal samples obtained from CIMMYT has shown that they are virtually unaffected by yellow rust. This material is undergoing further breeding development. Eight varieties bred by the Kyrgyz Research Institute of Agriculture, namely Adyr, Kayrak, Ralyub, EHOL, Dank, Nazdan, Vassan, and Taazhy, are protected by patents (Fig. 1). In 2024, two soft wheat varieties and one durum wheat variety were submitted for State Testing Trials. A new winter soft wheat variety, Taazhy, has also been approved for use across the Kyrgyz Republic.

Figure 1. Wheat varieties bred by the Kyrgyz Research Institute of Agriculture, supported by patents
Source: authors' photo

A crucial aspect of the wheat breeding department's work is primary seed production. In 2024, high-generation wheat seeds (P1, P2, R1, R2) were produced across 53 nurseries. These were primarily transferred to the Kyrgyz Experimental Breeding Station (KEBS) for Sugar Beet for further multiplication.

In summary, the breeding and seed production work within the wheat breeding and primary seed production department at the Kyrgyz Research Institute of Agriculture is being conducted to a high standard. In recent years, new wheat varieties such as Nazdan, Vassan, and Taazhy have been developed and approved for use in the Kyrgyz Republic. Three new varieties have been submitted for State Testing Trials. A patent has been obtained for one variety, Vassan, and patents for eight wheat varieties are maintained annually. The primary seed production of bred varieties is ongoing at the Kyrgyz Research Institute of Agriculture, ensuring the planned implementation of their varietal rotation and renewal.

In 2024, the competitive variety trial conducted on the semi-irrigated lands of the KEBS for Sugar Beet involved the study of 55 wheat varieties, planted in three replicates. Each plot for yield assessment measured 12 m^2. The average yield for the soft wheat standard, Tilek, was 5.96 tonnes per hectare, while the durum wheat standard, Melyanopus 223, yielded 4.00 tonnes per hectare (Table 2). The most significant increases in grain yield over the standard (tonnes per hectare) among the winter soft wheat varieties were observed in: Erythrospermum 302 (0.62), Erythrospermum 518 (0.92), Lutescens 1457 (0.87), Nazdan (0.72), 6 WONYR 03-222 (1.41), RWKLDN 03-49 (2.80), selection No. 24 – Erythrospermum 13 (2.76), 8WONIR 05-334 (1.05), 16 FAWWON 0911 (1.34), Lutescens 1704 (1.52), Erythrospermum 1708 (0.32), Lutescens 1687 (1.78), Lutescens 1694 (1.95), Lutescens 1706 (2.76), Grecum 1667 (1.94), CACWITIR 132 (1.09), 16IWWIYTIR 139830 (2.23), and Dostuk (0.51). Among the durum wheat varieties, the following showed the greatest yield increases relative to the standard: S/r 1 (1.81), S/4 (2.99), IDYT-SA 0502 (2.37), IDYTMD 05-35 (2.84), ICARASHA-1 (3.38), SWANA 32 IDYT MD (1.27), and 35 IDYT_MD 11-2 (2.36).

Table 2. Characteristics of winter wheat varieties in competitive variety trial, 2024

Col.	Origin, variety, line	Harvest, t/ha	Deviation from avg. standard, t/ha	Vitreous ness, %	Number of spikes, pcs.	Number of grains in spike, pcs	Grain weight per spike, g	1,000-grain weight, g	Test weight, g/L
1	Erythrospermum 302	6.58	0.62	87.0	19.0	48.0	2.5	50.4	778
2	Erythrospermum 518	6.89	0.92	91.0	18.6	42.8	2.1	48.8	760
3	Erythrospermum 976	5.67	-0.29	67.5	21.4	49.7	2.6	52.0	761
4	Lutescens 1457	6.83	0.87	86.0	20.6	52.2	2.5	47.2	785
5	Tilek, standard	5.89	-0.07	76.0	21.0	55.4	2.1	39.8	742
6	Erythrospermum 13	6.13	0.17	82.0	22.3	63.7	3.0	47.2	785
7	Nazdan	6.68	0.72	45.5	21.0	53.5	2.3	41.6	776
8	Erythrospermum 1627	5.56	-0.4	98.0	20.6	45.9	2.1	46.4	–
9	Erythrospermum 1686	5.24	-0.72	83.0	19.7	45.1	1.6	39.4	–
10	7 EYTIR03-9882	5.11	-0.85	87.0	20.5	44.7	2.0	38.6	777
11	6 WONIR03-222	7.37	1.41	73.5	21.7	63.9	2.1	40.8	760
12	6 WONIR03-228	4.75	-1.21	66.0	21.1	43.4	1.7	40.8	741
13	8 EITIR 04-9868	5.3	-0.65	74.5	18.9	43.4	1.6	39.2	–
14	RWKLDN 03-49	8.76	2.8	89.0	20.3	58.9	2.6	43.2	768
15	Tilek, standard	5.4	-0.56	88.0	21.9	56.0	2.2	40.8	794
16	Erythrospermum 13	6.51	0.55	87.0	22.1	62.7	2.4	39.4	754
17	8 WONIR 05-334	7.01	1.05	82.0	20.4	53.4	2.1	43.2	747
18	16 FAWWON 0911	7.3	1.34	86.0	21.7	47.8	2.0	41.6	768
19	Lutescens 1704	7.48	1.52	92.0	20.3	49.3	1.7	42.4	760
20	Erythrospermum 1708	6.28	0.32	86.5	21.4	50.5	2.4	39.6	730
21	Lutescens 1687	7.74	1.78	91.0	22.4	55.8	1.7	42.6	772
22	Lutescens 1694	7.91	1.95	89.0	23.5	54.9	2.5	44.0	756
23	Tilek, standard	6.48	0.52	85.0	22.6	47.1	2.0	42.8	760
24	Erythrospermum 13	8.72	2.76	79.5	22.3	70.5	3.0	42.4	752
25	Lutescens 1695	6.47	0.51	88.0	22.3	39.2	2.1	51.2	792
26	Grecum 1697	4.45	-1.51	84.5	20.7	49.0	2.2	45.6	–
27	Lutescens 1706	7.72	2.76	84.0	24.7	55.0	2.7	50.4	738
28	Grecum 1667	7.9	1.94	70.5	21.1	57.3	2.4	40.0	770
29	13 IWWYTIR 1057	5.87	-0.09	59.5	19.6	63.1	2.7	44.8	770
30	1st CACWITIR 132	7.05	1.09	47.5	20.9	54.8	2.2	40.8	747
31	1st CACWYTIR 1310	5.57	-0.39	61.0	19.7	47.2	2.0	43.2	782
32	1st CACWYTIR 1337	5.87	-0.09	66.0	18.2	48.6	1.8	36.0	748

Table 2. Continued

Col.	Origin, variety, line	Harvest, t/ha	Deviation from avg. standard, t/ha	Vitreous ness, %	Number of spikes, pcs.	Number of grains in spike, pcs	Grain weight per spike, g	1,000-grain weight, g	Test weight, g/L
33	Tilek, standard	6.06	0.1	80.0	20.4	58.7	2.5	43.2	750
34	Erythrospermum 13	6.31	0.35	75.0	21.6	64.9	2.5	39.2	760
35	16 IWWYTIR 139819	5.09	-0.87	76.0	19.4	53.1	1.9	35.4	770
36	16 IWWYTIR 139830	8.19	2.23	56.5	19.9	58.1	2.5	44.8	760
37	12 IWWYT-SA 1040	4.42	-1.54	49.0	19.2	48.9	1.4	36.2	736
38	Adyr	6.0	-0.04	75.5	21.5	49.9	2.2	40.8	774
39	12 IWWYTSA 1054	4.82	-1.14	93.0	19.1	57.1	2.4	47.6	741
40	12 IWWYTSA 1057	4.96	-1	86.0	20.8	45.5	2.0	45.2	771
41	Leucurum 121	5.21	1.21	89.0	24.4	40.0	1.8	46.4	781
42	Melyanopus 223, avg. std.	4.0	–	84.5	22.6	34.5	1.1	35.7	725
43	S/r 1	5.81	1.81	90.0	25.1	47.4	2.2	44.0	778
44	S/r 4	6.99	2.99	93.0	19.3	55.3	2.6	46.4	754
45	Melyanopus 223, std.	4.31	0.41	87.0	23.2	31.6	1.2	37.6	735
46	Kyrgyz Polukarlik	4.84	0.84	75.5	18.9	43.0	2.0	52.6	776
47	IDYT-SA 05-02	6.37	2.37	73.0	19.0	55.1	2.9	52.0	754
48	IDYT_MD 05-35	6.84	2.84	79.5	19.5	50.6	2.7	50.4	768
49	ICARASHA 1	7.38	3.38	76.5	18.9	66.5	3.1	44.8	780
50	Melyanopus 223, std.	3.68	-0.32	82.0	21.9	27.3	0.9	33.8	715
51	SWANA 32 IDYT MD	5.27	10.27	74.5	18.8	50.1	2.4	46.4	784
52	35 IDYT – MD 11-2	6.36	2.36	71.5	18.7	49.8	2.3	46.6	770
53	Dostuk	6.47	0.51	65.0	20.7	56.1	2.3	40.8	770
54	Kyzyl-dan	4.76	-1.2	71.0	20.3	50.0	1.9	40.8	–
55	Bermet	3.35	-2.61	39.0	24.1	53.3	1.3	30.6	–
Avg.	Tilek, standard	5.96	–	83.0	21.5	54.3	2.2	41.7	762
	LSD 05		0.31						

Source: developed by the authors

Almost all varieties exhibited a high vitreousness of grain (60%-90%), except Bermet, which was severely affected by yellow rust. The test weight across all varieties ranged from 740 to 780 g/L, with Lutescens 1706 (738), 12 IWWYT-SA 1040 (736), and Melyanopus 223 (725) being exceptions High 1000-grain weights were observed in the soft wheat varieties Erythrospermum 302 (50.4 g), Erythrospermum 518 (48.8 g), Erythrospermum 976 (52.0 g), Lutescens 1457 (47.2 g), Erythrospermum 13 (47.2 g), Lutescens 1706 (50.4 g), and Lutescens 1695 (51.2 g). Similarly, high values were seen in the durum wheat varieties Kyrgyz Polukarlik (52.6 g), IDYT-SA 05-02 (52.0 g), and IDYT-MD 05-33 (50.4 g). The tallest plants were found in the varieties Erythrospermum 1708 (114 cm), Lutescens 1694 (111 cm), and Lutescens 1706 (117 cm).

The results of these investigations have been presented at numerous international scientific and practical conferences In the view of the authors of this article, the entire process of developing new wheat varieties at the Kyrgyz Research Institute of Agriculture over the last 90 years (1934-2024) can be aptly described as the Green Revolution of wheat breeding in Kyrgyzstan. At the same time, it is considered necessary to strengthen efforts to establish licensing agreements with licensors in order to obtain commercial compensation in the form of royalties for the use of patented varieties in seed production.

Conclusions

The breeding and seed production work at the Kyrgyz Research Institute of Agriculture demonstrates consistent progress in developing high-yielding and adaptable wheat varieties for both semi-irrigated and rainfed lands. In recent years, three new soft wheat varieties – Nazdan, Vassan, and Taazhy – have been bred and approved for use across the Kyrgyz Republic, with a patent also secured for the Vassan variety. Patents for seven other varieties (Adyr, Kayrak, Ralyub, EHOL, Dank, Nazdan, and Taazhy) are consistently maintained, underscoring the high calibre of the breeding efforts. Two soft wheat varieties and one durum wheat variety have been submitted for State Testing Trials, and primary seed production ensures planned varietal rotation and renewal. The ecological trials of new varieties at the Issyk-Kul and Naryn experimental stations have allowed for an assessment of their adaptability to diverse soil and climatic conditions, including arid regions and areas with distinct vertical zonation The use of hybridisation, individual selection, and the introduction of genetic material from international centres (CIMMYT, ICARDA) has been instrumental in creating varieties with enhanced resistance to diseases, drought, and lodging, alongside superior baking qualities.

Future research will focus on intensifying efforts to create varieties with enhanced tolerance to climatic stresses, such as drought and extreme temperatures, by integrating modern genetic and biotechnological approaches. A key direction involves expanding collaboration with international breeding centres to introduce new genetic resources and implementing digital technologies for monitoring and analysing breeding material. It is also crucial to develop a robust system for licensing and securing royalties for the use of patented varieties, which will help improve the institute's material and technical resources. In the long term, plans include developing wheat varieties with improved nutritional characteristics to enhance food security in Kyrgyzstan. The Green Revolution of wheat breeding in Kyrgyzstan over the past 90 years provides a solid foundation for sustainable agricultural development in the face of global challenges.

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Conflict of Interest

None.

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Кыргызстанда буудай селекциясынын жыйынтыктары жана келечеги

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Аннотация. Буудай Кыргыз Республикасында азык-түлүк коопсуздугун камсыз кылууда маанилүү роль ойнойт. Ар жыл сайын болжол менен 250 миң гектар жер буудай эгүүгө пайдаланылат, ал эми айрым жылдары (мисалы, 1996-жылы) бул көрсөткүч 535 миң гектарга чейин жеткен. Буудай республиканын шарттуу сугат жана кайракы жерлеринде өстүрүлүп, нан азыктарын өндүрүү үчүн колдонулат. Селекциялык иштин баштапкы этабында баштапкы материалды түзүү жана колдонуу анын натыйжалуулугун жогорулатуучу маанилүү фактор болуп саналат. Изилдөөнүн максаты – 1935-2024-жылдар аралыгында Кыргызстанда жогорку түшүмдүү жана жергиликтүү шарттарга ылайыкташкан буудай сортторун иштеп чыгуу боюнча селекциялык программалардын натыйжалуулугун баалоо жана Кыргыз дыйканчылык илимий-изилдөө институтунун шартында аларды өркүндөтүү мүмкүнчүлүктөрүн аныктоо болгон. Селекцияда баштапкы материал катары маданий жана жапайы өсүмдүктөрдүн формалары колдонулат. Буудай селекциясында баштапкы материалды алуу үчүн негизги ыкмалар катары жаратылыш жана гибриддик популяциялар, ошондой эле жасалма мутациялар жана полиплоиддик формалар пайдаланылат. Буудай селекциясы жана баштапкы үрөнчүлүк бөлүмүндө тукум ичиндеги жана алыскы гибриддештирүү ыкмаларын колдонуу оригиналдуу баштапкы материалды алууга мүмкүндүк берип, андан индивидуалдуу тандоо жолу менен Кыргыз Республикасында колдонууга уруксат берилген сорттор чыгарылган: Лютесценс 46, Адыр, Эритроспермум 13. Глобалдык климаттын өзгөрүшү шартында жергиликтүү топурак-климаттык шарттарга ылайыкташкан сортторду иштеп чыгуу актуалдуу маселе бойдон калууда. Индивидуалдуу селекция жогору адаптацияланган формаларды аныктоого өбөлгө түзөт, ал эми кышкы буудайдын адаптивдүүлүк потенциалын жогорулатуу генетикалык рекомбиногенез аркылуу жүзөгө ашырылат. Тармактын туруктуу өнүгүүсүнүн маанилүү фактору болуп баштапкы үрөнчүлүк калууда. Кыргызстандагы буудай селекциясынын "жашыл" эволюциясы жогорку түшүмдүүлүккө жана баалуу чарбачылык белгилерге ээ болгон кышкы жана жазгы буудай сортторун киргизүү менен байланыштуу. Изилдөө өзгөрүп жаткан климат шарттарында айыл чарба өндүрүшүнүн туруктуулугун камсыз кылуу үчүн селекциялык программаларды мындан ары өркүндөтүүнүн зарылдыгын көрсөттү

Негизги сөздөр: азык-түлүк; коопсуздук; сугат; баштапкы материал; "жашыл" эволюция; сорт; баштапкы үрөнчүлүк

Результаты и перспективы селекции пшеницы в Кыргызстане

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Аннотация. Пшеница играет важную роль в обеспечении продовольственной безопасности Кыргызской Республики. Ежегодно под пшеницей занято 250 тысяч гектаров, а в отдельные годы (1996) площадь возделывания достигала 535 тысяч гектаров. Пшеница возделывается на орошаемых, условно орошаемых и богарных землях республики и используется для производства хлеба и хлебных продуктов. Создание и использование исходного материала на начальном этапе селекционной работы является важным фактором повышения ее эффективности. Целью исследования была оценка результативности селекционных программ по разработке высокопродуктивных и адаптированных сортов пшеницы в Кыргызстане за период с 1935 по 2024 годы, а также определение перспектив их совершенствования в условиях Кыргызского научно-исследовательского института земледелия. Установлено, что в качестве исходного материала в селекции используют культурные и дикие формы растений. В селекции пшеницы применяют следующие основные виды и способы получения исходного материала: естественные и гибридные популяции, а также искусственные мутации и полиплоидные формы. Использование внутривидовой и отдаленной гибридизации в селекционной работе отдела селекции и первичного семеноводства пшеницы позволило получить оригинальный исходный материал, из которого путем индивидуального отбора были созданы сорта, допущенные к использованию на территории Кыргызской Республики: Лютесценс 46, Адыр, Эритроспермум 13. В условиях глобального изменения климата актуальной задачей является разработка сортов, адаптированных к локальным почвенно-климатическим условиям. Индивидуальная селекция способствует выявлению форм с повышенной адаптивностью, а усиление адаптивного потенциала озимой пшеницы достигается за счет генетического рекомбиногенеза. Важным фактором устойчивого развития отрасли остается первичное семеноводство. «Зеленая» эволюция селекции пшеницы в Кыргызстане связана с внедрением высокопродуктивных сортов озимой и яровой пшеницы, обладающих ценными хозяйственными признаками. Исследование подчеркнуло необходимость дальнейшего совершенствования селекционных программ для обеспечения устойчивого сельскохозяйственного производства в условиях меняющегося климата

Ключевые слова: продовольствие; безопасность; орошение; исходный материал; «зеленая» эволюция; сорт; первичное семеноводство

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Economic and correlation analysis of perennial crop yields in the Chüy Region of the Kyrgyz Republic in the context of global climate change

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Abstract. Analysis of the effectiveness of agricultural resource use is becoming particularly important in the context of current climate and economic transformations. The study addressed the correlation between the indicators of orchard area, yield and gross harvest of fruit crops in the Chüy Region of the Kyrgyz Republic for the period 2022-2024. The study aimed to establish statistical correlations between the primary indicators of production and economic performance to support decisions aimed at enhancing the efficiency of the region's agricultural sector. The study used official statistical data, the calculation of Pearson's coefficients to identify linear dependencies and visual methods of presenting data. The analysis covered data for seed and stone fruit crops (apple, pear, plum, cherry, sweet cherry, apricot, peach), including area, gross harvest, yield, revenue, costs, profit and efficiency. The analysis showed a steady increase in yields and gross volume with a decrease in planted areas, indicating the introduction of a more intensive model in horticulture. High positive correlations were found between area and gross harvest ($r > 0.7$) and between gross harvest and yield ($r > 0.8$). A direct correlation between revenues and profits was also identified, which confirmed the importance of financial resource management. At the same time, the level of efficiency demonstrated a weaker dependence, indicating the multifactorial nature of its formation. The data obtained can be used to create regional strategies aimed at increasing the economic return on perennial fruit crops, with an emphasis on increasing yields, optimising costs and applying modern agricultural technologies. The findings highlighted the importance of integrating statistical methods of analysis into agricultural practice, which not only improved the accuracy of assessment of the current state of production but also created forecast models for effective resource management. Thus, the study demonstrated that the introduction of an integrated approach, including agrotechnical, economic and analytical components, is a key condition for increasing the sustainability and competitiveness of horticulture in the Chüy Region and similar agro-climatic zones

Keywords: agro-economic analysis; fruit-bearing crops; statistical correlation; production profitability; climatic factors; agro-technological efficiency; correlation dependencies

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Introduction

Modern agriculture is under the influence of many factors that significantly affect its efficiency and sustainability. One of the key challenges is global climate change, which manifests itself in the form of rising temperatures, more frequent dry periods, shifting growing seasons and instability in the distribution of precipitation. This determines a need for the agricultural sector to adapt to changing environmental conditions. In addition to climate, economic and social challenges, urbanisation, labour shortages, inflation and volatile markets are also increasing pressure on the agricultural sector, especially in emerging economies (Murabildayeva *et al*., 2024).

In the face of such challenges, it is especially important to find effective strategies for managing perennial plantations as one of the stable and resource-intensive segments of agricultural production. In Central Asian countries, including the Kyrgyz Republic, there is a downward trend in the area of agricultural land, including perennial plantations, due to soil degradation, water shortages and urbanisation. At the same time, statistics show an increase in yields, which indicates a transition to more intensive horticultural models. Such a transition is only possible with the introduction of modern drip irrigation technologies, breeding improved varieties, balanced plant nutrition and biological protection.

In this context, correlation analysis is substantial, identifying the relationship between agricultural and economic indicators and thus improving the accuracy of forecasts and the validity of management decisions. As noted by A. Ragimov & M. Mazirov (2022), correlation analysis is effective in assessing the impact of climatic and agronomic factors on fruit crop yields. O. Andreeva *et al*. (2022) emphasise that simple expansion of areas does not always lead to a proportional increase in yields and gross harvest, especially without proper agronomic support. T. Huang *et al*. (2024) proved the importance of varietal structure and irrigation methods for the optimal use of land resources. The study emphasised that the combination of high-yielding varieties with innovative cultivation methods can increase yields without extensive expansion of the territory. N. Parashar *et al*. (2024) showed that the use of multiple correlations makes it possible to quantify the contribution of each factor to the gross yield. A. Popova & O. Naumova (2021) added that without the cost components (e.g., costs per hectare), the economic analysis of agricultural activities loses its practical significance. It should also be noted that studies in Central Asian countries, including Kazakhstan and Uzbekistan, show similar trends. S. Shaitura *et al*. (2021) emphasise that regions that are actively implementing precision agriculture demonstrate higher production and economic efficiency even with limited natural resources. This data confirms the need for an integrated approach to managing perennial plantations, where economic and managerial aspects are taken into account alongside agricultural techniques.

For the Chüy Region of the Kyrgyz Republic, which is one of the national leading fruit-growing regions, the task of increasing the efficiency of the agricultural sector is particularly urgent. Given the limited land and water resources, as well as the growing demand for food, the region faces the need to develop and implement scientifically based solutions aimed at increasing the profitability and sustainability of production. International studies and regional experience show that analysis of the relationship between production indicators (area, gross harvest, yield) and economic results (income, costs, profit, efficiency) optimises agricultural policy and increases the effectiveness of investments (Talgarbekov *et al*., 2025).

The study aimed to conduct an economic and correlation analysis of the relationships between plantation area, gross harvest and yield of fruit crops in the Chüy Region of the Kyrgyz Republic for the period 2022-2024. Research goals include: analysis of the dynamics of production indicators for perennial plantations; determination of correlations between the main agricultural and economic indicators; and development of practical recommendations for improving the efficiency of perennial plantations management in the Chüy Region.

Materials and Methods

The study was conducted based on an analysis of official statistical data on perennial fruit crops grown in the Chuy region of the Kyrgyz Republic in 2022-2024. The data were obtained from reports from the Ministry of Agriculture of the Kyrgyz Republic (n.d.) and the National Statistical Committee of the Kyrgyz Republic (n.d.). The methodological basis included an economic correlation analysis aimed at identifying the relationships between three key indicators: the area of fruit-bearing plantations (ha), gross production (cwt), and yield (cwt/ha). Pearson's linear correlation coefficients were used to process the data, which made it possible to quantitatively assess the direction and degree of dependence between the variables. Microsoft Excel and SPSS Statistics software were used to process the information, which provided high accuracy of analysis and clear graphical representation of the results in the form of tables, graphs and diagrams.

The sample was based on complete annual data for the following crops (crops with incomplete data or an insignificant share in gross production were excluded from the sample):

- seeds: apple tree, pear tree;
- stone fruits: plum, cherry, sweet cherry, apricot, peach.

The following formulas were used to calculate the economic indicators:

Revenue (gross profit) was calculated using the following formula:

$$Revenue = Gross\ sales \times Unit\ price, \quad (1)$$

where *Gross harvest* – volume of products received in centners (c); *Unit price* – average market price (in conventional units) for 1 cwt of products.

Growing costs were determined by the formula:

$$Costs = Planted\ area \times Average\ cost\ per\ hectare, \quad (2)$$

where *Planted area* – total area of perennial crops (in hectares); *Average costs per hectare* – total costs of cultivation technology per 1 ha.

Profit was calculated as the difference between income and expenses:

$$Profit = Revenue\ Costs, \quad (3)$$

where *Income* – value from formula (1); *Expenses* – value from formula (2).

Efficiency of land use was calculated using the following formula:

$$Efficiency = \frac{Profit}{Plantation\ area}, \quad (4)$$

where Profit is calculated using formula (3); Plantation area in hectares. The indicator reflects the profit per hectare and is used as an indicator of the economic efficiency of cultivating a particular crop.

The methodology for calculating Pearson's correlation coefficient is described in the following formula:

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{n\sum x^2 - (\sum x)^2)(n\sum y^2 - (\sum y)^2))}}, \quad (5)$$

where: *x*, *y* – values of two variables; *n* – number of observations; *r* – Pearson's correlation coefficient, which characterises the direction and strength of the relationship between the variables.

These formulas quantified the production and economic parameters of perennial fruit growing in the region. This methodology can be successfully replicated in other areas with similar agro-climatic conditions and statistical bases.

Results and Discussion

The results of the study demonstrated that between 2022 and 2024, there was a decrease in the area of orchards in the Chüy Region, accompanied by an increase in harvest volumes and productivity indicators. This indicates an increase in the productivity and efficiency of agricultural land use. A correlation analysis revealed a moderately positive relationship between the area of plantations and gross harvest, confirming the importance of this indicator for forecasting production volumes. At the same time, the study determined a stable positive relationship between yield and gross harvest, emphasising the importance of technical and agrotechnological solutions in ensuring productivity (Filippova, 2025). Fluctuations in yield recorded in different years are probably due to unstable weather conditions, as well as differences in the application of agrotechnical measures (Konovalov *et al*., 2005).

The fluctuations in yields recorded in different years are possibly determined by unstable weather conditions, including longer dry spells and lower rainfall (Table 1).

Table 1. Changes in temperature, precipitation and dry periods in the Chüy Region

Year	Average air temperature, °C	Amount of precipitation, mm	Duration of dry period, days
2022	11.8	420	34
2023	12.4	390	41
2024	12.4	360	45

Source: compiled by the authors based on data from Kyrgyzhydromet (n.d.)

The highest yields were observed in those farms where innovative approaches to drip irrigation systems, modern fertilisation methods and high-yielding plant varieties were used, which confirms the importance of technological modernisation (Chekunov, 2019). The analysis of statistical data showed that the value of correlation coefficients between the main indicators for different years was in the range of 0.68-0.82, which characterises a high degree of interconnectedness.

Comparative analysis with the results of other studies demonstrated that sustainable yield growth, even with a reduction in planted areas, is possible due to the widespread adoption of modern agricultural technologies. In particular, studies in Kazakhstan and Uzbekistan show similar trends, where efficiency gains are achieved not through extensive expansion of planted areas, but through improved management decisions and more precise agricultural operations (FAO, 2018).

The analysis of the economic characteristics of key types of perennial crops for 2022-2024 revealed significant differences in income and costs of growth, which is an important factor for the subsequent analysis of their profitability and efficiency. The analysis calculated the total revenues and costs of growing each crop, including apple, pear, plum, cherry, sweet cherry, apricot, peach and other fruit trees. Costs were calculated based on typical costs per hectare, incorporating the specifics of agricultural practices for each fruit crop (Table 2).

Table 2. Revenues and expenses for perennial plantations in the Chüy Region in 2022-2024 (KGS)

Perennial plantations	Income, KGS			Costs, KGS		
	2022	2023	2024	2022	2023	2024
apple	4,575,100	3,937,850	4,117,800	5,917,000	3,331,000	3,277,000
pear	213,200	307,150	249,900	340,000	94,000	94,000
plum	531,400	593,450	603,250	478,000	392,000	392,000
cherry	876,450	1,012,200	1,073,300	680,000	616,000	616,000
sweet cherry	216,650	130,300	116,850	38,000	30,000	30,000
apricot	169,500	167,600	151,450	237,000	99,000	99,000
peach	2,400	14,900	15,150	5,000	10,000	10,000
others (cherry plum, etc.)	2,400	1,750	1,750	3,000	2,000	2,000
Total	6,587,100	6,165,200	6,329,450	7,698,000	4,574,000	4,520,000

Source: compiled by the authors based on data from the Ministry of Agriculture of the Kyrgyz Republic (n.d.)

Table 2 presents data on revenues and costs of perennial plantations (apple, pear, plum, cherry, sweet cherry, apricot, peach and other crops) for the period from 2022 to 2024. The table shows the following data for each crop. Revenues for 2022, 2023 and 2024 were calculated using a formula (e.g. for apple trees in 2022, the gross harvest was 91,502 centners and the price per unit was set at 50 conventional units):

$$Revenue_{apple} = 91{,}502 \times 50 = 4{,}575{,}100$$

The cost of perennial plantations was calculated based on the area of plantations and a fixed cost per hectare (e.g. 1,000 conventional units per hectare). A formula for calculating costs (e.g. for apple trees in 2022, if the area is 5,917 ha and the cost per hectare is 1,000 units):

$$Cost_{apple} = 5{,}917 \times 1{,}000 = 5{,}917{,}000$$

The data demonstrates the profitability of individual crops and the feasibility of further investment in certain areas of horticulture.

Table 3 presents data on the profit and efficiency of perennial plantations (apple, pear, plum, cherry, sweet cherry, apricot, peach and other crops) for the period from 2022 to 2024.

Table 3. Profit and economic efficiency of perennial crops in the Chüy Region for 2022-2024 (in thousands KGS and KGS/ha, rounded to the nearest tenth)

Perennial plantations	Income, KGS			Efficiency of som/ha		
	2022	2023	2024	2022	2023	2024
apple	-1,341.9	606.9	840.8	773.2	1,182.2	1,256.6
pear	-126.8	213.2	155.9	627.1	3,267.6	2,658.5
plum	53.4	201.5	211.3	1,111.7	1,513.9	1,538.9
cherry	196.5	396.2	457.3	1,288.9	1,643.2	1,742.4
sweet cherry	216,650	100.3	86.9	5,701.3	4,343.3	3,895
apricot	-67.5	68.6	52.5	715.2	1,692.9	1,529.8
peach	-2.6	4.9	5.2	480	1,490	1,515
others (cherry plum, etc.)	-0.6	-0.3	-0.3	800	875	875
Total	**-1,110.9**	**1,591.2**	**1,809.5**	**855.7**	**1,347.9**	**1,400.3**

Source: compiled by the authors based on data from the Ministry of Agriculture of the Kyrgyz Republic (n.d.)

Example calculation for apple trees (2022). Profit:

$$Profit_{apple} = 4{,}575{,}100 - 5{,}917{,}000 = -1{,}341{,}900$$

Efficiency:

$$Efficiencyapple = \frac{-1{,}341{,}900}{5{,}917} = 773.2$$

The analysis demonstrated that the profitability of different crops varied, and not all provided a sustainable positive income during the period under review. For instance, in 2022, negative profit was recorded for such crops as apple, pear, apricot and peach, due to high costs and relatively low income. However, by 2023-2024, there was an improvement in financial results, which was due to the modernisation of production and increased efficiency of technologies, the use of new agricultural technologies and, possibly, favourable weather conditions. The maximum efficiency indicators in the analysed years were characteristic of cherries and cherries, which indicates their high financial attractiveness for further investment in the Chüy Region. The dynamics of profits and efficiency over the analysed period is a substantial basis for the formation of regional programmes to support and develop specific areas of fruit growing.

It is also worth noting the positive dynamics of crops such as plums and pears, which initially showed moderate profitability, but significantly improved their positions in 2023 and 2024. Plums, with stable costs, showed consistent profit growth, indicating the crop's high adaptability to regional conditions and the potential for scaling up production. Despite negative profits in the initial period, pears became an economically stable crop by 2023, indicating a potential return on investment with proper agronomic support. In turn, crops such as peaches, apricots and others (cherries, etc.) remain less economically viable. Although there has been an improvement in indicators in some years, the overall level of profit and efficiency remains low, which requires further analysis of the economic feasibility of their continued cultivation in the region under review.

In addition, the use of profit and efficiency indicators enables not only current assessment but also planning of economic results for the future. The analysis suggests that with the steady introduction of modern agricultural technologies, such as precision irrigation, biologisation of farming, and the use of resistant varieties, a significant increase in profitability is possible even for crops that currently seem to be economically unprofitable.

Table 4 presents a correlation analysis between revenues, profits and efficiency of perennial plantations for the period from 2022 to 2024. The table presents correlation coefficients that show the relationship between various economic indicators for each year.

- Income: Reflects the correlation between income in different years. For instance: The correlation between the 2022 and 2023 earnings is 0.997, indicating a high degree of correlation between the earnings in these two years.
- Profit: Profit margins show the correlation between profits in different years. For instance: The correlation between the 2022 Earnings and the 2023 Earnings is -0.592, which indicates a weak negative relationship between the 2022 and 2023 earnings.
- Efficiency: The correlation between efficiency in different years shows how stable the economic efficiency indicators are. For instance: The correlation between Efficiency 2022 and Efficiency 2023 is 0.776, indicating a moderately high positive correlation.
- Correlation between different indicators. The values of the correlation coefficients range from -1 to +1. Positive values indicate that the two indicators are moving in the same direction, while negative values indicate an inverse relationship. For example, Revenue 2022 and Profit 2022 have a negative correlation of -0.846, which may indicate an inverse relationship between revenue and profit in the first year.
- Profit: Profit figures show a high degree of correlation between different years. For example, the correlation coefficient between profits in 2022 and 2023 is 0.984, and between 2023 and 2024 is 0.991, which indicates the stability of profit dynamics while maintaining the management and technological policy at the enterprise.
- Efficiency: In contrast to revenue and profit, the level of correlation between performance indicators was less pronounced. For instance, the correlation coefficients between efficiency in 2022 and 2023 were 0.894, and between 2022 and 2024 0.855. This may be due to the fact that efficiency is an integral indicator that depends on many variables: weather conditions, level of mechanisation, production costs and cost structure, which reduces the predictability of its fluctuations.

In general, the results of the correlation analysis confirm the stable dynamics of revenues and profits in the context of stable technological support, while the level of efficiency requires a more differentiated approach to planning. The data presented in the table can serve as a basis for developing forecasting models and making strategic decisions in the field of resource planning, financial management and investment analysis in the perennial plantations sector. The data obtained are of high applied value and can be used to build forecasting models, as well as to develop investment projects and state support programmes for the agricultural sector. Stable relationships between key economic indicators confirm the expediency of integrating statistical methods of analysis into the system of strategic management of agricultural production. Based on the analysis, it is recommended to pay more attention to the management of factors affecting the yield and cost of production, which will increase the level of efficiency even with limited resources. In addition, the results of the study can be adapted to the conditions of other regions with a similar agroclimatic structure, which expands the scope of their application and scientific significance.

Table 4. Correlation analysis of revenue, profit and efficiency of perennial plantations (2022-2024)

Name	Income			Profit			Efficiency		
	2022	2023	2024	2022	2023	2024	2022	2023	2024
Income of 2022	1	0.997434116	0.997819172	-0.846147469	0.919425132	0.952758633	-0.181387501	-0.32322199	-0.288174244
Income of 2023	0.997434116	1	0.999882883	-0.812215052	0.94397262	0.97135938	-0.195861817	-0.32865571	-0.292328653
Income of 2024	0.997819172	0.999882883	1	-0.814563021	0.940750247	0.969546951	-0.196259129	-0.335186393	-0.297735392
Profit of 2022	-0.846147469	-0.812215052	-0.814563021	1	-0.592032868	-0.656398594	0.277157172	0.313607104	0.322790943
Profit of 2023	0.919425132	0.94397262	0.940750247	-0.592032868	1	0.994116137	-0.159002475	-0.245643012	-0.205726993
Profit of 2024	0.952758633	0.97135938	0.969546951	-0.656398594	0.994116137	1	-0.169757591	-0.288662766	-0.244887716

Table 4. Continued

Name	Income			Profit			Efficiency		
	2022	2023	2024	2022	2023	2024	2022	2023	2024
Efficiency of 2022	-0.181387501	-0.195861817	-0.196259129	0.277157172	-0.159002475	-0.169757591	1	0.776644504	0.834519326
Efficiency of 2023	-0.32322199	-0.32865571	-0.335186393	0.313607104	-0.245643012	-0.288662766	0.776644504	1	0.98997595
Efficiency of 2024	-0.288174244	-0.292328653	-0.297735392	0.322790943	-0.205726993	-0.244887716	0.834519326	0.98997595	1

Source: compiled by the authors

Table 5. Correlation analysis of area, gross harvest and yield of perennial crops (2022-2024)

Name	2022			2023			2024		
	Area	Gross revenue	Yields	Area	Gross revenue	Yields	Area	Gross revenue	Yields
Area of 2022	1	0.992223001	-0.079765936	0.994722027	0.980865009	0.081107004	0.994277347	0.980867086	0.076359908
Gross collection 2022	0.992223001	1	0.025458512	0.999050476	0.996656165	0.177223789	0.999144384	0.996813984	0.176776488
Yield per hectare 2022	-0.079765936	0.025458512	1	-0.013627645	0.066940179	0.920010452	-0.010359902	0.06309829	0.929733425
Area of 2023	0.994722027	0.999050476	-0.013627645	1	0.994248194	0.138426527	0.999989495	0.994796068	0.13887889
Gross collection 2023	0.980865009	0.996656165	0.066940179	0.994248194	1	0.228852348	0.994691998	0.999851324	0.230001785
Yield per hectare 2023	0.081107004	0.177223789	0.920010452	0.138426527	0.228852348	1	0.141811692	0.220543555	0.99747342
Area of 2024	0.994277347	0.999144384	-0.010359902	0.999989495	0.994691998	0.141811692	1	0.995234776	0.142409385
Gross collection 2024	0.980867086	0.996813984	0.06309829	0.994796068	0.999851324	0.220543555	0.995234776	1	0.222667385
Yield per hectare 2024	0.076359908	0.176776488	0.929733425	0.13887889	0.230001785	0.99747342	0.142409385	0.222667385	1

Source: compiled by the authors

Table 4 shows the correlation between revenue, profit and efficiency for each year, which identified how changes in one indicator can affect the others. Correlation gives an indication of how strongly two indicators are related to each other but could not determine cause and effect. An example of a positive correlation is efficiency in 2022 with efficiency in 2023 ($r = 0.776$), which means that higher efficiency in one year is associated with higher efficiency in the following year.

Table 5 presents a correlation analysis between the area, gross harvest and yield of perennial plantations for the period from 2022 to 2024. The table presents correlation coefficients that show the relationship between these indicators for different years.

- Area: Reflects the relationship between the area of perennial plantings in different years. For example: The correlation between the area in 2022 and the area in 2023 is 0.9947, indicating a strong positive correlation, i.e., changes in the area in 2021 are strongly related to changes in 2023.
- Gross yield: Shows the correlation between gross revenue in different years. For instance: The correlation between the gross collection in 2022 and the gross collection in 2023 is 0.9967, which indicates a high positive correlation between the collections in these two years.
- Yield: Reflects the correlation between yield per hectare in different years. For example: The correlation between the 2022 yield and the 2023 yield is 0.9200, which indicates a high degree of positive correlation between the yields in these two years.
- Correlation between different indicators: The correlation between Area and Gross Collection in different years also shows a strong positive relationship. For example, area in 2022 and Gross Revenue in 2022 correlate 0.9922, indicating a strong relationship between these indicators.
- The correlation between gross harvest and Yield for 2022 was 0.025, which indicates a weak relationship between these indicators.

Table 4 demonstrates the relationship between area, gross harvest and yield for each year. This identified how changes in one indicator can affect the others, for example, how an increase in area can affect gross yield and yield. Positive values of correlation coefficients (close to 1) indicate that an increase in one indicator is associated with an increase in the other, while negative values (close to -1) indicate the opposite relationship.

In some cases, an increase in area is not accompanied by a corresponding increase in yield, which indicates the importance of introducing innovative approaches such as drip irrigation, selection of high-yielding varieties, and improvement of soil fertility. This highlights the need for comprehensive management of factors affecting yield. Thus, correlation analysis not only reveals statistical links between key production indicators but is also used for making informed decisions when planning the development of perennial crops in the context of climate and economic change. For a more visual interpretation of the relationship between income and profit of farms for 2022-2024, a logistic regression model was constructed. This model divided farms into two groups according to their level of efficiency, using income and profit values as classification criteria. The results are visualised in Figure 1.

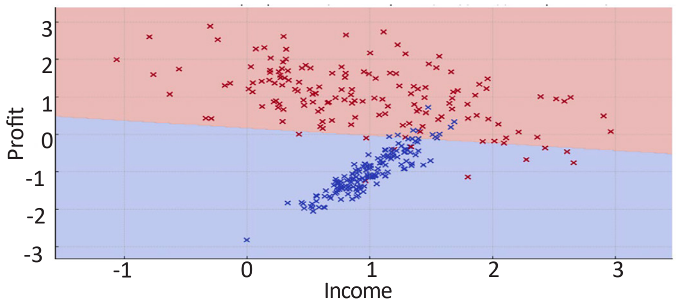

Figure 1. Logistic regression (income and profit classification) for 2022-2024
Source: compiled by the authors

Figure 1 shows a logistic regression model that classifies farms according to two economic indicators: income (X-axis) and profit (Y-axis). The coloured background of the graph shows the model's decision boundaries: the blue area corresponds to one class (e.g. less efficient farms), and the red area to another (e.g. more efficient farms). Each point on the chart represents a single observation. The colour of the point indicates the class to which the point belongs based on its income and profit values. Thus, the logistic regression model divides the sample into two groups and shows the areas of difference. This visualisation can be used to analyse the efficiency of farms based on income and profit for the period 2022-2024.

In addition to the previous classification model, an alternative version of the logistic regression model based on two generalised attributes was built. This model analysed the division of the sample under conditions of a different distribution of data, simulating differences between groups of farms in terms of efficiency, profitability or profitability. The visualisation is shown in Figure 2.

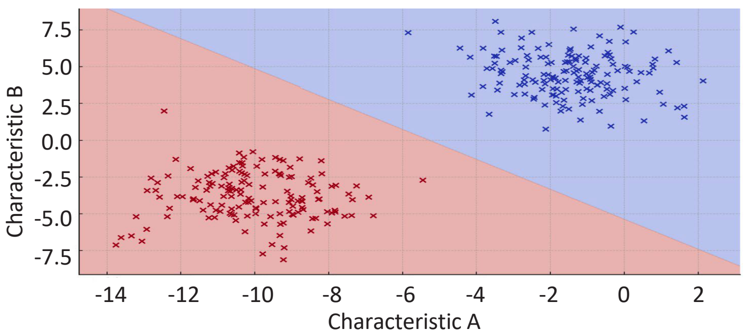

Figure 2. Logistic regression (alternative distribution) for 2022-2024
Source: compiled by the authors

Figure 2 visualises the results of applying a logistic regression model for the two-dimensional classification of data with the alternative distribution. The two clusters of points on the graph correspond to two different classes of objects, conventionally designated by colours: one class is red, the other is blue. These classes may represent, for example, farms with different degrees of efficiency, profitability or income levels. The coloured background shows the areas of space in which the model assigns objects to one class or another. The boundary between the colours is the decision boundary constructed by the logistic regression model. It shows the values of the two features at which the model changes its decision about whether an object belongs to a particular class. The axes of the graph are labelled Feature A and Feature B, but in an applied context, the axes can be interpreted as any economic, agricultural or social indicators (e.g. income and profit, crop area and yield, cost level and profitability, etc.). Thus, Figure 2 demonstrates the visual ability of logistic regression to classify objects based on two features and can be used for visual analysis of the effectiveness of separation in economic research.

Table 4 shows the relationship between area, gross harvest and yield for each year. This part of the chart shows strong correlations between area and gross harvest, as well as between yield and gross harvest, which helps to understand how changes in area or yield affect the total harvest. The construction of diagrams based on the results of the correlation analysis demonstrated the dependencies between the main economic and agricultural production indicators of perennial plantations. The value of graphical interpretation lies in the ability to visualise how a change in one parameter affects the others, which contributes to a more accurate understanding of cause-and-effect relationships and the development of informed management decisions.

The results of the analysis showed a pronounced positive correlation between revenues and profits throughout the entire period under study (2022-2024), which indicates a direct impact of revenue growth on profit growth. This emphasises the importance of an effective pricing and sales policy in ensuring sustainable profitability of perennial crop production. At the same time, the study noted that the correlation between the level of efficiency (profit per hectare) and other indicators is less pronounced. This may be due to the multifactorial nature of efficiency formation, including not only financial parameters but also agrotechnical, organisational and natural and climatic conditions.

The analysis also confirmed the existence of a stable positive correlation between the area under cultivation and gross yield, which logically reflects the quantitative side of production. However, yield had a decisive influence on gross harvest, demonstrating a strong correlation with the total volume of production. This highlights the need to focus more attention on increasing yield per hectare using resource-saving and innovative technologies. Thus, increasing crop yields, rational management of cultivated areas and the use of modern agricultural techniques are key factors determining the growth of gross harvest and total profits from fruit production in the Chüy Region.

The results of the study emphasise the importance of the relationship between revenues, profits and the efficiency of perennial crops. The high correlation between revenues and profits confirms the importance of revenue management for improving the overall profitability of agricultural production. It also points to the need to improve market strategies aimed at increasing revenues, which can be a major driver of economic growth in agriculture. Nevertheless, the results also demonstrated that the efficiency of perennial plantations does not always correlate directly with revenues and profits. This may reflect the complexity of economic processes in the agricultural sector, where other factors such as seasonal fluctuations, commodity price volatility or climatic conditions can significantly affect financial performance. Efficiency could depend on a variety of other variables such as management technology, labour quality and inputs used in the production process.

Furthermore, the correlation between area and gross harvest demonstrates a direct correlation: an increase in planted area leads to an increase in gross harvest. This confirms the hypothesis that expanding the area under perennial crops can significantly increase production. However, it is worth noting that an increase in area may also be associated with additional costs for the maintenance and cultivation of these lands. Therefore, the expansion of the area must be balanced with improvements in technology to optimise costs and increase overall production efficiency.

Yields, as an important factor, also demonstrated a significant impact on gross harvest. This underlines the importance of introducing innovative technologies to increase productivity per hectare, which will be a key factor in increasing production without significantly increasing the area. Based on the results obtained, it is possible to conclude that successful management of perennial plantations requires an integrated approach, including both increasing the area and increasing yields using modern technologies. However, these changes must be balanced with economic feasibility, which requires additional research and consideration of many factors.

Conclusions

The results of the study confirm the existence of a direct positive correlation between income and profits from perennial crops in the Chüy Region for 2021-2023. This highlights the importance of effective income management as a key factor in improving the overall profitability and financial sustainability of agricultural holdings in a changing climate. The analysis showed that increasing the area of perennial crops directly contributes to the growth of gross harvest. Expanding the area remains an important direction for increasing production volumes. However, in the context of global climate change, achieving maximum economic efficiency requires not only extensive growth but also the introduction of advanced agricultural technologies that reduce costs and adapt to climate risks. The study established that the yield of perennial crops has a significant impact on total gross harvest. Increasing yields per hectare without the need for significant expansion of the area improves the efficiency of the use of available resources, optimisation of production processes and reduction of costs, especially in conditions of unstable climatic conditions.

To sustainably increase the profitability and adaptability of perennial plantations, an integrated approach is required, combining increased areas, higher yields and the use of modern agricultural technologies.

This approach ensures an optimal balance between costs and profits, which is especially important in the context of global climate and economic challenges. It is recommended to conduct further research aimed at a deeper study of the impact of external factors, including climate change, market fluctuations and policy changes, on the efficiency of perennial plantations. This will improve the accuracy of economic forecasts and adaptation strategies.

Thus, to achieve high profitability and sustainability of the agricultural sector in the context of global climate change, it is necessary to combine the expansion of perennial plantations with increased yields through the introduction of innovative technologies. The integrated management of production parameters forms the basis for improving the overall economic efficiency and sustainable development of agriculture. For future research, it may be useful to conduct a more detailed analysis of the factors affecting efficiency, as well as consider the impact of climate and market conditions on financial performance. This will improve recommendations for the agricultural sector and identify optimal strategies to improve the economic sustainability of perennial plantations.

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Conflict of Interest

The authors declare no actual or potential conflicts of interest related to the publication of this article.

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Глобалдык климаттын өзгөрүүлөрүнүн шартында Кыргыз Республикасынын Чүй областынын көп жылдык өсүмдүктөрүнүн түшүмдүүлүгүнө экономикалык-корреляциялык талдоо

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Аннотация. Климаттын жана экономикалык шарттардын өзгөрүшүнүн шартында айыл чарба ресурстарын пайдалануунун натыйжалуулугун баалоо барган сайын маанилүү болуп баратат. Макала 2022-2024-жылдар аралыгында Кыргыз Республикасынын Чүй областында көп жылдык өсүмдүктөдүн аянтынын, дүң жыйымынын жана мөмө-жемиш өсүмдүктөрүнүн түшүмүнүн ортосундагы байланыштын экономикалык корреляциялык анализине арналган. Изилдөөнүн максаты региондун айыл чарба секторунун натыйжалуулугун жогорулатууга багытталган чечимдерди негиздөө үчүн негизги өндүрүштүк жана экономикалык көрсөткүчтөрдүн ортосундагы статистикалык байланыштарды аныктоо болуп саналат. Изилдөөнүн методологиялык негизи расмий статистикалык маалыматтарды иштеп чыгууну, Пирсондун сызыктуу корреляция коэффициенттерин колдонууну жана натыйжаларды визуалдаштырууну камтыды. Талдоо аянттардын, дүң жыйымдардын, түшүмдүүлүктүн, кирешенин, чыгашанын, пайданын жана эффективдүүлүктүн көрсөткүчтөрүн камтыган анарлуу жемиш өсүмдүктөрү (алма, алмурут, кара өрүк, алча, алча, абрикос, шабдалы) боюнча маалыматтар камтылган. Негизги жыйынтыктар айдоо аянтынын кыскаруусу менен да түшүмдүүлүктүн жана дүң жыйымдын туруктуу өсүшүн көрсөттү, бул багбанчылыктын интенсивдүү моделине карай тенденцияны чагылдырат. Аянт менен дүң жыйым ($r > 0,7$), ошондой эле дүң жыйым менен түшүмдүүлүк ($r > 0,8$) ортосунда жогорку оң корреляциялар белгиленген. Киреше менен пайданын ортосундагы түздөн-түз байланыш да аныкталды, бул финансылык ресурстарды башкаруунун маанилүүлүгүн тастыктады. Ошол эле учурда натыйжалуулуктун деңгээли алсызыраак көз карандылыкты көрсөттү, бул анын калыптанышынын көп факторлуулугун көрсөтөт. Изилдөөнүн практикалык мааниси анын жыйынтыктарын түшүмдүүлүктү жогорулатууга, чыгымдарды оптималдаштырууга жана заманбап агротехнологияларды колдонууга басым жасоо менен көп жылдык багбанчылыктын рентабелдүүлүгүн жогорулатуу боюнча региондук программаларды иштеп чыгуу үчүн пайдалануу мүмкүнчүлүгүндө турат. Алынган натыйжалар айыл чарба практикасына талдоо жүргүзүүнүн статистикалык ыкмаларын интеграциялоонун маанилүүлүгүн баса белгилейт, бул өндүрүштүн учурдагы абалын дагы так баалоого гана эмес, ресурстарды натыйжалуу башкаруунун болжолдуу моделдерин калыптандырууга мүмкүндүк берет. Ошентип, изилдөө агротехникалык, экономикалык жана аналитикалык компоненттерди камтыган комплекстүү мамилени ишке ашыруу Чүй областында жана ушул сыяктуу агроклиматтык зоналарда багбанчылыктын туруктуулугун жана атаандаштыкка жөндөмдүүлүгүн жогорулатуунун негизги шарты экенин көрсөтүп турат

Негизги сөздөр: агроэкономикалык талдоо; жемиш өсүмдүктөрү; статистикалык байланыштар; өндүрүштүн рентабелдүүлүгү; климаттык факторлор; агротехнологиялык эффективдүүлүк; корреляциялык көз карандылык

Экономико-корреляционный анализ урожайности многолетних насаждений в Чуйской области Кыргызской Республики в условиях глобальных изменений климата

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Аннотация. Анализ результативности применения аграрных ресурсов становится особенно важным на фоне текущих климатических и экономических трансформаций. В работе рассмотрена корреляционная взаимосвязь между показателями площади садов, уровнем урожайности и объемом валового сбора плодовых культур в Чуйской области Кыргызской Республики за период 2022-2024 гг. Исследование было направлено на установление статистических корреляций между основными показателями производства и экономической результативности для обоснования решений, направленных на повышение эффективности аграрного сектора региона. В исследовании использовались официальные статистические сведения, расчет коэффициентов Пирсона для выявления линейных зависимостей, а также визуальные методы представления данных. Анализ охватывал данные по семечковым и косточковым культурам (яблоня, груша, слива, вишня, черешня, абрикос, персик), включая показатели площади, валового сбора, урожайности, доходов, затрат, прибыли и эффективности. Анализ продемонстрировал стабильное увеличение показателей урожайности и валового объема при уменьшении посевных площадей, что указывает на внедрение более интенсивной модели в садоводстве. Были установлены высокие положительные корреляции между площадью и валовым сбором ($r > 0{,}7$), а также между валовым сбором и урожайностью ($r > 0{,}8$). Также была выявлена прямая зависимость между доходами и прибылью, что подтверждало значимость управления финансовыми ресурсами. В то же время уровень эффективности демонстрировал более слабую зависимость, свидетельствующую о многофакторном характере его формирования. Полученные данные могут быть применены при создании региональных стратегий, направленных на повышение экономической отдачи многолетних плодовых культур, с акцентом на повышение урожайности, оптимизацию затрат и применение современных агротехнологий. Полученные результаты подчеркнули важность интеграции статистических методов анализа в аграрную практику, что позволяет не только точнее оценивать текущее состояние производства, но и формировать прогнозные модели для эффективного управления ресурсами. Таким образом, исследование продемонстрировало, что внедрение комплексного подхода, включающего агротехнические, экономические и аналитические компоненты, является ключевым условием повышения устойчивости и конкурентоспособности садоводства в условиях Чуйской области и аналогичных агроклиматических зон

Ключевые слова: агроэкономический анализ; плодоносные культуры; статистическая взаимосвязь; рентабельность производства; климатические факторы; агротехнологическая эффективность; корреляционные зависимости

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