SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 28(3), 68-79

UDC 631.67:631.452
DOI: 10.48077/scihor3.2025.68

Justification of the impact of complex melioration on the fertility of compacted sierozem soils of irrigated lands of the Zhambyl region

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Article's History:
Received: 19.07.2024
Revised: 01.01.2025
Accepted: 26.02.2025

Abstract. The aim of the study was to develop effective methods of improving physical, chemical and biological properties of soil to increase its productivity and resistance to degradation under conditions of intensive agricultural use. The article presented a study of the impact of complex reclamation measures on the restoration of compacted grey soils in the conditions of irrigated lands of Zhambyl oblast. The experimental part included application of deep loosening and organic fertilizers, as well as water

Suggested Citation:
Kutymbek, N., Yestaev, K., Rustem, E., Musabekov, K., & Tursunbayev, Kh. (2025). Justification of the impact of complex melioration on the fertility of compacted sierozem soils of irrigated lands of the Zhambyl region. *Scientific Horizons*, 28(3), 68-79. doi: 10.48077/scihor3.2025.68.

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regime management using drip irrigation. The results of the study showed that ameliorative measures allowed reducing soil density by 15-20%, which provided improvement of its structure and increased water permeability by 300-400%. This created conditions for a more uniform distribution of moisture in the root-inhabited layer, which minimised surface run-off by 60-70% and prevented nutrient losses. The application of organic fertilizers increased the humus content by 15-20%, which improved the chemical composition of the soil and increased its ability to retain nutrients. Special attention was paid to the biological activity of the soil, which increased by 25-30% due to the activation of microbial communities. These changes improved the decomposition of organic matter and increased the availability of nitrogen, phosphorus, and potassium for plants. As a result of application of complex measures, an increase in wheat and maize yields by 15-20% was observed, which confirmed the effectiveness of the proposed approaches. The made conclusions demonstrate that the use of deep loosening, organic fertilisation and drip irrigation in complex is an effective method of restoration of degraded grey soils. The results of the study have significant practical value and can be recommended for implementation in agricultural production in arid regions

Keywords: land irrigation; soil fertility; crop yields; deep loosening; ecological technologies; agricultural productivity; water permeability

INTRODUCTION

The relevance of this study is conditioned by the need to improve the efficiency of land resources use in Zhambyl oblast, where grey soils are characterised by low natural fertility and high susceptibility to degradation processes. The arid climate of the region, limited water resources and intensive farming lead to soil compaction, deterioration of soil structure and reduction of wheat and maize yields. Ameliorative measures, including deep loosening and application of organic fertilizers, allow not only to improve physical and mechanical properties of soil, but also to increase its water permeability, humus content and biological activity. This creates a basis for increasing soil productivity and sustainable development of the agrarian sector of the region, which makes this area of research particularly relevant.

The problematics of the research is related to the deterioration of grey soils caused by compaction, lack of organic matter and low biological activity. These factors lead to a decrease in water-holding capacity and deterioration of plant access to nutrients, which in the conditions of arid climate leads to significant yield losses. The situation is aggravated by intensive tillage methods and irrational irrigation, which contribute to the leaching of nutrients, development of erosion processes and deterioration of soil structure. Insufficient study of the influence of complex melioration on fertility of compacted grey soils in conditions of Zhambyl oblast underlines the necessity of this research. Analysing the works of other authors, it can be noted that A. Rau *et al*. (2023) justified the necessity of introducing reclamation measures, such as deep loosening and application of organic fertilizers, to increase water permeability and moisture retention in the soil. According to the findings of A.T. Aimen *et al*. (2022) low humus levels and soil compaction in Central Asia significantly reduce crop yields. And emphasised that organic matter application and water regulation effectively increase soil biological activity. Researchers D. Raiymbekov *et al*. (2023) indicate that agronomic measures such as loosening and water table regulation help to reduce soil density and prevent erosion.

As noted by S. Razanov *et al*. (2022), standard intensive farming practices reduce soil fertility, but the introduction of a systematic approach including improvement of soil structure and chemical composition can achieve significant results. In the studies of Y. Kenjaev and A. Tursunkulova (2021), the authors draw attention to the fact that improper irrigation aggravates soil compaction, but the introduction of drip irrigation and reclamation measures contributes to the restoration of soil fertility. According to N.S. Mustakimovna (2021), the increase in the content of organic matter in the soil contributes to the increase of its biological activity and resistance to degradation, which confirms the need to apply organic fertilizers.

As noted by A. Tadesse and W. Hailu (2024), land degradation in arid regions requires an integrated approach, including physical and chemical methods of soil restoration. As the results of I.J. Roziyeva and K.U. Turabayeva (2022), in irrigated soils, the reduction of biological activity and nutrient deficiency are compensated by organic matter application and improvement of water regime. W.T. de Vries and I. Rudiarto (2023) emphasise successful soil rehabilitation strategies, including measures to reduce compaction and increase humus content, which is important for degraded soils. As indicated by I. Plisko *et al*. (2021), the use of spatial diagnostics of soil degradation allows to accurately identify problem areas and effectively plan reclamation measures, emphasising their importance for fertility restoration. Authors V. Gamayunova *et al*. (2024) highlight the key role of resource-saving technologies, including the use of straw to improve soil fertility. Studies show that the application of organic material contributes to humus recovery and increased yields, which confirms the effectiveness of organic approaches to the reclamation of grey soils. As noted by N.S. Kaya and O. Dengiz (2024) soil quality assessment using neutrosophic logic and

machine learning techniques can accurately identify factors limiting agricultural land productivity. These studies emphasise that rehabilitation of compacted grey soils requires an integrated approach combining traditional reclamation methods with innovative technologies and biological approaches.

Thus, the aim of the study was to justify reclamation measures to improve the properties of compacted grey soils in Zhambyl oblast and increase their productivity.

MATERIALS AND METHODS

The study was conducted in 2024 (June-August) on the basis of experimental fields of Taraz Regional University named after M.Kh. Dulaty in Taraz city, Zhambyl region. The study covered the summer period (vegetation period from 1 June to 31 August, 92 days), because at this time the most active processes of soil formation, dynamics of moisture and temperature regime, as well as the maximum vegetative activity of wheat and maize are observed, which allows the most complete assessment of the impact of reclamation measures. The climate of the region was characterised by sharply continental conditions, including hot and dry summers, with daytime temperatures of +22-30°C and nighttime temperatures of +15-18°C. The average annual precipitation was 120-200 mm, most of it falling in spring, which required the use of effective moisture conservation methods to maintain wheat and maize productivity. The object of the study was compacted grey soils, on which ameliorative measures were carried out to improve their physical and chemical characteristics.

The soils of the experimental plot were typical grey soils with low humus content (1.3-1.4%) and limited reserves of available nitrogen, phosphorus, and potassium. Before the experiment, soil samples were analysed, which revealed neutral acidity (pH 6.8-7) and low biological activity. The experiment was conducted on one plot of 1 ha with the use of ameliorative measures, including deep soil loosening (to a depth of 30-35 cm) in combination with the application of organic fertilizers (over-fermented cattle manure at a dosage of 30 t/ha). The study was conducted in three repetitions. Watering was carried out by drip irrigation for uniform moisture distribution and prevention of erosion processes. Soil water regime was evaluated by infiltration, water-holding capacity and evaporation. Infiltration rings were used to measure water permeability, and field water retention was determined based on the difference in soil moisture immediately after irrigation and after a certain time interval. Moisture evaporation was monitored by hydrometric methods. On the basis of the obtained data, the influence of land reclamation on soil water balance and its ability to maintain optimal moisture level for plants was analysed.

Complex application of loosening and organic fertilizers provided improvement of soil physical and chemical properties. It was expected that loosening would reduce soil density, increase its aeration and water permeability, and the application of organic matter would increase humus content, increase nutrient element availability and soil water-holding capacity. The change in the number of soil microorganisms was evaluated as an indicator of soil biological activity. Numbers were determined by culturing on selective nutrient media, which made it possible to trace the dynamics of microbial activity change. Measurements were carried out during the vegetation period. Changes in soil physical properties, dynamics of water regime, humus and nutrient elements content, as well as activity of soil microbiota were analysed. The obtained data allowed objectively assessing the efficiency of applied ameliorative measures and their impact on soil fertility restoration. Changes in soil physical properties were assessed by measuring its density, porosity, and water permeability. Density was determined by taking cylindrical samples, which were weighed to calculate volumetric weight. Water permeability was analysed using infiltration rings to determine the rate of water infiltration into the soil. Filtration coefficient was calculated using the Darcy formula (1):

$$K = \frac{V}{F \times t}, \quad (1)$$

where K is the index of soil filtration capacity expressed in centimetres per hour (cm/h); V is the total volume of water that passed through the soil during the experiment (cm^3); F is the cross-sectional area of the infiltration ring through which infiltration occurred (cm^2); t is the duration of the infiltration process measured in hours (h).

Soil chemical condition was studied on the basis of organic matter, nitrogen, phosphorus, and potassium content. The humus content was determined by the Turen method (DSTU 4289:2004, 2005), nitrogen was estimated by the Kjeldahl method (DSTU ISO 11261:2001, 2003), mobile forms of phosphorus were analysed by the standard colorimetric method (DSTU 4729:2007, 2008), and potassium content was determined by the flame photometric method (DSTU 7863:2015, 2016). All data were processed statistically using analysis of variance. The results were presented in the form of mean values with indication of standard errors, which provided reliability of data interpretation and allowed identifying reliable differences between control and treated plots.

RESULTS

Changes in soil density and porosity before and after melioration measures

Before the experiment, compacted grey soil showed high density in the range of 1.45-1.6 g/cm^3, which is critical for plant growth. The pre-intervention soil density was 1.45-1.6 g/cm^3 and water permeability was extremely low (0.05-0.1 mm/min). A drip irrigation system was applied to maintain a stable soil moisture level.

Such density values limited soil permeability for water and air, creating unfavourable conditions for the development of the root system of wheat and maize. This problem was especially acute in areas with intensive irrigation, where insufficient water permeability led to stagnation and erosion processes (Yeraliyeva *et al.*, 2017). After reclamation measures, including deep loosening, application of organic fertilizers, as well as improvement of drainage system, soil density on the studied plots decreased on average by 15-20%. Final density values varied in the range of 1.2-1.35 g/cm^3, which corresponds to optimal conditions for most wheat and maize cultivated under irrigated farming conditions. This indicates a significant improvement of soil agrophysical properties, which is confirmed by both quantitative and qualitative indicators.

The decrease in soil density was accompanied by an increase in porosity, which is important for water and air permeability. Before reclamation, the total soil porosity was about 40-42%, which is obviously insufficient to ensure a normal regime of moisture storage and aeration. After the measures this indicator increased up to 50-55%, and active porosity, responsible for gas exchange and water availability for plants, increased by 25-30%. Particularly noticeable changes occurred in the upper soil layer (0-30 cm), where the bulk of plant roots are concentrated. This increase in porosity contributes not only to a better supply of moisture to plants, but also to an increase in the biological activity of the soil.

Reduction of soil density also had a positive effect on water permeability. Before reclamation measures, soil filtration coefficient was extremely low – from 0.05 to 0.1 mm/min, which led to frequent stagnation of water on the surface and reduction of irrigation efficiency. After the introduction of reclamation measures, this indicator increased to 0.25-0.35 mm/min. This allowed significantly improving moisture distribution over the soil profile, reducing the volume of surface run-off and minimising erosion risks. Moreover, the water-holding capacity of the soil increased, which is especially important in the arid conditions of the region, where regular moisture supply plays a key role for wheat and maize growth (Kamzina *et al.*, 2022).

The findings confirm that reducing soil density improved the mechanical structure of the soil. Soil aggregates with a diameter of 1-3 mm became more stable and their number increased by 30%. Before the measures, the stability of aggregates was 30-35%, whereas after reclamation this indicator increased to 50-55%. Soil structure stability is an important factor, preventing reconsolidation and ensuring its stability under mechanical impact such as tillage or irrigation (Fedoniuk *et al.*, 2019; Panchenko *et al.*, 2024). Changes in soil density and structure resulted in improved conditions for plant growth and higher yields. The reclaimed plots showed an increase in wheat and maize yields by 15-20% compared to control plots. This is due to improved water-air regime, increased availability of nutrients and creation of more favourable conditions for root system development. In addition, the reduction in soil density reduced energy inputs for mechanical cultivation of fields, which increased the overall profitability of agricultural production (Table 1).

Table 1. *Changes in soil density and porosity before and after reclamation activities*

Parameter	Before reclamation	After reclamation	Change (%)
Soil density (g/cm^3)	1.45-1.6	1.2-1.35	-15-20
Total porosity (%)	40-42	50-55	+20-30
Filtration coefficient (mm/min)	0.05-0.1	0.25-0.35	+300-400
Aggregate stability (%)	30-35	50-55	+30-50
Yield (c/ha)	25-30	35-40	+15-20

Source:*developed by the authors*

These results demonstrate the significance of application of complex reclamation for restoration and improvement of physical and mechanical properties of grey soils in conditions of irrigated farming in Zhambyl oblast. The obtained data highlight the practical benefits of measures aimed at reducing soil density, which in the long term contributes to reducing the need for fertilizers by improving the availability of nutrients, increasing soil resistance to drought due to improved water-holding capacity, as well as stabilising soil structure, reducing its susceptibility to erosion and compaction. These changes ensure sustainable development of the region's agricultural sector and increase the efficiency of farming in an arid climate.

Change of soil water regime indicators before and after reclamation measures

The results showed significant improvement of soil physical characteristics, its water permeability and resistance to erosion. Soil filtration coefficient increased by 300-400%, which provided significant improvement of water distribution in the soil profile. Before reclamation, the soil was characterised by extremely low water permeability, due to which a significant part of irrigation water remained on the surface, causing stagnation, water erosion and nutrient leaching. After the introduction of measures, water began to penetrate deeper, evenly distributed over the root layer, which contributed to improved conditions for plant growth.

A 60-70% reduction in surface run-off was also a key result. Before the measures, about 30-40% of irrigation water was lost as run-off, carrying away fertile topsoil and nutrients. After reclamation, this figure was reduced to 10-15%, which significantly reduced moisture losses and minimised soil degradation. Improved water-holding capacity, which increased by 20-25%, played an important role in stabilizing the water regime. This allowed the soil to retain moisture longer during dry periods, which was particularly important for the agricultural sector in Zhambyl province, where irrigated agriculture depended on the rational use of water resources.

Total soil porosity increased by 20-25%, which improved conditions for gas exchange and moisture retention, promoting the development of plant root systems. This directly influenced the efficiency of irrigation water use, allowing crops to receive moisture evenly even at minimum irrigation volumes. This effect was especially significant in conditions of intensive irrigation, where excessive saturation of soil with water previously caused its compaction and reduced productivity. Reduction of soil erosion losses by 70-80% was another significant achievement. Before reclamation, annual soil losses due to water erosion were 4.5-5 tonnes/ha, which worsened its fertility. After implementation of measures, this indicator decreased to 1-1.5 tonnes/ha. This improvement was explained by increased soil resistance to surface water flows due to improved soil structure and increased organic matter content. Organic matter, the content of which increased by 15-20%, contributed to the formation of water-resistant aggregates, making the soil more resistant to erosion and leaching. The 15-20% increase in wheat and maize yields confirmed the positive impact of reclamation on soil productivity. Improvement of water regime created favourable conditions for plant growth, providing their access to water and nutrients. Especially it was reflected on grain crops yield, which increased from 25-30 c/ha to 35-40 c/ha.

The increase in the number of soil microorganisms by 25-30% also confirmed the positive impact of reclamation on the soil. Biological activity increased due to improvement of its moisture and structure, which created favourable conditions for microbiological activity. Microorganisms played a key role in the processes of organic matter decomposition and transformation of nutrients into forms available for plants. The growth of their number contributed to the increase of natural fertility of soil, making it more resistant to degradation (Table 2).

***Table 2**. Changes in soil water regime indicators before and after reclamation activities*

Parameter	Before melioration	After melioration	Change (%)	Notes
Filtration coefficient (mm/min)	0.05-0.1	0.25-0.35	+300-400	Improved infiltration and moisture redistribution
Surface run-off (% of volume)	30-40	10-15	-60-70	Reduction of water loss and erosion processes
Total porosity (%)	40-42	50-55	+20-25	Increasing pore volume for water and air
Water holding capacity (%)	18-20	23-25	+20-25	Preserving moisture during dry periods
Soil erosion losses (t/ha)	4.5-5	1-1.5	-70-80	Reducing the risk of fertile soil layer washout
Grain yield (c/ha)	25-30	35-40	+15-20	Improving conditions for plant growth and development
Organic matter content (%)	1.2-1.4	1.6-1.8	+15-20	Increasing the water-retaining properties of the soil
Number of soil microorganisms (thousand/g of soil)	2.5-3	3.8-4.2	+25-30	Increased activity due to optimal water regime

***Source:** developed by the authors*

The complex effect of reclamation measures was manifested in the improvement of all key soil characteristics. Increase in filtration coefficient, decrease in surface run-off and erosion losses, increase in water retention capacity and total porosity – all this contributed to a significant increase in fertility of sierozem soils. These results confirmed that integrated land reclamation was an effective tool for improving soil physical and chemical properties and an important factor for sustainable development of the agricultural sector under irrigated farming conditions.

Changes in organic matter and nutrient content

Before reclamation activities, the content of organic matter in the soil was at a low level – on average 1.2-1.4%. This limited the soil's ability to retain moisture and nutrients and reduced its biological activity. Low organic matter content also worsened the structural characteristics of the soil, making it prone to compaction and erosion. After the implementation of a set of measures including organic fertilizers, siderates and improved drainage system, the organic matter content increased by 15-20%, reaching 1.6-1.8%. This significant increase in organic matter improved the physical, chemical and biological properties of the soil, making it more resilient and more productive. The increase in organic matter content was accompanied by an increase in available nutrient elements such as nitrogen, phosphorus, and potassium. Before reclamation, the level of available nitrogen in the soil was about 40-50 mg/kg, which was insufficient to ensure normal plant growth. After the measures, this indicator increased by 25-30%, reaching 60-65 mg/kg. Similar changes were recorded for phosphorus: its content increased from 15-20 mg/kg

to 25-30 mg/kg. Potassium availability also increased by 20-25%, which strengthened the overall nutrient balance of the soil. These changes were related both to the application of organic fertilizers and to the activation of soil microorganisms, which accelerated the decomposition of organic matter and the transformation of nutrient elements into available forms.

Chemical changes in the soil were also due to the improvement of its structure and water regime. The increase in organic matter content favoured the formation of water-stable aggregates, which prevented the leaching of nutrients and increased their availability to plants. Due to this, the balance of nitrogen, phosphorus, and potassium in the soil became more stable, which created conditions for uniform nutrition of plants throughout their vegetation period. The increase in available nutrient elements directly contributed to higher yields, which increased by 15-20% compared to control plots. The research also revealed an increase in the number of soil microorganisms, which is an indicator of soil biological activity. Their numbers increased by 25-30%, which indicated the creation of favourable conditions for microbiological processes such as mineralisation of organic matter and nitrogen fixation. This growth additionally contributed to the increase of available nutrients and strengthening of natural soil fertility (Fig. 1).

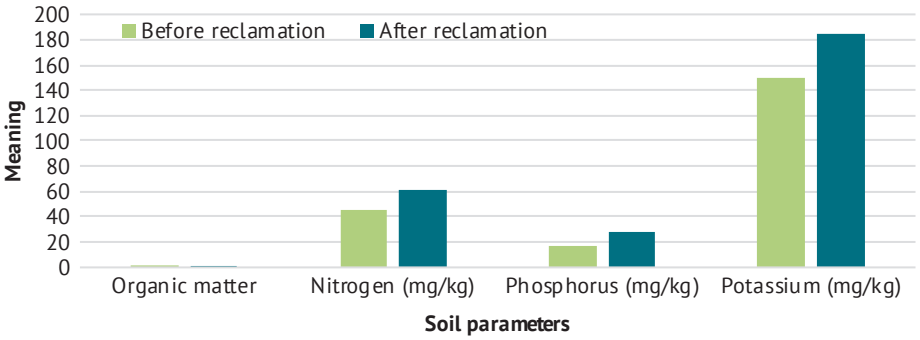

***Figure 1**. Changes in organic matter and nutrient content*
***Source:** developed by the authors*

The increase in the content of organic matter and nutrient elements had a complex positive impact on the ecological sustainability and productivity of the studied soils. These changes made the soil more resistant to degradation processes, such as compaction and erosion, and improved its ability to withstand external stresses, including intensive irrigation and mechanical cultivation.

Changes in the number of soil microorganisms and their impact on soil parameters

Before reclamation, the number of microorganisms was at low level – on average 2.5-3 thousand/g of soil. This limited the processes of organic matter mineralisation and worsened biological productivity of soil. The reason for low activity was both insufficient moisture and availability of organic matter and compacted soil structure, which prevented oxygen access. After a set of reclamation measures, including deep loosening, application of organic fertilizers and improvement of water regime, the number of microorganisms increased by 25-30%, reaching 3.8-4.2 thousand /g of soil. This increase was attributed to improved conditions for microbial activity, including higher moisture levels, increased organic matter content and improved gas exchange in the soil.

The restoration of soil biological activity was also manifested in the acceleration of organic matter decomposition processes. Increased microbial populations contributed to more efficient mineralisation, making nutrients such as nitrogen, phosphorus, and potassium available to plants. This in turn contributed to higher yields of wheat and maize. The increase in soil biological activity also had a positive effect on its resistance to degradation processes. The increase in the number of microorganisms favoured the formation of water-stable aggregates, which increased the structural stability of the soil. This reduced the risk of compaction and erosion, especially under conditions of intensive irrigation (Table 3).

***Table 3**. Changes in the number of soil microorganisms and their impact on soil parameters*

Parameter	Before reclamation	After reclamation	Change (%)
Number of microorganisms (thousand/g)	2.5-3	3.8-4.2	+25-30
Rate of organic decomposition (%)	50-55	65-70	+20-25
Humus content (%)	1.2-1.4	1.6-1.8	+15-20
Nitrogen availability (mg/kg)	45-50	60-65	+25-30
Soil structure stability (%)	30-35	50-55	+40-50

***Source:** developed by the authors*

The restoration of biological activity played a key role in maintaining ecological balance. Microorganisms, decomposing organic matter, not only provided plants with nutrients, but also contributed to the accumulation of humus, which improved the physical and chemical properties of the soil. The increase in the number of microorganisms confirmed the effectiveness of reclamation measures in increasing the natural fertility of grey soils.

Distribution of yield before and after melioration

The results of the research showed that complex reclamation significantly increased the yield of wheat and maize on the studied plots. Before reclamation measures, grain yields were 25-30 kg/ha, which was below the average level for irrigated farming conditions in Zhambyl oblast. The main limiting factors were compacted soil structure, low water permeability, weak biological activity and lack of available nutrients. After reclamation measures, yields increased to 35-40 kg/ha, which corresponded to an increase of 15-20%. Such increase was explained by improvement of water regime, chemical and biological properties of soil. Due to the decrease in soil density and increase in its porosity, the access of plant roots to water and air improved. In addition, the increased content of organic matter and available nutrients provided plants with everything they needed for active growth and yield formation. The even distribution of moisture throughout the soil profile helped to minimise the risk of drought, which is particularly important in a hot climate region. Increased water permeability and reduced surface run-off helped to reduce water and nutrient losses, providing plants with optimal nutritional conditions throughout the growing season. This played a key role in increasing yields.

An additional factor in yield growth was the activation of soil microflora. The increase in the number of microorganisms improved the decomposition of organic matter, accelerated the transformation of nutrients into available forms and contributed to the accumulation of humus. All this created more favourable conditions for root system growth and efficient resource assimilation (Fig. 2).

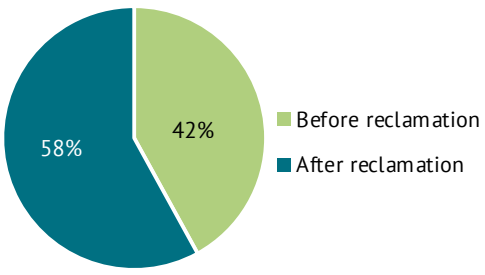

***Figure 2**. Yield distribution before and after reclamation*
***Source:** developed by the authors*

As a result of reclamation measures, the efficiency of crop cultivation has also increased. The increase in crop yields led to an increase in the profitability of agricultural production, while the reduction of fertilizer and irrigation costs due to improved soil properties allowed optimizing costs. These results confirmed the feasibility and efficiency of application of integrated land reclamation to increase the productivity of irrigated lands.

DISCUSSION

The results of the study showed that complex ameliorative measures effectively improve physical, chemical and biological properties of compacted grey soils of Zhambyl oblast. Reduction of soil density by 15-20% after deep loosening was accompanied by a significant increase in water permeability, which increased by 300-400%. These changes ensured improvement of soil water regime, promoted uniform distribution of moisture in the root layer and reduced erosion risks. The application of organic fertilizers increased the humus content of the soil by 15-20%, which had a positive effect on its fertility. Organic matter improved soil structure, increased its water-holding capacity and provided nutrients necessary for plant growth. The biological activity of the soil also increased, as evidenced by a 25-30% increase in the number of microorganisms. This indicates the activation of microbiological processes that play an important role in decomposition of organic matter and increasing the availability of nutrient elements (Kravchuk *et al.*, 2024).

Studies by C. Kimani (2021) and L.M. Giuliani *et al.* (2024) emphasise the need for an integrated approach to address soil degradation caused by intensive land use and anthropogenic factors. C. Kimani notes that increasing population density leads to increased pressure on soil resources, which contributes to their compaction, loss of organic matter and reduction of overall productivity. This creates additional difficulties for land rehabilitation, especially under intensive farming conditions. L.M. Giuliani *et al.* point out the importance of introducing systematic monitoring of soil conditions. The authors argue that regular monitoring of key characteristics such as density, humus content and water permeability allows timely identification of degradation zones and the development of effective restoration strategies. This study similarly demonstrates that reducing soil density and improving its water regime play a crucial role in restoring fertility. The use of reclamation measures such as deep loosening and organic enrichment significantly improved soil physicochemical properties.

The works of T.S. Telles *et al.* (2022), and D.C. Reicosky and A. Kassam (2021) highlight conservation agriculture as a key approach to the restoration of degraded soils. T.S. Telles *et al.* emphasise that minimum tillage and conservation of crop residues improve soil structure, reduce erosion and increase resilience. D.C. Reicosky and A. Kassam highlight maintaining carbon balance in the soil to improve its chemical properties and reduce carbon dioxide emissions. These

approaches focus on maintaining the natural balance of the soil and minimizing its mechanical impact. The present study also demonstrated the importance of soil organic enrichment, but the approach taken was more comprehensive. The use of deep loosening has significantly improved the physical characteristics of the soil, including its porosity and water-holding capacity. This is particularly important in the arid climate of Zhambyl Oblast, where soils are prone to compaction and moisture loss. In contrast to methods based on minimum tillage, in this study it was shown that deep loosening in combination with organic fertilizers creates favourable conditions for soil regeneration.

A. Rivera *et al.* (2023) and R.G. César *et al.* (2021) emphasise the influence of the surrounding landscape and soil chemistry management on soil recovery. A. Rivera *et al.* point out the application of microfertilizers to improve soil chemical properties and productivity. R.G. César *et al.* emphasise the role of vegetation cover and landscape context in maintaining soil resilience and preventing erosion, noting that the use of natural mechanisms contributes to long-term land restoration. This study shows that water management, including drip irrigation, promotes even distribution of moisture, which improves its availability to the plant root system and prevents surface run-off. In contrast to the above studies, the main focus is on internal soil changes, such as reduction of density and improvement of structure, which creates favourable conditions for microbiological activity. The activation of microbial communities helps to accelerate the decomposition of organic matter and increase the availability of nutrient elements for plants (Onopriienko *et al.*, 2023). This approach makes the proposed measures not only effective, but also adapted to the conditions of intensive agricultural use, especially in regions with arid climate.

In the studies of A. Kırcı and F. Türkmen (2023) and J.C. Nwite (2021), the authors emphasise on changes in land use and their effects on soil physical and chemical properties. A. Kırcı and F. Türkmen point out that long-term land use without considering erosion factors leads to loss of organic carbon and deterioration of soil structure. The authors point out that soil restoration is possible by improving organic matter management and erosion control. J.C. Nwite, on the other hand, focuses on the importance of nutrient replenishment through fertilizer application to improve soil fertility and productivity. In this study, as in these studies, it is demonstrated that the application of organic fertilizers improves soil chemical properties. However, unlike these studies, here we additionally consider the impact of reclamation measures on soil physical characteristics, including reducing density and increasing water retention capacity, which makes the approach more comprehensive and effective for intensive agriculture.

In the works of S. Lieder and C. Schröter-Schlaack (2021), and M. Jafari *et al.* (2022), the authors discuss modern approaches to soil management, including the use of technology and vegetation to restore soil properties. S. Lieder and C. Schröter-Schlaack highlight smart farming as a tool to improve soil management accuracy, minimise water loss and improve soil productivity. M. Jafari *et al.* emphasise the role of vegetation cover in preventing erosion and restoring degraded land. In this study, the use of drip irrigation has effectively managed the water regime by providing uniform moisture distribution. However, the difference lies in the study of internal soil changes, such as activation of biological processes and improvement of its structure, which makes the proposed measures more adapted to the conditions of arid climate and intensive land use.

Studies by Y. Ulko (2022) and S. Laiskhanov *et al.* (2023) focus on approaches to fertility restoration and land reclamation. Y. Ulko emphasises that innovative agro-ameliorative approaches, including soil structure improvement and soil fertility management, play an important role in improving the productivity of agricultural land. S. Laiskhanov *et al.* consider the rehabilitation of abandoned land through ecological and reclamation measures, emphasizing the importance of improving organic matter content. This study similarly finds that a combination of deep loosening and organic fertilizer application contributes to the restoration of soil structure. However, additional attention is paid to improving water regime and biological activity, which makes the proposed measures more universal and adapted for use in the conditions of Zhambyl oblast.

In the studies of S. Kaldybaev *et al.* (2022) and Z. Mazhitova *et al.* (2022), the authors emphasise the need for adaptive approaches to land reclamation in Central Asia and Kazakhstan, taking into account the ecological conditions of the region. S. Kaldybaev *et al.* focus on landscape solutions, such as regulating water flows and minimizing erosion, to rehabilitate degraded lands. Z. Mazhitova *et al.* analyse the environmental impacts of virgin and fallow land development, including soil degradation caused by intensive farming. Both studies agree that restoration of soil structure and chemical composition is the basis for sustainable land use. This study supports these conclusions by demonstrating that reclamation measures, including deep loosening and application of organic fertilizers, effectively restore soil structure, improve its water-holding capacity and reduce erosion risks. However, the difference is that this study additionally considers biological aspects, including the activation of microbial communities, making the approach more comprehensive and versatile. S. Kaldybaev *et al.* also draw attention to the importance of water management to prevent overuse. This aspect echoes the results of this study, where the use of drip irrigation reduced surface run-off and ensured uniform moisture distribution, contributing to the restoration of the soil water regime.

In studies by P. Smith *et al.* (2024) and F.B. Baloch *et al.* (2024), the authors examined the influence of soil characteristics on the sustainability of agricultural ecosystems. P. Smith *et al.* emphasised the global state of soils, stressing the importance of maintaining soil structure and fertility to prevent degradation. At the same time, F.B. Baloch *et al.* analysed the effects of volatile organic compounds produced by rhizobacteria on plant nutrition and soil health. Both studies confirmed that active management of soil properties significantly increased its productivity and tolerance to stress conditions. This study similarly demonstrated that reclamation improved the physical and chemical characteristics of the soil, but additional attention was paid to its biological activity, including microbial abundance and its role in organic matter decomposition.

New approaches to the study of soil stability were presented in the works of G. Ntsomboh-Ntsefong *et al.* (2024), Z. Haj-Amor *et al.* (2022) and W.-P. Zhang *et al.* (2024). G. Ntsomboh-Ntsefong *et al.* considered innovative technologies to improve soil productivity, including conservation agriculture and biofertilizers. Z. Haj-Amor *et al.* analysed the effect of salinity on microbial communities and yields, proving that high salt concentration impaired soil regeneration capacity. W.-P. Zhang *et al.* studied agronomic systems with different rooting strategies, confirming that integrated practices increased water-holding capacity and improved soil physical structure. This study supported the findings of these works, demonstrating the significant effect of reclamation on improving soil properties. However, the main difference was the combination of mechanical loosening with biological enrichment of soil with organic fertilizers, which provided sustainable results under arid climate conditions. In contrast to W.-P. Zhang *et al.*, not only the influence of agronomic strategies, but also the dynamics of soil microorganisms involved in organic matter decomposition were studied here.

Thus, these studies support the need for an integrated approach combining landscape, chemical and biological measures to restore degraded land. However, the methods proposed in this study stand out for their application and effectiveness in arid climate conditions.

CONCLUSIONS

The study was aimed at development and justification of effective reclamation measures to improve the condition of compacted grey soils of irrigated lands in Zhambyl oblast. An integrated approach including physical, chemical and biological methods of soil rehabilitation allowed studying in detail the impact of reclamation measures on its key properties. The main focus was on reducing soil density, improving its water regime, increasing the content of organic matter and activating biological processes.

The results of the experiment showed that the use of deep loosening reduced soil density by 15-20%, which improved its porosity and promoted better air and water penetration. Soil water permeability increased by 300-400%, which was the basis for uniform moisture distribution in the soil profile. This minimised water losses through surface run-off by 60-70%, which is particularly important for erosion prevention and nutrient conservation. The application of organic fertilizers provided a significant increase in humus content by 15-20%, which improved the chemical composition of the soil. The increase in organic matter improved its water-holding capacity and the availability of key nutrients such as nitrogen, phosphorus, and potassium. These changes were directly reflected in improved conditions for plant growth and productivity. Special attention in the study was paid to the biological activity of the soil. The analysis showed that the number of microorganisms increased by 25-30%, which indicates the activation of microbiological processes. This improved decomposition of organic matter and increased availability of nutrient elements for plants, which plays a key role in restoration of soil fertility. Application of the proposed ameliorative measures contributed to an increase in wheat and maize yields by 15-20%. This confirms that an integrated approach including deep loosening, organic enrichment and water regime management is an effective method to restore degraded soils.

Thus, the conducted study has demonstrated that integrated reclamation measures allow not only to improve physical and chemical properties of soil, but also to activate its biological processes. These methods can be recommended for wide application in arid regions, where rehabilitation of degraded lands is critical for sustainable agricultural production. Prospects for further research include long-term monitoring of changes in soil characteristics under the influence of reclamation measures, as well as the study of optimal dosages and types of organic fertilizers. Additionally, it is necessary to assess the impact of land reclamation on soil microbiological community and its relationship with yield in long-term dynamics.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Обґрунтування впливу комплексної меліорації на родючість ущільнених сіроземних ґрунтів зрошуваних земель Жамбилської області

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Анотація. Метою дослідження була розробка ефективних методів поліпшення фізичних, хімічних і біологічних властивостей ґрунту для підвищення його продуктивності та стійкості до деградації в умовах інтенсивного сільськогосподарського використання. У статті представлено дослідження впливу комплексних меліоративних заходів на відновлення ущільнених сероземів в умовах зрошуваних земель Жамбилської області. Експериментальна частина включала застосування глибокого розпушування та внесення органічних добрив, а також управління водним режимом з використанням крапельного зрошення. Результати дослідження засвідчили, що меліоративні заходи дали змогу знизити щільність ґрунту на 15-20 %, що забезпечило поліпшення його структури та збільшення водопроникності на 300-400 %. Це створило умови для більш рівномірного розподілу вологи в кореневмісному шарі, що мінімізувало поверхневий стік на 60-70 % і запобігло втратам поживних речовин. Внесення органічних добрив сприяло збільшенню вмісту гумусу на 15-20 %, що поліпшило хімічний склад ґрунту та підвищило його здатність утримувати поживні елементи. Особливу увагу приділено біологічній активності ґрунту, яка зросла на 25-30 % за рахунок активізації мікробних спільнот. Ці зміни покращили процеси розкладання органічної речовини та підвищили доступність азоту, фосфору і калію для рослин. У результаті застосування комплексних заходів спостерігалося збільшення врожайності пшениці та кукурудзи на 15-20 %, що підтвердило ефективність запропонованих підходів. Зроблені висновки демонструють, що використання глибокого розпушування, органічного удобрення та краплинного зрошення в комплексі є ефективним методом відновлення деградованих сероземів. Результати дослідження мають значущу практичну цінність і можуть бути рекомендовані для впровадження в сільськогосподарське виробництво в посушливих регіонах

Ключові слова: меліорація; зрошення земель; родючість ґрунтів; урожайність культур; глибоке розпушування; екологічні технології; сільськогосподарська продуктивність; водопроникність