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Optimising Techniques and Technologies for Cultivating Sweet Clover and its Mixture with Sudan Grass in the Aral Sea Region of Kazakhstan

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Abstract

The aim of this study was to substantiate the effectiveness of using biopreparations to increase the productivity of sweet clover, Sudan grass, and their mixture, improve forage quality, and restore soil fertility under the arid climate conditions of the Kazakhstan Aral Sea region, as well as to determine their impact on key agroecosystem processes. This research examined the effects of the biopreparations "Fitobacirin", "Plantobacirin", and "Azotobacterin" on growth characteristics, yield, forage quality, and soil condition in sweet clover, Sudan grass, and their mixture. The experiment comprised four treatments: a control (without biopreparation treatment) and three experimental treatments with the application of biopreparations. Indicators assessed included plant height, crop productivity, protein content, fibre, mobile phosphorus and potassium levels, as well as soil microbial activity. The results showed that biopreparation treatments significantly enhanced crop growth and productivity. The greatest yield increase was observed with "Plantobacirin", which also led to a marked improvement in plant phosphorus nutrition. Biopreparations further increased protein content and metabolisable energy in the forage while reducing fibre content, indicating improved nutritional quality. The mixture of sweet clover and Sudan grass demonstrated a synergistic effect, resulting in higher productivity and enhanced forage quality compared to monocultures. Additionally, soil condition improved following the application of biopreparations: levels of organic matter, mobile phosphorus, and potassium increased,

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and biological soil activity was stimulated, as evidenced by higher dehydrogenase activity. This suggests restoration of soil fertility and activation of biological processes. The findings of this study confirm the effectiveness of biopreparations in boosting yields, improving forage quality, and enhancing soil health in arid environments. The results may be applied in the development of sustainable agricultural technologies aimed at increasing productivity and restoring agroecosystems in the Aral Sea region of Kazakhstan.

Keywords:
Biostimulants, soil microflora, biological activity, forage base, plant productivity.

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Introduction

Modern agriculture faces numerous challenges caused by climate change, soil degradation, and declining soil fertility. This is particularly true for arid regions such as the Aral Sea region of Kazakhstan, where limited water resources and low nutrient content in the soil render traditional crop cultivation methods ineffective. Under these conditions, the search for innovative agricultural technologies aimed at enhancing crop resilience and restoring soil fertility becomes critically important. The relevance of this study lies in the urgent need to develop environmentally friendly and efficient methods for cultivating agricultural crops in arid regions, where water scarcity and poor soil fertility are the main factors limiting agricultural productivity. The Aral Sea region of Kazakhstan, as a region characterised by extreme climatic conditions and depleted soils, is in urgent need of innovative technologies that can not only ensure stable crop yields but also contribute to the restoration of soil fertility. One promising solution to this problem is the use of biopreparations based on beneficial microorganisms, such as nitrogen-fixing and phosphate-mobilising bacteria, which can improve plant nutrition, activate soil biological processes, and reduce dependence on chemical fertilisers.

The findings of this study have broad applicability to other parts of the world facing similar arid conditions, such as regions in the Middle East, Africa, and parts of Australia. The use of biopreparations can significantly improve soil fertility, enhance crop productivity, and restore degraded soils in these areas. This approach offers a sustainable alternative to conventional farming methods by reducing reliance on chemical fertilisers and promoting biological processes that improve soil health and resilience. In regions with water scarcity and nutrient-deficient soils, such techniques may foster the restoration of agricultural productivity while mitigating the environmental impacts of traditional farming

The problem addressed in this study is the need to solve a complex set of agronomic and environmental challenges typical of arid regions, such as the Aral Sea region of Kazakhstan. The primary issue relates to moisture deficiency and nutrient-poor soils, which lead to low productivity of agricultural crops and deterioration in the quality of the forage base. Traditional cultivation methods that rely on mineral fertilisers are ineffective under drought conditions and often exacerbate soil degradation, resulting in reduced biological activity and declining fertility.

At the same time, although the use of drought-resistant crops such as sweet clover and Sudan grass is a recognised approach, these crops do not always achieve their full productive potential without the application of additional growth stimulants. Moreover, the complex effects of biopreparations on plant growth, yield, and forage quality, as well as their role in restoring soil fertility, remain insufficiently explored.

The relevance of using biopreparations and optimising agricultural technologies for improving the productivity of forage crops in arid regions is confirmed by the findings of several researchers. For instance, Zh.Sh. Zhumadilova et al. (2023), in their analysis of the growth and development of grass mixtures during pasture restoration, demonstrated that biological preparations significantly stimulate plant growth and enhance their adaptation to stressful environmental conditions.

In the study by Y. Dawuti et al. (2024), which examines the effect of fermented juices and the addition of Sudan grass on the quality of alfalfa silage, it was concluded that such technologies significantly enhance the nutritional value of forages and improve their consistency. Similarly, the research conducted by A. Shayakhmetova et al. (2023) on agricultural technologies for the establishment of pastures and hayfields in the steppe zone of Northern Kazakhstan highlights the importance of adapting crops to climatic challenges and implementing innovative solutions for sustainable forage production.

As V.M. Kindomihou (2020) notes, in his analysis of key achievements in the study of grasses and herbaceous ecosystems, grass mixtures such as sweet clover and Sudan grass play a crucial role in forming stable and productive forage resources, particularly in arid regions.

In addition, Q. Yu et al. (2023), in their study of the impact of mowing stages and various additives on the quality of Sudan grass silage, confirmed that the timely application of stimulants and the optimisation of harvesting periods directly influence the final quality of the forage.

Furthermore, M. Balehegn et al. (2022), in a review of forage conservation practices in sub-Saharan Africa, emphasise that the introduction of innovative technologies can minimise nutrient losses and ensure high-quality forage even under limited resource conditions. These findings are supported by the research of A. Marroquin (2022), who points out that heat-tolerant cereal grasses, including Sudan grass, have significant potential for enhancing the forage base in drought-affected areas.

As highlighted in the work of A. Shayakhmetova et al. (2024), optimising the productivity of forage crops through the introduction of green conveyor systems is an effective strategy for adapting agroecosystems to climatic instability, particularly in Northern Kazakhstan. Comparable results were obtained by A. Nogayev et al. (2022), who demonstrated that cultivating forage crops under steppe conditions can enhance their nutritional value and support livestock production, particularly in dairy farming.

Recent research underscores the importance of bio-stimulants and advanced optimisation techniques for enhancing sustainable crop production under abiotic stress. Bio-stimulants such as microbial and seaweed-derived formulations have been shown to improve plant growth, nutrient uptake, stress tolerance, and overall yield across diverse crop species by modulating physiological and metabolic processes in plants (Bahran et al., 2024). Response Surface Methodology (RSM) has been widely recognised as a robust statistical tool for optimising biostimulant effects and other agronomic inputs by identifying optimal combinations of variables that maximise desirable responses, including nutrient use efficiency and crop performance (Ben Slimene Debez et al., 2024).

Moreover, as S. Kumar et al. (2023) argue, in their analysis of the potential of genetic and technological approaches to improving the forage base, the optimisation of agricultural practices through the use of biopreparations remains a key avenue for increasing the productivity of forage crops.

Thus, the works of the aforementioned authors emphasise the necessity of developing sustainable methods for cultivating forage crops and applying biological preparations under arid conditions. However, a comprehensive study of the effects of biological preparations on the growth, productivity, and forage quality of sweet clover and Sudan grass, as well as their impact on soil condition in the Kazakhstani Aral Sea region, remains insufficiently explored and requires further scientific substantiation. The purpose of this study is to investigate the effects of biological preparations “Fitobacirin”, “Plantobacirin”, and “AFG” on the growth, productivity, and forage quality of sweet clover, Sudan grass, and their mixture under the conditions of the Kazakhstani Aral Sea region, with the aim of developing environmentally friendly agricultural technologies. The objectives of the study include: analysing the effects of biological preparations on plant growth and yield formation; examining changes in the chemical composition of forages; assessing improvements in soil characteristics during the cultivation of sweet clover, Sudan grass, and their mixture.

Materials and Methods

The study was conducted in 2024 (March–September) at the Karauyltyubinsk Experimental Production Farm of the Kazakh Scientific Research Institute of Rice Cultivation named after Ibray Zhakhaev. The climate of the region is characterised by sharply continental conditions, with hot, dry summers, where daytime air temperatures range between +22–30 °C and night-time temperatures between +15-18 °C, as well as short springs and winters with minimal snowfall. The average annual precipitation is 120-150 mm, with the majority falling in spring, which necessitates the use of moisture conservation techniques when cultivating crops. The soils of the experimental site are grey soils with a low humus content (0.8-1.3%) and limited supplies of mobile nitrogen, phosphorus, and potassium. Prior to the experiment, soil samples were analysed, confirming neutral pH (6.8-7) and a low level of biological activity.

The objects of the study were sweet clover (*Melilotus*), Sudan grass (*Sorghum sudanense*), and their mixture (sweet clover + Sudan grass). Sweet clover was selected as a highly adaptive leguminous crop capable of fixing atmospheric nitrogen through symbiosis with *Rhizobium* bacteria, which makes it valuable for improving the nitrogen balance in soils. Sudan grass, a cereal crop, was chosen for its drought resistance and its capacity to accumulate significant biomass even on nutrient-poor soils. The mixture of sweet clover and Sudan grass was included to evaluate the synergistic effects of their joint

cultivation, particularly regarding productivity, forage quality, and improvements in soil properties.
The experiment included four main variants: a control (without the use of biopreparations) and treatments with the biopreparations "Fitobacirin", "Plantobacirin", and "AFG". The experiment was conducted in three replications for each crop: sweet clover, Sudan grass, and their mixture. Sowing was carried out in March, following optimal seeding rates: for sweet clover – 25 kg/ha, for Sudan grass – 15 kg/ha, and for the mixture – 20 kg/ha. Biopreparations were applied separately to each crop and their mixture using two methods: pre-sowing seed treatment and foliar spraying. For pre-sowing seed treatment, a working solution at a concentration of 100-150 ml per 1 kg of seeds was used uniformly across all treatment options. Spraying was performed during the early active growth phase at an application rate of 5-6 L/ha.
"Fitobacirin" acts as a plant growth stimulant and synthesises biologically active substances, providing partial breakdown of cellulose and dense seed coats, and improves nitrogen nutrition in plants. "Plantobacirin", based on phosphate-mobilising bacteria (*Bacillus megaterium*), enhances phosphorus availability from poorly soluble soil compounds "AFG" contains *Azotobacter* species, which fix atmospheric nitrogen and stimulate plant growth processes. Control plots were left untreated with biopreparations and served as a baseline for comparison with the experimental treatments.
The effectiveness of biopreparations was assessed based on plant growth characteristics, crop productivity, forage quality, and soil condition.
Growth characteristics were evaluated by measuring plant height every 30 days throughout the growing season (June-August). In each plot, measurements were taken from 20 randomly selected plants, after which the average value for each variant was calculated.
Crop productivity was determined by measuring the yield of air-dry plant mass at the full ripening stage. Biomass was collected manually from the experimental plots, and the yield was recalculated in t/ha to facilitate comparison between treatment variants.
Forage quality was assessed through chemical analysis of samples taken from each plot. The analysis included the determination of crude protein, fibre, mobile phosphorus, potassium, and metabolisable energy content. Measurements were performed using infrared spectroscopy with an FT-NIR device, ensuring high analytical accuracy.
Soil condition was evaluated at the end of the growing season. The assessment included key fertility indicators, such as organic matter content, total nitrogen, mobile phosphorus, and exchangeable potassium. Biological activity of the soil was determined by measuring dehydrogenase activity, which reflects the intensity of microbiological processes in the soil.
The data obtained were processed using analysis of variance (ANOVA) in the Statistica 12 software package. Statistical analysis enabled the identification of significant differences between control and experimental variants, and provided an evaluation of the effectiveness of biopreparations for each crop and their mixture. The results are presented as mean values with standard errors.

Results

Effect of Biopreparations on Growth Characteristics of Sweet Clover and Sudan Grass
In the control plots, where biopreparations were not applied, plant growth indicators were significantly lower compared to the treated plots. By the end of June, sweet clover in the control plots reached a height of 59 cm, Sudan grass – 170 cm, and the mixture of these crops – 175 cm. The first mowing was carried out on 25 June 2024.
The use of "Fitobacirin" demonstrated a positive effect on all studied crops. Sweet clover treated with this preparation reached 61.2 cm by the end of June, which is 10.4% higher than the control value. Sudan grass, treated with "Plantobacirin", exhibited an even more pronounced growth response: by the end of June, prior to the second cutting, its height reached 222 cm. The mixture of sweet clover and Sudan grass, treated with the same preparations, also showed significant results, with a plant height of 235 cm. In addition, treated plants demonstrated better resistance to the dry conditions of July. Sweet clover treated with Fitobacirin and Sudan grass treated with Plantobacirin maintained a high growth rate, continuing to accumulate biomass even under stress conditions. These results confirm that improved phosphorus absorption promotes the activation of plant metabolic processes, which in turn ensures more intensive growth, higher yields, and improved biomass quality characteristics (Tables 1, 2).

Table 1. Dynamics of growth of forage crops using biopreparations (sweet clover, average values), cm

Experience options	Plant height by interphase period of development					
	Before the 1st mowing				Before the 2nd mowing	
	3-4 leaves	6-7 leaves	Beginning of branching	Branching	Regrowth	Branching
Without treatment (control)	7.6	14.6	32.4	59	14.2	64.9
Treatment with the biopreparation "Fitobatsirin"	8.6	19.2	36.9	61.2	14.8	70.8

Table 2. Dynamics of growth of forage crops using biopreparations (Sudan grass, average values), cm

Experience options	Plant height by interphase period of development	
	Tillering	Earing
Without treatment (control)	27.4	170
Treatment with the biopreparation "Plantobatsirin"	30.8	222

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Data analysis showed that mixtures of sweet clover and Sudan grass responded more effectively to the application of biopreparations than monocultures. This effect is attributed to the synergistic interaction between the crops, whereby Sudan grass more efficiently utilised the improved growth conditions created by the biopreparation treatments.

Changes in crop productivity under different biopreparation treatment schemes

As a result of the study, it was found that the application of biopreparations "Fitobacirin", "Plantobacirin", and "AFG" led to a significant increase in the productivity of sweet clover, Sudan grass, and their mixture (sweet clover + Sudan grass) under the conditions of the Kazakh Aral Sea region. Experimental data collected during the summer months indicate that treatment with biopreparations had a complex and beneficial effect on the growth and productivity of crops, contributing to an increase in green biomass, overall yield, and nutrient content. Biometric analyses, carried out for sweet clover, Sudan grass, and their mixture, allowed for an assessment of crop accumulation dynamics depending on the type of crop and the biopreparation used.

Control plots, where no biopreparations were applied, demonstrated significantly lower productivity levels. The yield of sweet clover was 12.7 t/ha, Sudan grass – 27 t/ha, and the mixture of sweet clover and Sudan grass – 47.1 t/ha. These results served as baseline values for evaluating the effectiveness of the different treatment schemes.

The use of "Fitobacirin" resulted in an increase in sweet clover yield to 15.1 t/ha, which is 12% higher than the control. Sudan grass, treated with "Plantobacirin" in July, demonstrated a yield increase of 11.7%, reaching 31.5 t/ha. The mixture of sweet clover and Sudan grass also showed a significant improvement in productivity, achieving 56 t/ha, which is 12% higher than the control. This increase in productivity can be attributed to enhanced root nutrition and an expanded photosynthetically active surface area, particularly during the active growth period documented for each crop.

Although "AFG" also had a positive effect on crop productivity, its efficiency was slightly lower compared to "Plantobacirin". The yield of sweet clover with "AFG" treatment reached 13 t/ha, Sudan grass – 28 t/ha, and the mixture of sweet clover and Sudan grass – 47.9 t/ha (representing a 27% increase compared to the control) (Table 3). These findings are supported by data on the improvement of the nitrogen balance in the soil, which is particularly critical during the key months of crop formation (Jnawali et al., 2015).

Table 3. Changes in crop productivity (t/ha) under different treatment schemes with biopreparations

Culture	Biopreparation	Yield (t/ha)
Sweet clover	Control	12.7
Sweet clover	Fitobatsirin	15.1
Sweet clover	AFG	13
Sudan grass	Control	27
Sudan grass	Plantobacirin	31.5
Sudan grass	AFG	28
Mixture (Sweet clover + Sudan grass)	Control	47.1
Mixture (Sweet clover + Sudan grass)	Fitobacirin + plantobacirin	56
Mixture (Sweet clover + Sudan grass)	AFG	47.9

The application of biopreparations also influenced the nutrient composition of the crops. Specifically, treatment with biopreparations resulted in an increase in crude protein content by 15% in sweet clover, 12% in Sudan grass, and 14% in the crop mixture.

Effect of Biopreparations on the Quality of Obtained Feed

During the study, a comprehensive assessment of the quality of feed obtained from sweet clover, Sudan grass, and their mixture (sweet clover + Sudan grass) was carried out under various schemes of treatment with biopreparations. The analysis showed that the use of biopreparations “Fitobatsirin”, “Plantobatsirin”, and “AFG” significantly improved the nutritional properties of the crops by increasing the content of protein, exchange energy, phosphorus, and potassium, as well as reducing the level of fibre.

Control plots, where biopreparations were not used, demonstrated basic indicators. The content of crude protein in sweet clover was 14.3%, in Sudan grass – 9.5%, and in August, in the mixture of crops – 12.5%. Phosphorus indicators for sweet clover were at the level of 0.21%, for Sudan grass – 0.2%, and for the mixture of crops – 0.2%. The fibre content remained high: 26.8% in sweet clover, 27.5% in Sudan grass, and 28.6% in the mixture. The exchange energy was 9.2 MJ/kg for sweet clover, 9.7 MJ/kg for Sudan grass, and 9.1 MJ/kg for the mixture.

The use of “Fitobatsirin” increased the crude protein content in sweet clover to 18.1%, which was 12.6% higher than the control value. With the use of “Plantobatsirin”, Sudan grass demonstrated an increase in protein content to 10.5%, and the crop mixture reached 14.2%. Phosphorus indicators also improved: for sweet clover, the phosphorus content increased to 0.26%; for Sudan grass, it reached 0.21%; and for the mixture of crops, 0.24%. The fibre content decreased to 23.5% in sweet clover, 25.9% in Sudan grass, and 27.4% in the mixture, which significantly improved feed digestibility. The exchange energy index increased to 9.5 MJ/kg for sweet clover, 10.1 MJ/kg for Sudan grass, and 9.7 MJ/kg for the mixture.

“AFG” also had a positive effect. The protein content in sweet clover reached 16.74%, in Sudan grass – 9.8%, and in the mixture – 12.6%. The phosphorus index was 0.27% for sweet clover, 0.22% for Sudan grass, and 0.25% for the mixture of crops (Table 4). The fibre content decreased to 22.1% in sweet clover, 20.2% in Sudan grass, and 17% in the mixture. The exchange energy was 8.7 MJ/kg for sweet clover, 8 MJ/kg for Sudan grass, and 8.4 MJ/kg for the mixture.

Table 4. Effect of biopreparations on the quality of obtained feed (per 100% dry matter)

Culture	Biopreparation	Crude protein (%)	Fiber (%)	Metabolic energy (MJ/kg)	Phosphorus (%)
Sweet clover	Control	14.3	26.8	9.2	0.21
Sweet clover	Fitobacirin	18.1	23.5	9.5	0.26
Sweet clover	AFG	16.7	22.1	8.7	0.27
Sudan grass	Control	9.5	28.6	9.7	0.2
Sudan grass	Plantobacirin	10.5	23.5	10.1	0.26
Sudan grass	AFG	9.8	22.1	8	0.22

Mixture (Sweet clover + Sudan grass)	Control	12.5	28.6	7.8	0.2
Mixture (Sweet clover + Sudan grass)	Fitobacirin + plantobacirin	14.2	27.4	9.7	0.24

Thus, the effectiveness of biopreparations was most evident in the improvement of feed quality parameters, as confirmed by the presented data.

Effect of Biopreparations on the Condition of the Soil under Sweet Clover, Sudan Grass and their Mixture

In the course of the study, the effect of the biopreparations “Fitobatsirin”, “Plantobatsirin”, and “AFG” on the condition of the soil under sweet clover, Sudan grass, and their mixture (sweet clover + Sudan grass) was studied. In the control plots, where the biopreparations were not used, the organic matter content under sweet clover was 1.8%, under Sudan grass – 1.7%, and under the mixture – 1.75%. The level of total nitrogen remained stable and was 0.12% for all crops. Mobile phosphorus varied from 14 mg/kg under Sudan grass to 15 mg/kg under sweet clover and under the mixture. Exchangeable potassium in all variants was at the level of 120 mg/kg. The biological activity of the soil (dehydrogenase activity) was also minimal: 15.2 µg TPF/g under sweet clover, 14.8 µg TPF/g under Sudan grass, 15 µg TPF/g under the mixture.

The use of “Fitobatsirin" improved soil fertility. In June, the organic matter content under sweet clover increased to 2.1%, under the mixture – to 2.05%. The level of total nitrogen for all crops increased to 0.14%. Mobile phosphorus reached 18 mg/kg in all variants, and exchangeable potassium – 135 mg/kg. The biological activity of the soil also increased: under sweet clover in June, it was 18.4 µg TPF/g, and under the mixture in August – 18.2 µg TPF/g.

“Plantobatsirin” demonstrated the highest efficiency among all biological preparations. In June, the organic matter content under Sudan grass reached 2.2%, and under the mixture – 2.25%. The total nitrogen level reached 0.16% in all cases. Mobile phosphorus under Sudan grass was 21 mg/kg, and in August under the mixture – 22 mg/kg. Potassium in June under Sudan grass was 142 mg/kg, and in August under the mixture – 144 mg/kg. The biological activity of the soil was the highest: 19.8 µg TPF/g under Sudan grass in July and 20 µg TPF/g under the mixture in August.

The use of “AFG” also had a significant positive effect on soil parameters (Table 5). In June, the organic matter content under sweet clover was 2.2%, in July under Sudan grass – 2.1%, and in August under the mixture – 2.15%. The total nitrogen level increased to 0.15% in all cases. Mobile phosphorus reached 20 mg/kg, and exchangeable potassium – 140 mg/kg for all crops. The biological activity of the soil increased to 19 µg TPF/g under sweet clover in June, 18.5 µg TPF/g under Sudan grass in July, and 18.7 µg TPF/g under the mixture in August.

Table 5. Effect of biopreparations on the condition of the soil under sweet clover, Sudan grass and their mixture

Culture	**Biopreparation**	**Organic matter (%)**	**Total nitrogen (%)**	**Mobile phosphorus (mg/kg)**	**Exchangeable potassium (mg/kg)**	**Dehydrogenase activity (µg TPF/g/day)**
Sweet clover	Control	1.8	0.12	15	120	15.2
Sweet clover	Phytobacterin	2.1	0.14	18	135	18.4
Sweet clover	AFG	2.2	0.15	20	140	19
Sudan grass	Control	1.7	0.12	14	120	14.8
Sudan grass	Plantobacirin	2.2	0.16	21	142	19.8
Sudan grass	AFG	2.1	0.15	20	140	18.5

Mixture (sweet clover + sudan grass)	Control	1.75	0.12	15	120	15
Mixture (sweet clover + sudan grass)	Fitobacirin + Plantobacirin	2.05	0.14	18	135	18.2
Mixture (sweet clover + sudan grass)	Phosphoenterin	2.25	0.16	22	144	20
Mixture (sweet clover + sudan grass)	AFG	2.15	0.15	20	140	18.7

Thus, taking into account the influence of biological preparations over different months has made it possible to determine their effectiveness in improving soil fertility and biological activity.

The Share of Soil Fertility Improvement Depending on the Biopreparations

The study confirmed that the use of the biopreparations “Fitobatsirin”, “Plantobatsirin”, and “AFG” had a complex positive effect on crop productivity, forage quality, and soil condition, which is consistent with the results of similar studies (Kaur et al., 2024). The productivity of sweet clover, Sudan grass, and their mixture increased by 20-33% compared to the control plots. The quality of forage improved due to an increase in crude protein, phosphorus, and potassium content, as well as higher metabolic energy, which aligns with existing data on the role of biopreparations in optimising plant nutrition (Mahmud et al., 2021; Ramasamy et al., 2020). At the same time, a decrease in fibre content was observed, which enhanced the nutritional value of the forage.

Biopreparations also contributed to a significant improvement in soil condition (Figure 1). The organic matter content increased by 17-28%, while total nitrogen, mobile phosphorus, and exchangeable potassium levels increased by 20-47%, depending on the biopreparation used. The biological activity of the soil, as measured by dehydrogenase activity, rose by 20–30%, indicating an increase in the metabolic activity of soil microorganisms, which corresponds to findings highlighting the impact of biopreparations on soil microbiological activity (Soni et al., 2024).

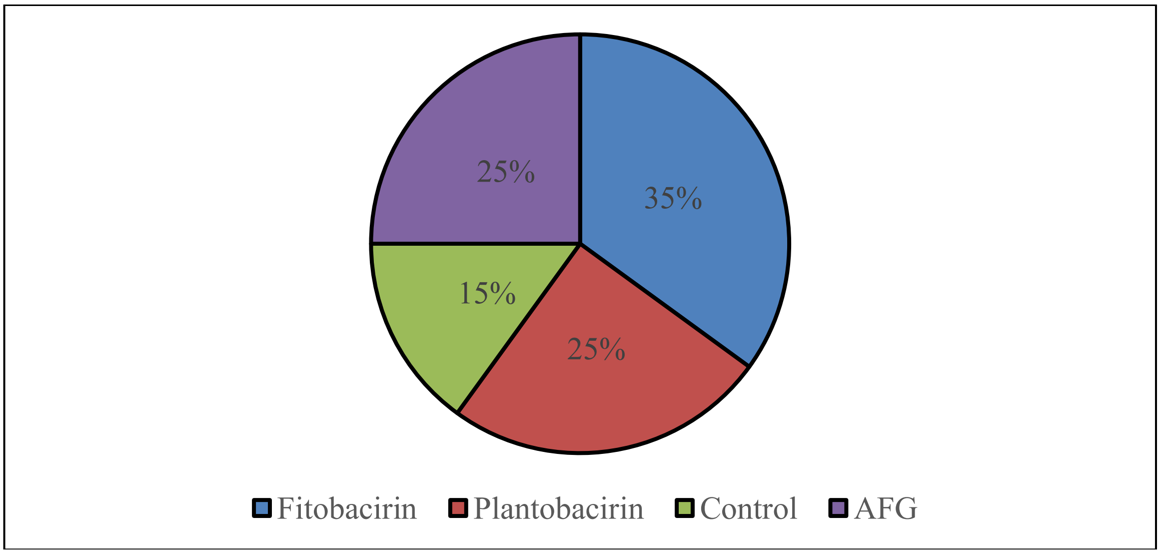

Figure 1. The share of soil fertility improvement depending on biopreparations

The statistical analysis of ANOVA results revealed significant improvements in key indicators following the application of biopreparations. For sweet clover, treatment with “Fitobacirin” resulted in an increase in yield with a p-value of <0.01. Sudan grass treated with Plantobacirin showed an increase with a p-value of <0.01. The mixture of sweet clover and Sudan grass treated with “Fitobacirin” + “Plantobacirin” exhibited a yield increase with a p-value of <0.01. For “AFG” treatment, sweet clover, Sudan grass and the mixture increased with a p-value of <0.05. Additionally, crude protein content in sweet clover, Sudan grass, and the mixture showed significant improvements, with p-values of <0.01 for all treatments, which confirms the effectiveness of biopreparations in enhancing crop yield and quality under arid conditions.

These studies confirm that the use of biopreparations not only increases crop productivity, but also restores soil fertility, which is particularly important in the conditions of the Kazakhstani Aral Sea region. These findings are consistent with previous research demonstrating that biopreparations play a key role in the sustainable development of agriculture (Li et al., 2020). The results obtained indicate high prospects for the integration of biopreparations into the region's agro-technological systems, enabling a simultaneous increase in crop yields and improvement of soil quality. This makes biopreparations a valuable tool for promoting the sustainable development of agriculture in arid conditions.

Moreover, the use of biopreparations has the potential for long-term environmental benefits, particularly in terms of soil health and climate resilience. By improving soil organic matter, enhancing microbial activity, and promoting nutrient cycling, biopreparations contribute to the restoration of soil fertility for sustaining agricultural productivity over time. Eventually, biopreparations can help build climate resilience by enhancing the soil's ability to retain moisture and reduce erosion, making crops more resilient to drought and extreme weather events in long-term perspective.

Discussion

The obtained results demonstrate a significant effect of biopreparations on growth characteristics, productivity, forage quality, and soil condition under sweet clover, Sudan grass, and their mixture in the conditions of the Kazakh Aral Sea region. The use of biopreparations "Fitobatsirin", "Plantobatsirin", and "AFG" confirmed their effectiveness compared to the control plots, where the plants were grown without treatment.

Growth analysis showed that plants treated with biopreparations exceeded the control groups in height and development intensity. This result can be explained by the improved availability of nitrogen and phosphorus for plants, due to the activation of soil microorganisms contained in the biopreparations. Sweet clover, Sudan grass, and their mixture exhibited different responses to treatment, indicating the necessity of selecting specific biopreparations for each crop to maximise their effectiveness.

B. Mukhambetov et al. (2021) focused on studying the effectiveness of soil cultivation methods for pastures in the arid regions of Central Asia and Kazakhstan. The authors concluded that mechanical tillage combined with the use of organic fertilisers contributes to increased pasture fertility and productivity. They emphasised that improved soil structure positively affects nitrogen content and biological activity. In contrast to their approach, this study focused on the use of biopreparations, which enabled comparable improvements in soil fertility without the need for intensive mechanical tillage. At the same time, these results demonstrated a more significant increase in the content of mobile phosphorus, highlighting the advantage of using "Plantobatsirin" in optimising the mineral nutrition of plants.

In the work of I.R. Thomas et al. (2024), the authors studied a sorghum – Sudan grass mixture intercropped with lupine to improve pastures in regions of moderate humidity. They noted a significant increase in pasture productivity and improved feed value due to the interaction between cereals and legumes. Their data on the synergistic effect confirm the results of this study, where a mixture of sweet clover and Sudan grass also demonstrated an increase in yield and nutritional characteristics. However, unlike their work, in which biological products were not applied, this study showed that the use of "Plantobatsirin" and "AFG" allowed for the further activation of biological processes in the soil and increased the protein content of the forage. This highlights the advantage of integrating biological stimulants to enhance the efficiency of agricultural technologies.

M.A. Akber and X. Fang (2024) focused on diseases caused by the soil pathogen *Rhizoctonia solani* in alfalfa cultivation. The authors emphasised that this disease significantly reduces crop productivity, although integrated management strategies, including improving soil conditions and using resistant varieties, can minimise damage. Although their study addresses a different aspect of agriculture, their findings resonate with this research in terms of improving crop resilience to stress conditions. In contrast to their approach, the current study focused on the use of biopreparations to activate biological processes in the soil, thereby increasing the availability of nitrogen and phosphorus. These findings confirm that biopreparations can serve as an effective tool for sustainable agriculture in arid conditions, offering an alternative to more traditional agronomic approaches.

D. Datta et al. (2022) analysed the potential of cover crops in the context of climate change adaptation. The authors concluded that cover crops such as alfalfa and sorghum–Sudan grass mixtures effectively improve soil moisture retention and prevent soil degradation, particularly under drought conditions. Although their approach demonstrated improvements in soil characteristics and increased forage productivity, the present study showed a more significant effect on forage protein content and soil biological activity due to the use of biopreparations. These results suggest that the integration of biopreparations may represent a more effective strategy for agriculture in regions with extreme climatic conditions.

The results of the study by D.S. Ashilenje et al. (2022) examined the adaptive mechanisms of grass crops for saline and arid areas. The authors noted that the selection of suitable grass species and their stress tolerance play a crucial role in improving agroecosystems. Their findings demonstrated that Sudan grass and other drought-resistant crops can significantly increase productivity and positively impact ecosystem services, including reduction of water evaporation and enhancement of carbon fixation. In contrast, the present study showed that biopreparations can amplify these beneficial effects by further enhancing nitrogen and phosphorus nutrition of plants. This, in turn, leads to improved plant growth and an increase in forage quality, demonstrating the added value of using biological preparations alongside stress-tolerant crops in arid ecosystems.

The work of M. Hasnain et al. (2023) focused on the use of halophytes as a sustainable alternative to traditional forage crops in saline soils. The authors noted that halophytes possess a high potential for improving ecosystem services by utilising salt resources; however, their nutritional value remains limited. In contrast, the present study concentrated on optimising forage quality through the application of biopreparations, which significantly increased both the protein content and metabolisable energy of Sudan grass and sweet clover. This highlights that biopreparations may offer a more versatile approach, suitable not only for saline soils but also for dryland and arid environments.

The study by C.B. Naidu et al. (2022) examined the potential of green manure for sustainable agriculture, focusing particularly on its impact on nutrient dynamics and soil microbial activity. The authors demonstrated that green manure contributed to an increase in organic matter content and enhanced microbial activity, although the effect was limited in duration. In comparison, the present study showed that the use of biopreparations, such as AFG, led to sustained improvements in soil biological activity and increases in nitrogen and phosphorus levels, thus offering a longer-term and more versatile solution for arid conditions.

Finally, M. Griffiths et al. (2022) focused on optimising the root systems of cover crops to enhance ecosystem services, including water retention and erosion reduction. The authors emphasised that well-developed root systems are critical for enhancing agroecosystem resilience. By contrast, this study emphasised the activation of soil processes through biopreparations, which not only stimulated root growth but also led to a general increase in soil biological activity. These results highlight that biopreparations can be integrated as a complement to cover crops, thereby enhancing their effectiveness.

Comparison with these studies underscores the advantage of the current approach, which involves using biopreparations to achieve a comprehensive improvement in crop performance, soil health, and forage quality. This allows us to conclude that the use of biopreparations represents a promising direction for sustainable agriculture, particularly in arid and challenging climatic conditions.

Biopreparations offer practical benefits for local farmers by boosting crop yields, improving forage quality, and enhancing soil health, all while reducing reliance on chemical fertilisers. For the agricultural and livestock industries, these treatments ensure higher-quality, more stable yields, supporting sustainable farming practices. Their adoption can also help farmers adapt to arid conditions, improve productivity, and contribute to environmental conservation.

Also, the research of the integration of advanced engineering techniques, such as bioreactors and artificial intelligence (AI) in farming remains extremely promising, as it could further enhance the effectiveness of biopreparations in agricultural systems. Bioreactors, designed to cultivate specific beneficial microorganisms at scale, could enable more efficient production and application of biopreparations, ensuring a consistent and high-quality supply of growth-promoting agents. Additionally, AI-powered systems could monitor and optimise biopreparation applications by analysing soil and crop health in real time, enabling more precise and targeted treatments.

Conclusions

The conducted study made it possible to evaluate the influence of the biopreparations “Fitobatsirin”, “Plantobatsirin”, and “AFG” on growth characteristics, productivity, feed quality, and soil condition under sweet clover, Sudan grass, and their mixture in the arid climate of the Kazakhstan Aral Sea region. The experiment included a detailed assessment of plant growth indicators, air-dry biomass productivity, nutritional value of forage, and soil characteristics in both control plots and plots treated with biopreparations. The biopreparations had a positive effect on all the studied parameters. The use of “Plantobatsirin” produced the greatest effect, ensuring a significant improvement in phosphorus nutrition of the plants, which directly contributed to enhanced growth and productivity. “AFG” demonstrated high efficiency in improving nitrogen nutrition, which is particularly important for sweet clover as a leguminous crop. The mixture of sweet clover and Sudan grass exhibited a synergistic effect, which was expressed in increased productivity and improved feed quality, including an increase in crude protein content and a reduction in fibre levels.

The quality of the obtained forage also improved as a result of biopreparation treatments. Biochemical analysis showed that plant treatment significantly increased the content of metabolisable energy, mobile phosphorus, and potassium, making the forage more nutritious and valuable for livestock production. These data confirm that biopreparations can play a key role in supporting forage production in regions with limited resources.

The condition of the soil under the influence of biopreparations also changed significantly. An increase in organic matter, mobile phosphorus, and exchangeable potassium, along with the activation of biological activity, expressed by an increase in dehydrogenase activity, indicates a restoration of soil fertility. This highlights the environmental importance of using biopreparations, especially in degraded soils typical of arid regions.

Thus, the results of the study confirmed that the application of biopreparations helps optimise agricultural technologies for the cultivation of forage crops in arid conditions. This approach allows not only to increase yields and improve feed quality, but also to restore soil fertility, which is essential for sustainable agriculture. The data obtained can serve as a basis for introducing innovative agricultural technologies in the Aral Sea region of Kazakhstan and other regions with similar climatic conditions. A limitation of the study is its focus on short-term effects of biopreparation use, without assessing their long-term impact on agroecosystems and soil processes. Further research should be directed at examining the long-term effects of biopreparations, their interaction with other agricultural technologies, and expanding their application to other arid areas. Additional studies should focus on testing biopreparations in different soil types and climatic conditions to assess their efficacy in diverse agricultural environments. Moreover, future work should investigate the long-term impacts of biopreparations on soil health, crop yields, and ecosystem sustainability, particularly under prolonged drought conditions. Investigating the combination of biopreparations with other sustainable farming practices, such as crop rotation and agroforestry, could provide valuable insights into optimising agricultural productivity in arid regions while promoting environmental conservation.

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Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that they have no conflict of interest.

References

1. Akber, M.A., & Fang, X. (2024). Research progress on diseases caused by the soil-borne fungal pathogen *Rhizoctonia solani* in Alfalfa. *Agronomy*, *14*(7), 1483. https://doi.org/10.3390/agronomy14071483

2. Ashilenje, D.S., Amombo, E., Hirich, A., Kouisni, L., Devkota, K.P., El Mouttaqi, A., & Nilahyane, A. (2022). Crop species mechanisms and ecosystem services for sustainable forage cropping systems in salt-affected arid regions. *Frontiers in Plant Science*, 13, 899926. https://doi.org/10.3389/fpls.2022.899926

3. Bahran, Y.K., EricksonTchuda, M.L., & Gins, M.S. (2024). Role of bio-stimulants on the advancement of vegetable production: A review. *Agricultural Science and Technology, 16*(4), 3-17. https://doi.org/10.15547/ast.2024.04.035

4. Balehegn, M., Ayantunde, A., Amole, T., Njarui, D., Nkosi, B.D., Müller, F.L., Meeske, R., Tjelele, T.J., Malebana, I.M., Madibela, O.R., Boitumelo, W.S., Lukuyu, B., Weseh, A., Minani, E., & Adesogan, A.T. (2022). Forage conservation in sub-Saharan Africa: Review of experiences, challenges, and opportunities. *Agronomy Journal*, *114*(1), 75-99. https://doi.org/10.1002/agj2.20954

5. Ben Slimene Debez, I., Houmani, H., Mahmoudi, H., Mkadmini, K., Garcia-Caparros, P., Debez, A., Tabbene, O., Djébali, N., & Urdaci, M.-C. (2024). Response Surface Methodology-Based optimization of the chitinolytic activity of *Burkholderia contaminans* Strain 614 exerting biological control against phytopathogenic fungi. *Microorganisms*, *12*(8), 1580. https://doi.org/10.3390/microorganisms12081580

6. Datta, D., Ghosh, S., Saha, R., & Nath, C.P. (2022). Cover crops: Potential and prospects in conservation agriculture. In: R. Saha, D. Barman, M. Behera, G. Kar (Eds)., *Conservation Agriculture and Climate Change* (pp. 167-187). London: CRC Press. https://www.taylorfrancis.com/chapters/edit/10.1201/9781003364665-14/cover-crops-potential-prospects-conservation-agriculture-debarati-datta-sourav-ghosh-saha-nath

7. Dawuti, Y., Kuerban, Z., Cheng, Z., Guo, P., Gao, J., & Yimingniyazi, A. (2024). Enhancing Effect of adding previously fermented juice and Sudan grass on the quality of alfalfa silage. *Fermentation*, *10*(8), 418. https://doi.org/10.3390/fermentation10080418

8. Griffiths, M., Delory, B.M., Jawahir, V., Wong, K.M., Bagnall, G.C., Dowd, T.G., Nusinow, D.A., Miller, A.J., & Topp, C.N. (2022). Optimisation of root traits to provide enhanced ecosystem services in agricultural systems: A focus on cover crops. *Plant, Cell & Environment*, *45*(3), 751-770. https://doi.org/10.1111/pce.14247

9. Hasnain, M., Abideen, Z., Ali, F., Hasanuzzaman, M., & El-Keblawy, A (2023). Potential of halophytes as sustainable fodder production by using saline resources: A review of current knowledge and future directions. *Plants*, *12*(11), 2150. https://doi.org/10.3390/plants12112150

10. Jnawali, A.D., Ojha, R.B., & Marahatta, S. (2015). Role of *Azotobacter* in soil fertility and sustainability – A review. *Advances in Plants & Agriculture Research*, *2*(6), 250-253. https://doi.org/10.15406/apar.2015.02.00069

11. Kaur, H., Mir, R.A., Hussain, S.J., Prasad, B., Kumar, P., Aloo, B.N., Sharma, C.M., & Dubey, R.C. (2024). Prospects of phosphate solubilizing microorganisms in sustainable agriculture. *World Journal of Microbiology and Biotechnology*, *40*(10), 291. https://doi.org/10.1007/s11274-024-04086-9

12. Kindomihou, V.M. (2020). Introductory chapter: Milestones in grasses and grassland research. https://doi.org/10.5772/intechopen.90770

13. Kumar, S., Singh, P., Devi, U., Yathish, K.R., Saujanya, P.L., Kumar, R., & Mahanta, S.K. (2023). An overview of the current fodder scenario and the potential for improving fodder productivity through genetic interventions in India. *Animal Nutrition and Feed Technology*, *23*(3), 631-644. https://doi.org/10.5958/0974-181X.2023.00054.9

14. Li, H., Penttinen, P., Mikkonen, A., Stoddard, F.L., & Lindström, K. (2020). Response of soil bacterial community diversity and composition to time, fertilization, and plant species in a sub-boreal climate. *Frontiers in Microbiology*, 11, 1780. https://doi.org/10.3389/fmicb.2020.01780

15. Mahmud, A.A., Upadhyay, S.K., Srivastava, A.K., & Bhojiya, A.A. (2021). Biofertilizers: A Nexus between soil fertility and crop productivity under abiotic stress. *Current Research in Environmental Sustainability*, 3, 100063. https://doi.org/10.1016/j.crsust.2021.100063

16. Marroquin, A. (2022). Assessing warm-season annual grasses to increase forage inventory. https://doi.org/10.7275/30949968

17. Mukhambetov, B., Abdinov, R., Kadasheva, Z., Alzhanova, R., Doskaliyeva, S., & Kabiyev, Y. (2021). Soil cultivation efficiency in pasture management of the arid zone of Central Asia and Kazakhstan. *IOP Conference Series: Earth and Environmental Science*, 839, 022029. https://doi.org/10.1088/1755-1315/839/2/022029
18. Naidu, C.B., Yernaidu, Y., & Mekala, S. (2022). Chapter-1 Potential of green manuring in sustainable agriculture-soil nutrient and microbial dynamics. In: T.A. Usmani (Ed)., *Advances in Agriculture Sciences* (pp. 5-23). New Delhi: Akinik Publication.
19. https://www.researchgate.net/publication/362834007_Chapter_-1_Potential_of_Green_Manuring_in_Sustainable_Agriculture_-Soil_Nutrient_and_Microbial_Dynamics
20. Nogayev, A., Serekpayev, N., Stybayev, G., Baitelenova, A., & Mukhanov, N. (2022). Yield and nutritional value of forage crops for dairy goat production in the steppe of northern Kazakhstan. *International Journal of Ecosystems & Ecology Sciences*, *12*(4), 481-490. https://doi.org/10.31407/ijees12.461
21. Ramasamy, M., Geetha, T., & Yuvaraj, M. (2020). Role of biofertilizers in plant growth and soil health. https://doi.org/10.5772/intechopen.87429
22. Shayakhmetova, A., Bakirov, A., Savenkova, I., Nasiyev, B., Akhmetov, M., Useinov, A., & Auzhanova, M. (2024). Optimization of productivity of fodder crops with green conveyor system in the context of climate instability in the North Kazakhstan region. *Sustainability*, *16*(20), 9024. https://doi.org/10.3390/su16209024
23. Shayakhmetova, A., Savenkova, I., Nasiyev, B., Akhmetov, M., Useinov, A., & Temirbulatova, A. (2023). Agrotechnology for feed cultivation and creation of hayfields and pastures in the forest and steppe zone of Northern Kazakhstan. *SABRAO Journal of Breeding and Genetics*, *55*(4), 1245-1258. http://doi.org/10.54910/sabrao2023.55.4.18
24. Soni, S.K., Dogra, S., Sharma, N., Thakur, B., Yadav, J., Kapil, A., & Soni, R. (2024). Nanotechnology in agriculture: Enhancing crop productivity with sustainable nano-fertilizers and nano-biofertilizers. *Journal of Soil Science and Plant Nutrition*, *24*, 6526-6559. https://doi.org/10.1007/s42729-024-01988-3
25. Thomas, I.R., Nieman, C.C., Coffey, K.P., & Popp, M.P. (2024). Sorghum-sudangrass intercropped with cowpea improved pasture for stocker cattle in the mid-south. *Applied Animal Science*, *40*(6), 708-716. https://doi.org/10.15232/aas.2024-02568
26. Yu, Q., Li, M., Zhang, Y., Xu, J., Li, P., Sun, H., Xie, Y., Dong, R., Zheng, Y., & Chen, C. (2023). Effects of different cutting stages and additives on the fermentation quality and microbial Community of Sudangrass (*Sorghum sudanense* Stapf). silages. *Fermentation*, *9*(8), 777. https://doi.org/10.3390/fermentation9080777
27. Zhumadilova, Zh.Sh., Toktamyssov, A.M., & Baimbetova, G.Z. (2023). The effect of a biological drug on the growth and development of grass mixtures during the restoration of pasture lands. *Agricultural Sciences*, *66*(3-1), 259-266. https://doi.org/10.52081/bkaku.2023.v66.i3.086