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RESEARCH ARTICLE
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Role of Tillage and Bio-Humus in The Restoration of Degraded Pastures of *Agropyrum Pectiniforme* in the Steppe Zone of Northeast Kazakhstan Under Changing Climatic Conditions

Altinay Kukusheva[1], Zibagul Kakezhanova[1]*, Zhastlek Uakhitov[1], Ardager Sarbasov[1] and Beybit Nasiyev[2]

[1]Toraighyrov University, Pavlodar, Kazakhstan
[2]Zhangir Khan West Kazakhstan Agrarian - Technical University, Uralsk, Kazakhstan
*Corresponding author: zkakezhanova@mymail.academy; kakezanovaz@gmail.com

ABSTRACT

Expanding the area of hay and pasture lands is not just a solution to the problem of desertification but a necessity to ensure a consistent supply of livestock feed in the current climate change scenario. Therefore, this work, which aims to identify effective methods for improving degraded perennial grass stands, using wheatgrass (*Agropyrum pectiniforme*) as an example, is of utmost importance. The study was conducted over three consecutive years in the steppe zone of Northeast Kazakhstan, where the physical and chemical properties of water and soil were examined, and the biometric indicators and productivity of plants were monitored. The research results indicate that disc harrow tillage is the most effective treatment for compacted wheatgrass lands. This method reduced soil bulk density by 0.14g/cm^3, increased water permeability, and made 15.6mm more moisture available. Additionally, the humus increased by 0.18% compared to the variant without tillage. The process of decomposition of organic plant residues following tillage may be enhanced through the application of microbiological preparations and complex fertilizers containing useful microorganisms and biostimulants, which can optimize nutrition. Combining these fertilizers with bio-humus is also beneficial, as it can further enhance the decomposition process. Restoration techniques result in a fresh grass gain of 0.96-1.07t/ha (1.4-1.5 times) compared to disc harrow tillage alone. Additionally, it yields 1.61-1.72t/ha (2 times) more than the variant without restoration techniques. These findings demonstrate the positive impact of combined tillage and biological treatments on soil health and pasture productivity. Conclusively, integrating disc harrow tillage with bio-humus and microbiological preparations offers a viable and effective approach to restoring degraded pastures, mitigating desertification, and ensuring sustainable livestock feed production under changing climatic conditions. The urgency of this research topic underscores the importance of the role of agricultural professionals and policymakers in implementing these findings.

Keywords: Wheatgrass; Restoration; Forage land; Mechanized treatment; Microbiological preparation; Bio-humus

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INTRODUCTION

The degradation of forage lands and desertification caused by global climate change reduce human living space (Smith et al., 2020). Pastures and hayfields slow atmospheric warming and increase soil carbon sequestration (Nasiyev & Bekkaliyev, 2019; Liu & Shao, 2024). However, due to the increase in frequent extreme weather events such as drought and dry winds, ecosystems cannot fully function (Ummenhofer & Meehl, 2017). Scientists have found that climatic changes impact carbon and water cycles, mineral element cycles, solar energy inputs, and species composition of biocenoses (Moiseenko, 2017). This, in turn, affects the productivity of

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forage lands (Getabalew & Alemneh, 2019). Research has shown that a decrease in precipitation, coupled with a 2-4°C increase in air temperature, leads to a decrease in aboveground crop growth (Fay et al., 2011). For instance, in northern China, climatic changes that have occurred for 30 years have reduced aboveground net primary productivity in pastures by an average of 6.1% (Sunil et al., 2020; Wu et al., 2021).

Climate warming will affect pasture grass quality and forage capacity (Zhao et al., 2023). Plants used on pasture for many years are adapted to inter-annual changes in winter precipitation. However, annual warming and decreasing humidity may reduce the vegetation period of pasture grasses, potentially leading to a deficit of pasture fodder (Dovrat et al., 2021). Extreme weather conditions are also dangerous because they disrupt microbial communities in the soil, especially the bacterial community, which is much more sensitive to heat than the fungal community. This disturbance of the soil's microbial balance can impact plant health (de Vries et al., 2018; Whitton et al., 2022). Experts are developing measures and strategies to maintain sustainable agriculture to mitigate global warming's effects. To address the challenges of heat and water shortages, pest management, and monocultures of rangelands, strategies such as developing heat and drought-resistant pasture plants, improving cropping technologies, replacing monocultures with legume-grass mixtures, using water more efficiently, and informing farmers about these strategies have been proposed (Vicca et al., 2012). However, these farming strategies have both advantages and disadvantages. Mixed crops not only help cope with adverse conditions but also require more resources to manage and harvest. Despite improved cultivation techniques, there is evidence that cropping systems reduce moisture content and total organic carbon levels (Topa et al., 2021; Orzech et al., 2021).

Carbon sequestration efforts are effective by restoring degraded lands to a high diversity of dominant perennial plants. At the same time, there is also a decrease in nitrate leaching, a decrease in the variation in the amount of aboveground mass over the years, fewer invasive plant species, and a decrease in N_2O emissions into the soil (Dreesen et al., 2012; García-Palacios et al., 2018). Overseeding multicomponent mixtures of perennial grasses, which are highly adaptable and resistant to different modes of use, against the background of radical improvement and surface treatment, increases productivity by 65-70% higher than without improvement (Laidlaw & Frame, 2013).

Different biostimulants can improve physiological processes and nutrient absorption by increasing plant resistance to abiotic and biotic stresses (da Silva et al., 2021; Nasiyev et al., 2022a). The impact of climate change on forage lands, their sustainability, and productivity growth in difficult climatic conditions is a relevant issue for the global community and Kazakhstan. Restoration of forage lands is a crucial issue in the Pavlodar region, northeast of Kazakhstan, due to the presence of large fodder massifs. As of 2021, pastures make up 67% of all agricultural land in the region, according to the Ministry of Agriculture of the Republic of Kazakhstan. According to a 2021 report, degraded pastures made up 41.7% of the Pavlodar region. Concurrently, a greater proportion of pastures were found to have been weeded with *Stipa capillata* (12.86%). Additionally, there were observed pastures exhibiting signs of overgrazing (8.76%), shrub proliferation (5.08%), stone obstruction (2.98%), surface irregularities (1.0%), and tree encroachment (0.01%). Moderate to severe overgrazed pastures account for 726.1 thousand hectares. Pasture degradation occurs when low-yield, non-edible, and annual plant species replace high-value fodder grass stands. This is caused by climate change, which leads to aridity and irrational human economic activity. The increase in run-down pastures is attributed to irrational human activity (Alipbeki et al., 2023). Annual changes in climatic conditions negatively affect the quality and yield of green mass of forage grasses, reducing the rate of livestock production (Godde et al., 2021).

Pasture resilience can be enhanced by selecting perennial grass species that exhibit drought tolerance and possess other valuable characteristics that enable them to withstand the adverse effects of droughts and dry winds (Nasiyev, 2014; Nasiyev et al., 2019). Grasses with deep root systems demonstrating increased drought tolerance are promising for adapting to drought conditions (Serikbay et al., 2024). The defense mechanisms of perennial grasses that save them from drought stress include prevention of dehydration, resistance to dehydration, escape, or summer dormancy (Taleb et al., 2023).

However, seeding grasses as a restoration technique may need to be more effective in the steppe zone due to the lack of moisture. Annual precipitation ranges from 250-310mm, with the highest precipitation occurring in the second half of summer. During the vegetation period, up to 50% of the precipitation falls. However, due to high air temperatures and air humidity below 30%, a significant portion of the precipitation that falls in the summer is evaporated, and only a small amount is consumed by plants. Therefore, there is no accumulation of moisture due to rainfall. The uneven distribution of precipitation results in a sharp aridity during the spring and the first half of summer. Poor moisture leads to the drying of the upper layer of soil, causing grass seedlings to die at the beginning of their growth. At the same time, it is believed that restoring forage lands while maintaining moderate grazing and rational use of grass stands is more economically effective than creating new areas by sowing forage grasses (Nasiyev et al., 2022b; Baidalina et al., 2023).

Due to unfavorable climatic conditions, the region's range of cultivated forage grasses is limited. Crested wheatgrass (Agropyrum pectiniforme) is the dominant species on hay and pasture lands of the steppe areas of the Pavlodar region, as it is a precious crop for both hay production and grazing. It is notable for its adaptability to various habitats, high-quality forage, prolonged productivity, and beneficial impact on soil characteristics (Derevjannikova, 2020). Wheatgrass has a well-developed root system that can penetrate the soil up to 2 meters. During two years of vegetation, it can accumulate up to 21 tons of root residues per hectare in the arable soil layer. The root mass of wheatgrass in the 0-20cm topsoil in the second year of wheatgrass life is as follows (kg/ha air-dry weight): according to Krasnokutsk experimental station - 835, Saratov experimental station of animal husbandry - 1122, Kazakh Research Institute of Agriculture - 1050 (Velichko, 2006). Extended grassing with perennial grasses can increase the flow of fresh organic matter into the soil, replenishing the soil with nutrients and carbon. Livestock such as cattle, horses, and sheep find wheatgrass pastures a nutritious food source. Wheatgrass is known for its exceptional drought tolerance compared to other perennial grasses. According to Levykin et al. (2021), the transpiration coefficient of crested wheatgrass ranges from 412-712, while thick spike wheatgrass ranges from 386-642. According to research, wheatgrass plants over a year old can withstand extreme temperatures in both winter and spring. Specifically, they can tolerate drops as low as minus 40-48°C in winter and minus 20°C in spring. This is due to the high concentration of carbohydrates and other organic substances in the tillering zone, underground shoots, and roots (Plotnikova et al., 2023).

The effective bulk density of the topsoil for sowing wheatgrass is important for farming purposes. Plants come into great contact with soil particles and develop a robust root system to the detriment of the aboveground vegetative mass due to extensively loose soil. In contrast, in soil with an excessively high bulk density, the root system of wheatgrass is situated in the topsoil horizons, which frequently experience desiccation, limiting the plants' access to sufficient moisture. The optimal composition of the plow layer is essential for developing a normal root system that can effectively absorb nutrients from the upper and moisture from the lower horizons (Velichko, 2006). Therefore, loosening the soil by breaking the compacted sod, and dividing the root mass into small parts with the help of cultivation tools, will enable new root systems of wheatgrass to form young roots, form new shoots, or "rejuvenate" it by improving the water-physical properties of the soil. For instance, in arid zone conditions, Yurchenko (1986) proposed spring harrowing of wheatgrass in the second year of life with a tooth harrow "Zig-Zag" in one to two passes, contingent on the soil type. The primary objective of such tillage is to loosen the heavily cracked topsoil by 2-3cm, destroy low-stemmed weed vegetation, and thus preserve moisture for sown grassland growth. However, according to Larin et al. (1975), harrowing did not positively affect the yield of forage lands in the forest zone, forest-steppe, steppe, and mountainous areas. As observed by Pryanishnikov (1971), the positive impact of disk tillage on thick spike wheatgrass crops three years old and older was evident on waterlogged and heavy soils in the semi-desert zone of south-eastern Kazakhstan. The combination of disk tillage and harrowing increased the dry weight yield of wheatgrass by an average of 5.3-5.8hkg/ha compared to the variant without any tillage.

Furthermore, the variant with harrowing was found to increase the dry weight yield by an average of 3.0-4.7hkg/ha. Donskiy & Mora Ilarion (2017) have also developed a method for enhancing the surface quality of aged Eastern galega (*Galega orientalis*) crops through the use of two-pass disking, incorporating legume and cereal grass seeds. This technique increased the proportion of the studied species within the grass stands by 78%. However, the efficacy of mechanical tillage in diverse natural settings is variable, contingent upon the specific soil, climatic (temperature, moisture), and wind resistance characteristics of the soil surface (wind erosion). Consequently, the optimal method for improving degraded, compacted, and low-yielding wheatgrass crops is contingent upon a multitude of potential solutions, the selection of which should be based on a comprehensive analysis of the specific environmental conditions prevailing in a given region. Overall, the data suggests that soil compaction increases due to soil turning. High bulk density means that roots have difficulty growing through the upper layers of any soil type, so most of the root network is located in the deeper layers, making the plant more susceptible to water and fertilizer stress (Mwiti et al., 2022).

Nunes et al. (2019) reported a significant ($P<0.05$) decrease in shoot elongation (27.1%) and leaf area (67.8%) at high penetration resistance. In addition, there was a significant decrease in fresh and dry root weight by 39.1 and 37.8%, respectively, at high penetration resistance levels. In a study designed to evaluate how mechanical impedance would interact with nutrient stress, Wang et al. (2021) found out that even with adequate phosphorus supply, which plants require to promote healthy root growth and early seedling emergence, mechanical impedance significantly reduced shoot and root growth. This denotes that bulk density should be monitored in harrowing forage lands.

At the same time, the need for environmentally friendly food products makes organic agriculture a priority. Biological methods, such as the combination of stimulating bacteria and humic substances, are promising approaches to improve metabolic processes and plant's green mass growth and can reduce agricultural production's economic and environmental costs. (Olivares et al., 2017). In soils with low fertility, the application of humic acids and H. seropedicae resulted in a greater maize yield than in the control variant (Canellas et al., 2015). In sugarcane cultivation, foliar inoculation of *Herbaspirillum seropedicae, H. rubrisubalbicans* and *Gluconacetobacter dizotropicus* in combination with potassium humate resulted in a 37% increase in stalk yield compared to that observed in untreated plants (da Silva et al., 2017). Inoculation of *Bacillus megaterium* and *Bacillus subtilis* in combination with the application of 400kg/ha of humic acids in potato plantations resulted in a 140% increase in gross tuber production compared to the control variant (Ekin, 2019). In the Northeastern region of Kazakhstan, the research has primarily focused on utilizing biohumus in agricultural settings, particularly in cultivating field crops. The yield increase resulting from the application of bio-humus in wheat was 2.3-2.4hkg/ha, in peas, it was 2.6-2.9, and in buckwheat, it was 1.8-2.3hkg/ha. Nevertheless, the impact of biohumus on pasture grasses remains uninvestigated (Mustafaev et al., 2014).

Therefore, the primary objective of this study is to identify and evaluate effective methods for restoring degraded perennial grass stands in the steppe zone of

Northeast Kazakhstan, with a specific focus on the use of surface tillage techniques, bio-humus, and microbiological preparations**.** In particular, it is necessary to consider that the population's demand for products from livestock is growing, so the problem of increasing crop yields is very topical (Singh et al., 2022).

This study aims to determine the impact of these methods on soil properties, plant growth, and overall pasture productivity, contributing to sustainable livestock feed production in the face of climate change.

MATERIALS & METHODS

Description of the Research Object

The experimental research was conducted from 2021 to 2023 at Toraighyrov University in the steppe zone on the farm "Zamandas" in the Irtyshsky district of Pavlodar region in Northeast Kazakhstan. The research focused on degraded and compacted crops of crested wheatgrass (Agropyrum pectiniforme). The experiment focused on studying the Karabalyk 202 variety, which is known for its high drought tolerance and winter hardiness. The plant has a slightly spreading bush and non-raw stems and grows in early spring. To achieve the research goal, two field experiments were conducted, and their schemes are presented in Table 1 and 2.

Table 1: Scheme for Experiment 1. Developing effective methods to improve degraded wheatgrass pastures in the steppe zone (2021–2023)

No	Variants
1	Without improvement (control)
2	Processing with tooth harrows
3	Processing with needle harrows
4	Processing with disk harrows

Table 2: Scheme for Experiment 2. Developing methods for the restoration of the bioresource potential of degraded wheatgrass pastures using fertilizers and microbiological preparations in conditions of the steppe zone (2022-2023)

No	Variants
1	Naturally degraded wheatgrass pastures (control 1)
2	Processing with disk harrows (control 2)
3	Processing with disk harrows, application of an organomineral fertilizer containing bacteria and potassium humate (100kg/ha), along with biohumus (0.5 t/ha)
4	Processing with disk harrows, application of bio-humus (0.5 t/ha)
5	Processing with disk harrows, application of a microbiological fertilizer containing ef-fective microorganisms (10 l/ha), along with bio-humus (0.5 t/ha)

When conducting mechanical treatments on wheatgrass grass stands, Zig-Zag tooth harrows, BIG-3A needle harrows, and BDT-7 disk harrows were utilized. The total area of each variant is 100m^2; the size of a registration plot in each variant is 10m^2. The repetition of plots is fourfold. The depth of loosening by the tooth harrow was 3-5cm, the soil spiker was 7cm, and the disc harrow was 10cm. The tools were attached to a John Deere 6150M tractor, operated at a speed of 4-5km/h when the harrows were used and 8km/h when the disc harrow was used. All tillage operations were conducted only once during the first year of research, in the second decade of September 2021.

Disc harrow tillage was conducted on September 2nd, 2021, at a depth of 10cm at a tractor speed of 8 km/h. Fertilizers and a microbiological preparation, "Baikal EM-1," were applied on an annual basis (in 2022 and 2023) during the period of full growth of wheatgrass and after the initial mowing.

The application of biological preparations and biohumus should occur during the period of full growth of wheatgrass and after the first mowing. This will provide the regrowing plants with the necessary nutritional elements. To produce organomineral fertilizer, lowland peat with a high degree of decomposition, potassium humate, and bacteria *Bacillus subtilis* and *Bacillus mucilaginosus* are used. The microbiological fertilizer, "Baikal EM-1", was selected for use in this experiment. It contains effective microorganisms, including *Lactobacillus casei, Streptococcus lactis, Phodopseudomonas palestras, and Saccharomyces cerevisiae*. The biohumus "Pavlodar" utilized in the experiment was obtained using a patented technology developed by scientists from NAO Toraighyrov University. The humus content of the bio-humus ranges from 12.2 to 17.42%, while the ash content ranges from 34 to 45%.

Climatic Conditions in the Study Area

Fig. 1 presents a summary of the meteorological conditions observed during the 2021-2023 period. During 2021, the average monthly temperature in June, July, and August exceeded the mean annual temperature by 2.4, 2.8, and 1.2°C, respectively, after surface tillage, according to the experiment scheme. However, the amount of precipitation was above the norm by 5, 6, and 19mm, respectively, which favorably influenced the process of grass regrowth. The climatic indicators were within the norm for the remaining months.

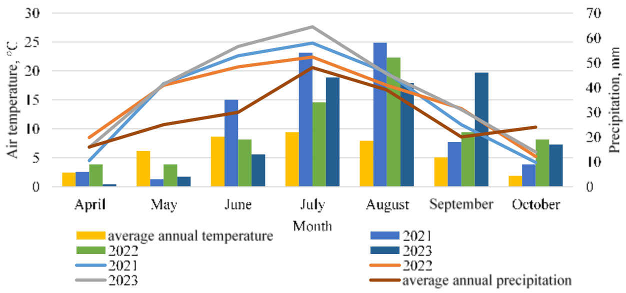

Fig. 1: Air temperature and precipitation in Irtysh district (Northeast Kazakhstan) from April to October 2021-2023.

In the following year 2022, April experienced moderately warm and dry weather with below-normal precipitation, which was 54% of the norm. The growth of wheatgrass began on April 16th, after the snow melted. In May, temperatures increased by 3.1°C above normal, but precipitation was below normal at only 34% of the norm. The unfavorable weather conditions during the spring months harmed the growth and development of the grasses, which accelerated the phenological phases.

The vegetation period 2023 was marked by unusually high air temperatures and low precipitation. In April, precipitation was only 6% of the norm; in May, it was only 13%. The lack of moisture hurt the growth of the wheatgrass, and vegetation only resumed in the first ten days of May. The temperature in June was significantly higher than the average annual air temperature, reaching a maximum of 40.3°C (4°C higher). Additionally, there was a precipitation deficit of 43% of the norm. The faster development of wheatgrass and reduced accumulation of green mass during harvest ripeness can be attributed to unfavorable conditions during the month. Moreover, the average monthly temperature exceeded the norm by 5.6°C in July and by 1°C in August.

Studying the Grass Stand of Wheatgrass on the Experimental Plot

All measurements and observations in the two experiments were conducted on registration on 10m^2 plots in four repetitions using approved methods (Dospekhov, 1985; Nazarenko et al., 2023). Grass stand height was measured with a ruler before mowing. Measurements were taken along the diagonal of the plot of 10 plants during the first and third repetition, from the soil surface to the top of the stem or the end of the inflorescence. The grass density, measured as the number of bushes per 1m^2, was determined by overlapping square frames (0.25m^2) on the diagonals of the plot at equal distances. Yield structure was established by weighing the stems, leaves, and inflorescences on laboratory scales VM-153M (manufactured by OOO "OKB VESTA", Russia) before mowing. The percentage of each fraction was then calculated. The continuous mowing method determined the fresh yield by variant during the harvest ripeness period. The green mass was mowed from the accounting plot of all replications at the height of 5cm using a hand sickle "Travnik-47" (manufactured by OAO "Artinskiy Zavod," Russia) and weighed on laboratory scales VM-153M. The crude protein content of wheatgrass plant samples was analyzed using the infrared analyzer "Spectran-119M" (manufactured by OOO "LOMO Photonica", Russia) at the Research and Development Center "Agroinnovation and Biotechnology" at NAO Toraighyrov University.

Soil Sampling

The experimental plot's soils are southern carbonate chernozems. The water-physical and chemical properties of the soil cover on the experimental plot were studied to determine the impact of improvement techniques on degraded forage lands. Soil samples were taken from all experiment variants in the 0-30cm soil layer (layer by layer every 10cm) to assess the influence of surface tillage on soil parameters. The available water capacity was also estimated in the 0-100cm layer. Sampling was repeated four times.

Physical and Chemical Analysis of Soil

Soil bulk density was determined using the cutting cylinder method with undisturbed soil samples, following (Krasilnikov et al., 2009). Samples were taken from soil layers at depths of 0-10, 10-20, and 20-30cm using a 300cm^3 cylinder drill manufactured by OOO "PTF InterStroyPribor-SPb" in Russia. In the laboratory, the soil was dried in the "SESH-3 EM" drying cabinet manufactured by OOO "NPP Priborinform," Russia, at 105°C until it reached a constant weight. By using the weight of the weighing bottle with dried soil and the weight of the empty weighing bottle, we could calculate the weight of air-dry soil. We then determined the soil bulk density by dividing the weight by its volume, which was measured using the drill cylinder.

To determine the available water capacity, we took soil samples layer by layer every 10cm to a depth of 1m using the soil drill AM-26 (manufactured by NPO "Typhoon", Russia). The soil samples were then dried in the "SESH-3 EM" drying cabinet at a temperature of 105^{0}C until a constant mass was achieved. The percentage of water evaporated during soil drying, expressed as a proportion of the mass of completely dry soil, corresponds to its field moisture. Available water capacity was assessed in the meter layer on the scale described by Vadyunin and Korchagin and mentioned by Faithfull (2002). Available water capacity (AWC) in soil was calculated in millimeters per hectare according to the following formula (1):

$$AWC = 0,1 * h * d * (FSM - WM) \quad (1)$$

where d - soil bulk density (g/cm^3); h - thickness of soil layer (cm); FSM - field soil moisture (%); WM -wilting moisture (%)

Soil samples were taken in the 0-30cm layer for humus content during full regrowth of the wheatgrass. The samples were analyzed at the laboratory of the Republican Scientific and Methodological Center of Agrochemical Service of the Ministry of Agriculture of the Republic of Kazakhstan (Pavlodar, Kazakhstan). The analysis was conducted using the method of Tyurin, which is based on the oxidation of soil organic matter by chromic acid to form carbon dioxide (Dospekhov, 1985). The humus contents were determined on the Orlov and Grishina scale, as mentioned by Biryukova et al. (2008).

Data Analysis

The experimental plot's vegetation and soil productivity indicators underwent statistical processing through one-factor dispersion analysis (Kruskal–Wallis H-test) using the SPSS IBM STATISTICS program (version 19). The differences were considered statistically significant at $P<0.05$. The climatic indicators and grass stand structure diagram were created using MS Excel tabular editor. Correlation coefficients were calculated to evaluate the significance of relationships between indicators (Kendall Tau-b correlation coefficient): soil parameters and vegetation indicators.

RESULTS

Change in Soil Parameters based on Surface Tillage

In all variations involving surface tillage of degraded crops of wheatgrass from 2021 to 2023, there was an increase in available water capacity by 2.6-15.6mm compared to the variant without tillage (Table 3). Moisture was accumulated most significantly when processing with disk harrows, with 17.5% more accumulation than in the control. This is since the tillage with these tools not only loosens the soil but also breaks the dense sod, thereby increasing its water permeability and reducing moisture evaporation from the soil surface. Thus, the moisture supply rate will determine the further growth of the crop and the formation of fresh yield.

Table 3: Changes in indicators of southern chernozem in the steppe zone of Northeastern Kazakhstan, based on the methods of processing degraded grasslands of wheatgrass, on average for 2021-2023

Variant	Available water capacity in 0-100cm depth, (mm)	Soil bulk density, on average in the layer of 0-30cm (g/cm3)	Average humus content in the layer of 0-30cm (%)
Without improvement (control)	89.3	1.39	3.58
Processing with tooth harrows	91.9	1.31	3.60
Processing with needle harrows	95.6	1.27	3.72
Processing with disk harrows	104.9	1.25	3.76

In the variants with the introduction of mechanized tillage, there is a notable reduction in soil bulk density, with values ranging from 0.08 to 0.14g/cm^3 compared to those without tillage, which exhibited a density of 1.39g/cm^3. The reduction in soil bulk density has been shown to enhance the permeability and capacity of the soil to retain water, as evidenced by the observed growth in the available water capacity in the variants. Concurrently, the variant with disc harrow tillage exhibited more optimal indicators. Low humus content is a characteristic feature of southern chernozem in the steppe zone of the Northeastern region of Kazakhstan. During mechanized tillage, a small increase in humus content of between 0.02% and 0.18% is observed, depending on the intensity of the impact of tools on the sod layer.

The correlation analysis using the Kendall Tau-b correlation coefficient between soil parameters in the variants indicates a direct relation between the amount of moisture in the soil and the grass density before mowing (rxy = + 0.53), the height of plants (rxy = + 0.41), their yield (rxy = + 0.54), and the humus content (rxy = + 0.47) (Table 4). At the same time, an increase in soil bulk density showed a negative correlation with various indicators, such as the density of the grass stand before mowing (rxy = - 0.61), height (rxy = - 0.70), leaf coverage (rxy = - 0.62), and yield of wheatgrass (rxy = - 0.75).

The Effect of Surface Tillage on the Indicators of Wheatgrass Stands

During the research period, an acceleration of the phenological phases of wheatgrass was observed, which may be attributed to climatic factors. Consequently, this resulted in a reduction in grass height and the accumulation of green tops (Fig. 2). The height of plants before mowing (flowering phase) exceeded the control in all variants by 0.3-12.8cm. The tallest plants were observed within the plot with disc harrow tillage, measuring 36.1cm. This may be because tillage can create optimal conditions for plant growth by increasing the feeding area, loosening the soil, and improving the water permeability of the upper horizon.

When evaluating grass density during 2021 after surface tillage, the number of bushes per 1m^2 decreased by 8-12 pieces depending on the intensity of the impact of the tools on the sod, compared to the variant without tillage. The reason for this is that when compacted sod is cut, some of the old bushes are killed. The stronger the impact, the more old shoots die off in the year of tillage. As a result of improved growing conditions, young shoots appear in their place. The more intensive the tillage, the more young shoots are formed, leading to an increase in the density of the grass stand in the following years. For instance, in the variant with a disc harrow tillage, the density of the grass stand increased by an average of 58.1% over the years compared to the control plot. The analysis of the yield structure elements revealed that the majority of the plant mass is concentrated in the stems, ranging from 57.9 to 76.2%, and in the inflorescences, ranging from 19.6 to 28.0%. The lowest percentage of plant foliage was observed within the control plot, at 4.2%. This percentage slightly increased in tooth and needle harrow variants, reaching 5.9 and 5.6%, respectively. In the variant with disc harrow tillage, the percentage of leaves increased to 15.8%, and the plants were taller with larger inflorescences than those within the control plot (Fig. 3).

The evaluation of the techniques employed for the restoration of wheatgrass stands, as determined by the Kruskel-Wallis H-criterion, revealed statistically significant differences in the structure of wheatgrass stands, specifically in the proportion of leaves (P=0.009), the proportion of stems (P=0.005), and the proportion of inflorescences (P=0.016). These findings were deemed statistically significant at the $P<0.05$ level.

The productivity of plants was positively affected by surface tillage. On average, there was an increase in green mass from these methods over the years. Specifically, the yield increased 2.9 times with disc harrow tillage, 1.8 times with needle harrow tillage, and 1.2 times with tooth harrow tillage compared to the control plot.

Fig. 4 shows the results of the restoration of wheatgrass grass after mechanized treatments (tooth harrows and disk harrows). The impact of mechanized treatments on sodded wheatgrass crops was assessed to determine their effect on the fresh yield over 2021-2023. The results showed a significant correlation between the yield level and soil and biometric indicators. For instance, the Kendall Tau-b correlation coefficient indicates a strong inverse relation (rxy = - 0.75) between the fresh yield of wheatgrass and soil bulk density (Table 5). Soil loosening and removing the sodden layer improved water permeability and increased the decomposition of organic matter. As a result, the fresh yield was closely and directly related to available water capacity (rxy = + 0.54) and humus content (rxy = + 0.74).

The correlation between fresh yield and vegetation cover indicators was identified, revealing a strong direct relation with leaf coverage (rxy = + 0.53), the number of inflorescences (rxy = + 0.54), plant height (rxy = + 0.80), and grass density before mowing (rxy = + 0.61).

The Impact of Disc Harrow Tillage, Combined with Biopreparations and Bio-humus Application, on the Indicators of the Wheatgrass Stand

The evaluation of the methods used to restore grass

Table 4: Correlation analysis of the assessment of the significance of relationships between soil and wheatgrass indicators under different mechanised treatments

Indicator	Correlation coefficient Kendall's Tau-b	Average humus content in the layer of 0-30cm, %	Grass density (number of bushes or plants per 1 m2), pieces	Height of plants, cm	Fresh yield, t/ha
Available water capacity (0-100cm), (mm)	r_{xy}	0.475	0.532	0.417	0.544
	P	<0.011	0.004	0.024	0.003
Soil bulk density, on average in the layer of 0-30cm (g/cm3)	r_{xy}	-	0.61	- 0.70	-0.747

Table 5: Correlation analysis of the effect of soil and grass parameters on the yield of green mass of wheatgrass under different mechanised treatments

Indicator	Correlation coefficient Kendall's Tau-b	Fresh yield, t/ha
Available water capacity (0–100cm), mm	r_{xy}	0.544
	p	<0.003
Soil bulk density, on average in the layer of 0-30cm, g/cm3	r_{xy}	-0.747
	p	<0.001
Average humus content in the layer of 0-30cm, %	r_{xy}	0.740
	p	<0.001
Grass density (number of bushes or plants per 1 m2), pieces	r_{xy}	0.610
	p	<0.001
Height of plants (cm)	r_{xy}	0.795
	p	<0.001
Structure of the herbage of bromegrass - share of leaves, %	r_{xy}	0.532
	p	<0.004
Structure of the herbage of bromegrass - proportion of inflorescences, %	r_{xy}	0.544
	p	0.003

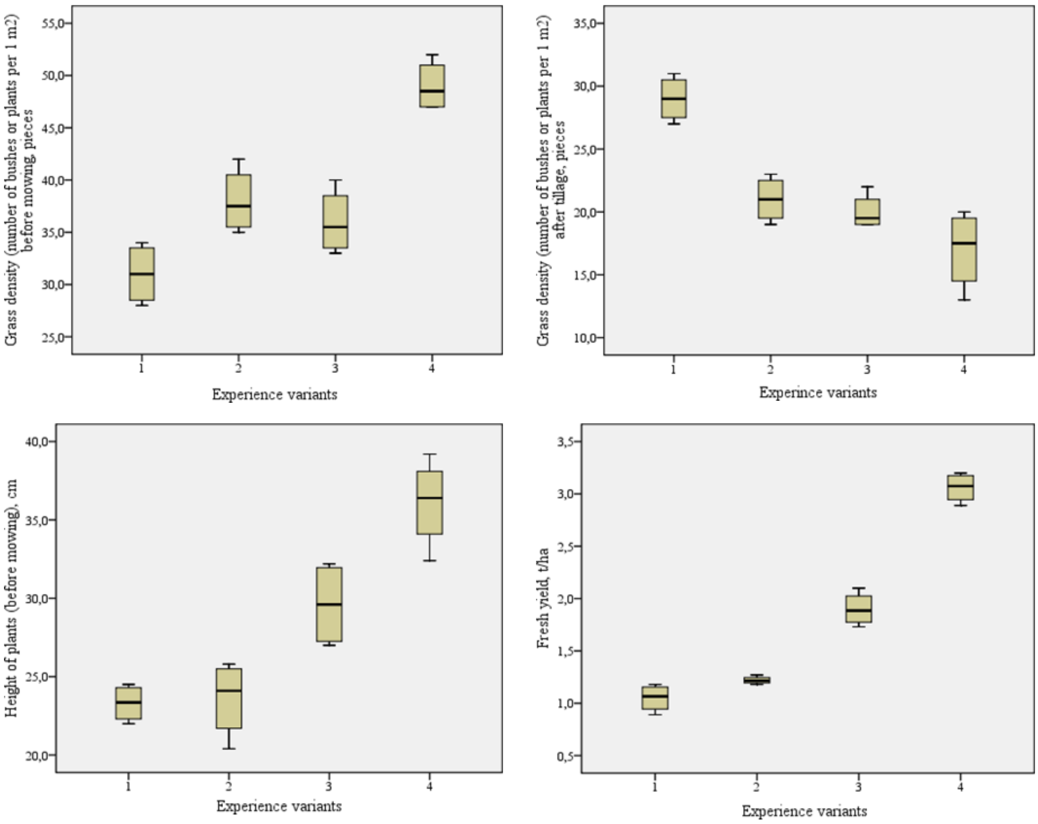

Fig. 2: Wheatgrass stand indicators on forage lands in the steppe zone of Northeast Kazakhstan, based on the methods of tillage, on average for 2021-2023; Experience variants: 1 - Without improvement (control); 2 - Processing with tooth harrows; 3 - Processing with needle harrows; 4 - Processing with disk harrows

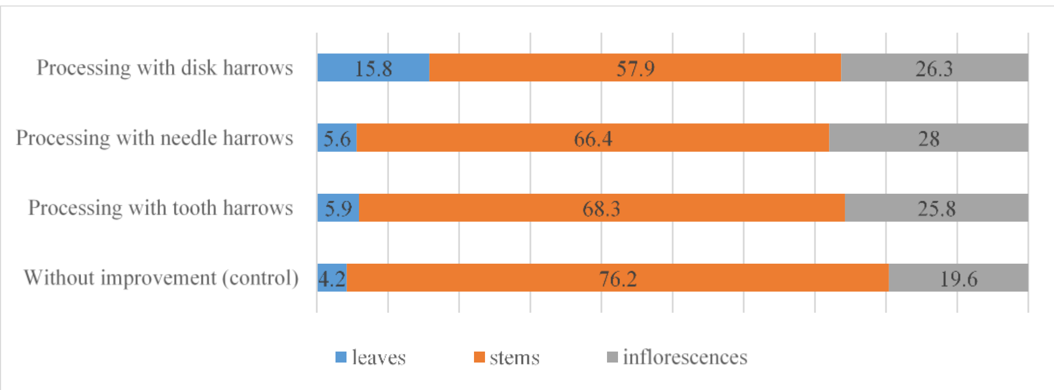

Fig. 3: Structure of wheatgrass (%) stand depending on cropping practices (average for 2021-2023)

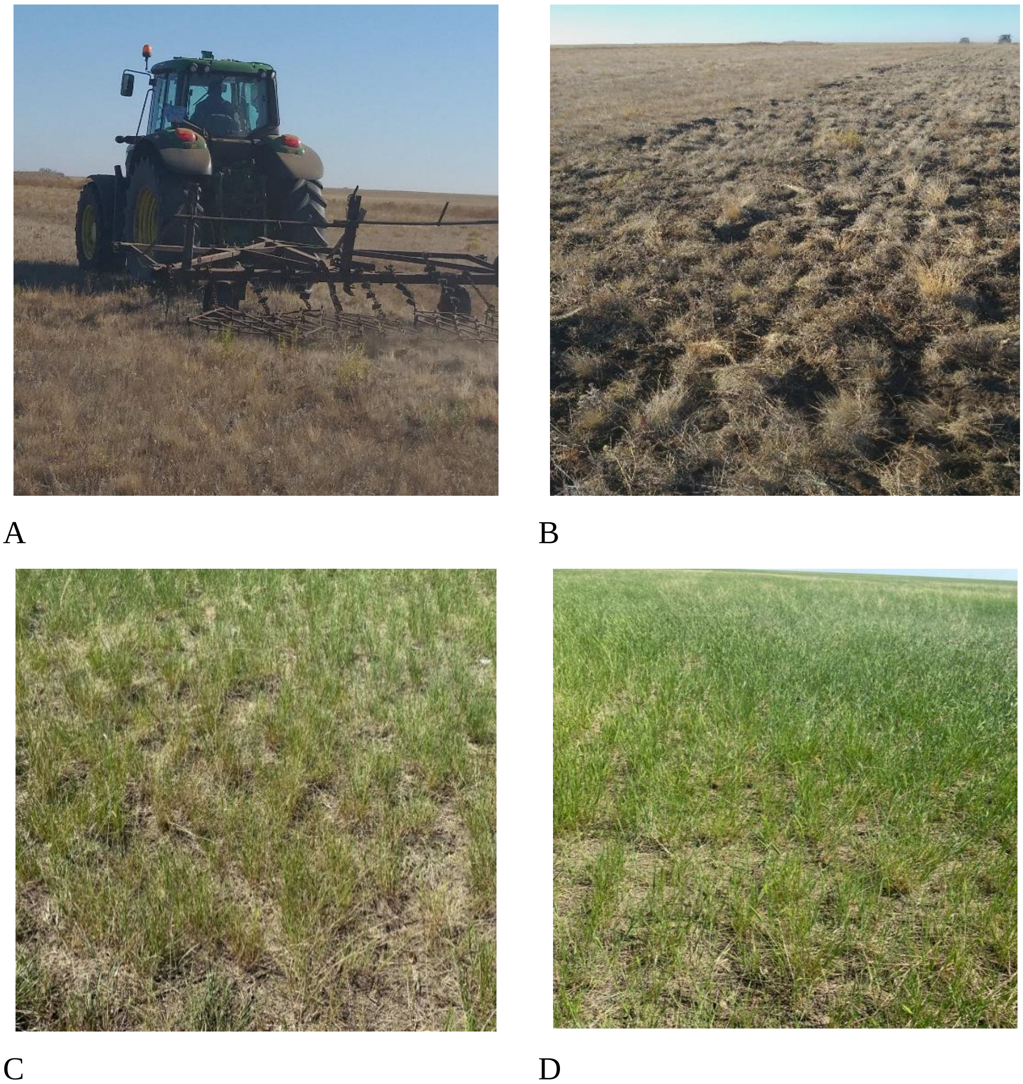

Fig. 4: Restoration of perennial ryegrass pastures: A - with tooth harrows treatment, 2021; B - with disk harrows treatment, 2021; C - ryegrass stand in the variant with tooth harrow treatment, 2023; D - ryegrass stand in the variant with disk harrows treatment, 2023

stands of wheatgrass using biological preparations and biohumus, according to the Kruskal–Wallis H-test, revealed statistically significant differences in the following indicators: grass density (P=0.002), height of wheatgrass before mowing (P=0.011), and fresh yield of wheatgrass (P=0.003). The obtained data were considered statistically significant at P<0.05 (Table 6).

The study notes a positive effect on plant height in variants that utilize biopreparations and bio-humus, exceeding the variant only with disc harrow tillage by 11-26% (Table 7).

The assessment of grass density (number of bushes) before harvesting during 2022-2023 indicates an increase in the number of wheatgrass bushes in the variants that use microbiological preparation and biohumus, up to 53-60 pieces per square meter. This increase is associated with the intensive impact of disc harrow tools on the grass stand and the improvement of soil conditions. The application of microorganisms in the composition of preparation accelerates the process of decomposition of organic matter of sod, while biohumus provides young regrowing shoots with available nutritional elements. The fresh yield is higher in variants where disc harrow tillage and biological agents are jointly applied, compared to the variant without tillage and their application, by 1.61-1.72t/ha or 2 times. When evaluating the effect of microbiological preparations and biohumus on the surface tillage, fresh yield increased by 0.96-1.07t/ha (1.4-1.5 times) compared to the tillage with disc harrow only. This demonstrates the positive effect of bioorganic substances on the fresh yield. At the same time, there was a slight increase in productivity in the variant that utilized complex organomineral fertilizer containing bacteria, potassium humate, and biohumus. The fresh yield was 2-3% higher than the variants that used effective microorganisms with biohumus or only biohumus. The analysis of correlations using the Kendall Tau-b correlation coefficient revealed that the grass density of wheatgrass (rxy= + 0.71) and the height of plants before mowing (rxy= + 0.60) had a direct impact on the growth of fresh yield of wheatgrass in all variants of the experiment (Fig. 5).

The variants showed an increase in crude protein content by 0.9-1.9% compared to those without restoration techniques. This increase is associated with better grass stand foliage and the emergence of additional young shoots during disc harrow tillage and the application of microbiological preparation and fertilizers.

Table 6: Results of assessment of statistically significant differences of the studied methods of restoration of wheatgrass with the use of fertilizers, microbiological preparation on herbage indicators according to the H-criterion of Kraskell-Wallis

Indicator	Naturally degraded wheatgrass pastures (control 1)	Processi ng with disk harrows (control 2)	Disc harrow tillage, combined with application of organomineral fertilizer and biohumus	Disc harrow tillage, combined with application of bio-humus	Disc harrow tillage, combined with application of microbiological preparation with effective microorganisms	p
Grass density (number of bushes or plants per 1 m^2), pieces	33.5 [29.8-35.8]	41.5 [39.3-45.3]	59.5 [57.3-63.3]	54.5 [50.3-57.3]	53.5 [49-56.5]	0.002
Height of plants, cm	29.8 [28.3-32.3]	34.7 [32.8-36.3]	43.2 [41.1-46.3]	37.8 [36.2-41.2]	40.7 [32.2-44.8]	0.011
Fresh yield, t/ha	1.6 [1.5-1.7]	2.2 [2-2.6]	3.3 [3.3-3.4]	3.2 [3.1-3.3]	3.3 [3.2-3.3]	0.003

Table 7: Indicators of wheatgrass stands on forage lands in the steppe zone of Northeast Kazakhstan depending on disc harrow tillage combined with microbiological preparation and fertilizers application, on average for 2022-2023

Variants	Height of plants,cm	Grass density (number of bushes or plants per 1 m2), pieces	Fresh yield, t/ha
	before mowing		
Naturally degraded wheatgrass pastures (control 1)	30.1	33	1.60
Processing with disk harrows (control 2)	34.6	42	2.25
Disc harrow tillage, combined with application of organomineral fertilizer and biohumus	43.5	60	3.32
Disc harrow tillage, combined with application of biohumus	38.4	54	3.21
Disc harrow tillage, combined with application of microbiological preparation with effective microorganisms	39.2	53	3.26

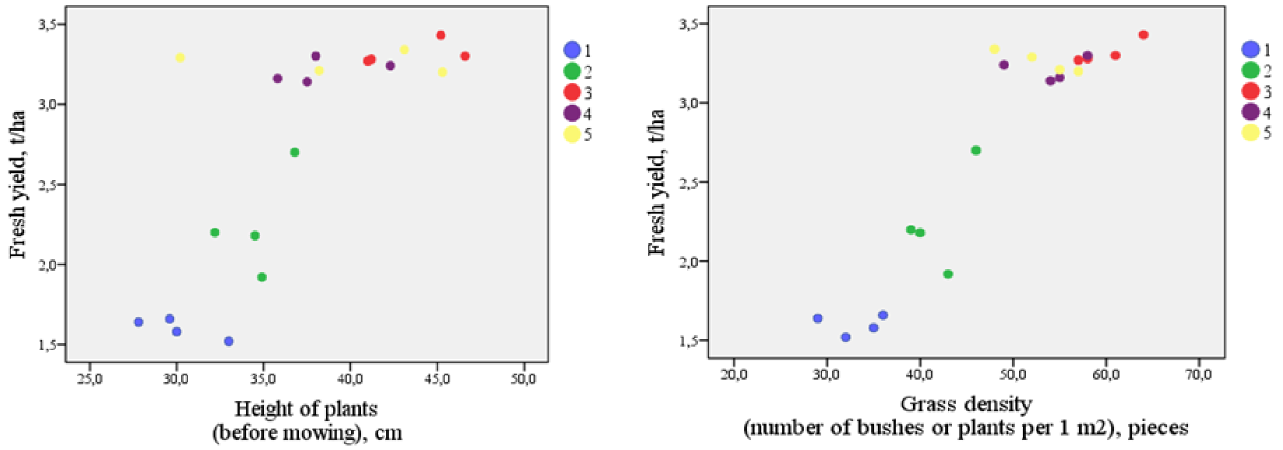

Fig. 5: Dependence of the yield of green mass of fatty bromegrass on the height and density of the grass stand when using different restoration techniques (average for 2022-2023); Experience variants: 1 - Naturally degraded wheatgrass pastures (control 1); 2 - Processing with disk harrows (control 2); 3 - Disc harrow tillage, combined with the application of organo-mineral fertilizer and bio-humus; 4 - Disc harrow tillage, combined with the application of biohumus; 5 - Disc harrow tillage, combined with the application of microbiological preparation with effective microorganisms

DISCUSSION

Improvement of Soil Indicators on Degraded Forage Lands of Wheatgrass in the Steppe Zone

Moisture availability is crucial for plants in the steppe zone of Northeast Kazakhstan. This is because evaporation exceeds precipitation by 2-3 times and groundwater is deep, limiting plant use. During the research period, unfavorable climatic conditions such as high temperature, low relative air humidity, precipitation deficit, and increased wind activity caused intensive soil moisture evaporation. As a result, a significant moisture deficit was created.

During the research three-year period (2021-2023), the moisture availability for plants during critical periods of growth and development, including tillering and stem elongation, was low. For instance, in May, the amount of precipitation for three years ranged from 3 to 9mm, with a long-term average of 25mm. High air temperatures further intensified the negative impact of the lack of moisture. These factors significantly impacted plant growth and aboveground mass accumulation, accelerating phenological phases and producing a low fresh yield.

Soil bulk density is of great agronomic importance as it significantly affects the living conditions of plants and soil organisms. Therefore, reducing soil bulk density to optimal values in compacted sodded wheatgrass crops in the steppe zone is crucial. According to Biryukova et al. (2008), an increase in compaction by 0.1g/cm^3 leads to a 10% increase in water content inaccessible to plants.

Soil compaction affects plant growth, resulting in stunted height, pale leaves, and disrupted root systems, ultimately leading to decreased crop yield. Depending on the soil and climate conditions, the extent of the yield loss can range from 5-25% (Remmert, 2012). Regulating soil bulk density is crucial for optimizing agricultural crop growth. Therefore, tillage compacted sodded forage lands with a disc harrow is more effective regarding productive moisture accumulation and soil bulk density level. The disc harrow loosens the soil well and increases its water permeability.

On the other hand, the toothharrow used in the experiment was inefficient as it was constantly clogged with plant residues and required additional cleaning. When used, the tines penetrate the soil to a depth of only 3-5cm, insufficient to significantly improve aeration in waterlogged soils. On uneven surfaces, the tines simply glide over the surface, while the harrow tines remove most of the living plants and sever individual surface roots of parent plants (Kukusheva et al., 2023).

Needle hoes have seemed to be more effective in agrotechnical indicators than tooth hoes: needles increase soil crumbling by an average of 7% and damage the crop 3-7 times less (Eremenko et al., 2018). Using a needle harrow on wheatgrass crops yielded different results than tooth harrows. It is worth noting that the needle harrow did not get clogged with plant residues during cultivation. Each needle penetrated the ground to a 7-10cm depth, loosening the soil and rupturing the root system of the pockmarked wheatgrass crops (Kukusheva et al., 2023). Needle harrows are primarily designed to loosen soil and create a loose mulch layer, which reduces moisture evaporation and protects against wind erosion. They can be used to accumulate moisture in forage lands. Using this tool on wheatgrass crops, particularly sodded grass stands, generally yields positive results compared to the variant without tillage. Our research indicates that the humus content increased in the variants with more active tillage impact on sodded areas of the wheatgrass, specifically during tillage with the needle harrow and disc harrow. Extended grassing with perennial grasses can increase the flow of fresh organic matter into the soil, replenishing the soil with nutrients and carbon. Due to its extensive root system, which can penetrate up to 2 meters deep, wheatgrass can accumulate up to 21 tons of root residues per hectare in the arable layer of soil over two years of vegetation. Studies conducted at the Ural Agricultural Experimental Station have shown that the growth of wheatgrass in the same location for several years increased the humus content in the 0-20cm soil layer to 3.07 and 2.7% in the 20-40cm layer (Chekalin, 2009). However, high soil bulk density reduces the number of microorganisms and their biological activity, which in turn disturbs normal gas exchange. Anaerobiosis begins to appear at densities greater than 1.45g/cm3 due to the reduction of macropores and large capillaries. This decreases air diffusion and gas exchange between the soil and atmosphere. This reduction in oxygen content in soils is significant. The direction of the biological transformation of substances changes, and the decomposition of organic matter is suppressed (Remmert, 2012).

Effectiveness of Applied Technologies on Restoration of Vegetation Cover of Wheatgrass in the Steppe Zone

Wheatgrass is distinguished by its ability to form a robust root system and, within a relatively short timeframe, develop a dense layer of strong sod. Over time, the density of the grass stand increases significantly, leading to increased competition between plants for water and nutrients. This, in turn, can result in a decline in yield. By the end of the first year, each wheatgrass shoot had developed 5-10thin roots, with each bush exhibiting at least 30- 50 roots. Perennial grass stands have 300-500 roots or more per bush (Shain & Karunin, 1950). Thus, our studies have shown that the disc harrow's high-speed movement effectively breaks apart compacted wheatgrass bushes, particularly those from the previous year, allowing for the formation of new root systems and young shoots (Kukusheva et al., 2023). Other authors' works support these findings. For instance, in the harsh conditions of the Far North East, mechanical treatments such as disking and harrowing were implemented to enhance low-productive meadow agrophytocenoses. The aim was to restore valuable local grass species in the herbage, as they are highly responsive to agronomic practices. As a result, the density of the grass stand increased to 980-1367 pieces per 1 m2, and the plant height exceeded the control by 2.3 times (Miller et al., 2020). Furthermore, surface tillage is equally efficient as root improvement, with the added benefit of faster cost recovery due to reduced soil preparation. Additionally, it increases fodder production by 50% (Grebennikov et al., 2021; Honina & Shipilov, 2021).

In the western piedmont of the Ural Mountains, disc tillage of old-growth crops of Eastern galega resulted in root shoot formation 10-20 days earlier than the control (Zubarev et al., 2016). In the dry-steppe zone of Northern Kazakhstan, plots of tillage with disc harrow and needle harrow BIG-3A positively affected the wheatgrass stand. The treatment resulted in early regrowth in spring and accelerated growth and development of plants during the growing season, compared to the variant without tillage (Bakhralinova et al., 2016). The Kruskal–Wallis H-test was used to compare the surface tillage methods of grass stands.

Statistically significant differences were found in the following indicators: soil bulk density (P=0.004), humus content (P=0.008), wheatgrass density (P=0.007), plant height (P=0.005), leaves proportion (P=0.009), stems proportion (P=0.005), inflorescences (P=0.016), and fresh yield (P=0.003). The differences were considered statistically significant at $P<0.05$. Therefore, all experimental variations significantly impacted the soil parameters and vegetation cover indicators, except for the amount of productive moisture (P=0.053). This may be due to the small number of observations, which did not provide enough power for the criterion.

The use of biological methods for restoring degraded pastures together with treatment by a disc harrow had a positive effect on the growth of wheatgrass crops and the formation of elements of their productivity. The microbiological preparation "Baikal EM-1" used in the experiment, containing a complex of natural living microorganisms, increases the drought and frost resistance of the crop, helps strengthen plant immunity, accelerates seed germination and plant regrowth, and ensures an increase in crop yields of up to 48-57% (Ivanova et al., 2022; Nellis, 2016). The high content of effective microorganisms in the composition of the microbiological preparation “Baikal EM-1” makes it possible to reduce the undesirable influence of pathogens in the environment; the resolution of microbial bodies leads to the entry of phosphorus into the soil, assimilated by plants in the form of nucleic acids and phospholipids, which quickly hydrolyzed by soil microflora with transfer of available phosphorus to plants (Nellis, 2016). The use of “Baikal EM-1” contributed to an increase in the leaf area of plants by 1.1-1.3 times (Hisamova et al., 2016).

Another type of biological additives is organo-mineral fertilizers. Low economic efficiency limits their use, mainly due to logistical difficulties in applying large volumes of organic fertilizers to vast areas. In addition, the insufficient nutritional value of materials such as cow manure and cake encourages industry to enrich them with soluble mineral components. This allows for achieving high nitrogen, phosphorus, and potassium concentrations in smaller volumes. Thus, organo-mineral fertilizers are a combination of organic and mineral elements that can be created in various proportions to meet the needs of crops (Timsina, 2018).

The composition of complex granular organo-mineral fertilizer fixes mineral nutrition elements in the organic granule, increasing their assimilation and reducing losses. For instance, the addition of organo-mineral fertilizers to sugar cane increased the yield by approximately two times compared to mineral fertilizers, depending on the fertilizer rate (Crusciol et al., 2020). According to other data, both mineral and organic, as well as organo-mineral fertilizers, increase the yield of grain crops, but there was no significant difference between them (Mumbach et al., 2020). The application of organo-mineral fertilizer stabilizes the humus soil conditions, improves the phosphate and potassium nutritional regimes of plants, and increases the yield by 2.2-13.3%, depending on the application dose (Naliukhin et al., 2018; Ageev et al., 2021). Additionally, a microbiological additive containing *Bacillus Subtilis* and *Bacillus Mucilaginosus* improves soil structure in the root zone, protects roots from pathogenic bacteria, and provides the plant with nutrients that are in the soil but not readily available for absorption (Dmitriyev et al., 2023).

Moreover, these bacteria belong to the growth-promoting rhizobacteria that inhabit the roots (Mahapatra et al., 2022). Soil rhizobacteria are important for increasing plant tolerance to biotic and abiotic stresses. This is achieved through the immune mechanism of induced systemic resistance, biofilm formation, and lipopeptide synthesis (Ramakrishna et al., 2020; Yadav et al., 2020a; Yadav et al., 2020b). They also act as effective agroecosystem denitrifying agents, promoting carbon sequestration at optimal concentrations (Rahimi et al., 2020). Inoculation with B. subtilis can positively and negatively affect endophytic and semi-synthetic microbial communities, significantly affecting plant health. Soil structure, type, pH, concentration, and strain of bacteria are key factors regulating these processes. Kiesewalter et al. (2020) reported that mutant strains of Bacillus subtilis in a semi-synthetic community either reduced the abundance of only two genera or had no effect on the microbiota. Li et al. (2015) demonstrated that soil type significantly modifies the effects of B. subtilis on bacteria: the soil had a significant negative correlation with bacterial diversity in the cucumber rhizosphere in clay compared to loamy and sandy soils.

According to our data, applying organo-mineral fertilizer together with vermicompost increased crop productivity by 3.4% more than in the variant with vermicompost. Bio-humus introduced in the experiment is also a good source of humic substances (up to 32% by dry weight), which gives it high agrochemical and growth-stimulating properties, ensuring an almost doubling of wheatgrass productivity in the experiment. All nutrients are present in a balanced combination of compounds bioavailable to the plant; it has good antagonistic properties against pathogenic microflora (Vuković et al., 2021; Rehman et al., 2023). Even replacing 40 and 50% of mineral fertilizers with biohumus on tomatoes significantly increased the weight and yield of fruits, accelerating ripening (Steffen et al., 2019). However, the effectiveness of organic fertilizers will correlate with climatic conditions. It was found that the health-improving effect of applying organic fertilizers in low-temperature zones increased significantly by 69.85% compared to high-temperature zones (Wang et al., 2024). When microbial suspensions and humic substances are applied together to stimulate plant growth, they induce physiological and metabolic changes that enhance plant defense against stress (Canellas et al., 2020; Bezuglova & Klimenko, 2022). For example, using biohumus enriched with cellulolytic microorganisms increased wheat's morphological, physiological, and biochemical parameters of wheat under conditions of severe drought. Inoculation with effective microorganisms and vermicomposting can reduce decomposition time and increase nutrients such as total nitrogen and phosphorus, humic substances, and carbon content (Apdraim et al., 2023). This helps in microbial soil structuring and reduces the influence of pathogenic microorganisms, increasing the stability of biocoenosis and resulting in a 1.5-2 times increase in yield (Maji et al., 2017; Pereira et al., 2022). This method also increases the yield of environmentally friendly and safe livestock products per unit. The use of bio-humus with the addition of various microorganisms increased the productivity of okra plants and improved soil fertility, compared with the option of using bio-humus alone (Baliah & Muthulakshmi, 2017). Humic substances, which are part of organic matter, stimulate the growth and development of the root system and aboveground parts of the plant, mitigating stress damage, including stress from lack of moisture (García et al., 2012). They increase nutrient availability and absorption by changing root anatomy and soil physicochemical properties (Nardi et al., 2017). They also promote the release of organic acids from plant roots, which are fed by bacteria, actively promoting their repopulation of the root zone. This creates benefits for both plant and soil health (da Silva et al., 2021). The application of humic substances and growth-stimulating microorganisms can enhance plant growth, resulting in increased weight and higher nutrient content (Nikbakht et al., 2008; Balmori et al., 2019; Gomes et al., 2019; Kováčik et al., 2022). For instance, the application of Bacillus inoculation and humic substances to tomato plants resulted in higher iron and potassium contents, as well as increased shoot and root growth. Similarly, the use of potassium humate on chicory led to plant growth and changes in the number of bacterial autotrophic and heterotrophic nitrifiers in the soil (Galambos et al., 2020). Applying a bio-stimulator based on humic acids and microorganisms has shown effectiveness on okra and cassava, increasing their yield by 70 and 50% on lands of natural fertility (Canellas et al., 2022). Thus, the various studies presented on the combined use of humic substances in the composition of bio-humus and microorganisms confirm our results and show the effectiveness of this technique for increasing crop productivity and improving the soil health of degraded lands.

Conclusion

The research results indicate that the most effective method for restoring degraded crops in the steppe zone of Northeast Kazakhstan is surface tillage with a disc harrow. This method reduces soil bulk density, improves water and air permeability, and increases humus content by loosening the soil and destroying part of the sod. The joint application of disc harrow tillage with biological preparations and bio-humus had a positive effect on the biometric indicators and fresh yield of wheatgrass plants, increasing it by almost two times. Therefore, increasing the area of hay and pasture lands in the steppe zone can solve issues related to desertification and provide a stable supply of nutritious fodder for livestock in extreme climatic conditions. This can be achieved through the introduction of effective methods of restoration of degraded wheatgrass crops and their rational use.

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Conflict of Interest

The authors state no conflict of interest.

Author Contribution

AK: conceptualization, resources, writing - original draft. ZK: methodology, resources, writing - review & editing. ZU: resources, validation, data curation. AS: methodology, resources. BN: conceptualization, funding acquisition.

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