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Bio-Organic Fertilizer Application for Forage Quality Improvement and Rangeland Restoration in Northern Kazakhstan's Steppe Ecosystems

Zhibek Nokusheva[1], Beybit Nasiyev[2], Elmira Kantarbayeva[3*], Nurbolat Zhanatalapov[2], Askhat Bekkaliyev[2], Aigerim Khairush[2], Askhat Okshebayev[2]

[1] LLP "North Kazakhstan Scientific Research Institute of Agriculture", Astana 010000, Kazakhstan
[2] Zhangir Khan West Kazakhstan Agrarian-Technical University, Uralsk 090000, Kazakhstan
[3] Department of Agronomy and Forestry, M. Kozybayev North Kazakhstan University, Petropavlovsk 150000, Kazakhstan

Corresponding Author Email: e.kantarbayeva@gmail.com

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ABSTRACT

The study is devoted to developing technologies and methods for harvesting fodder from the forage lands of Kazakhstan in the framework of sustainable management. In the context of climate change, pasture degradation, and the growing need for fodder resources, providing high-quality fodder for the agricultural sector is becoming a key factor in the country's food security. The paper analyzes the effects of modern organic fertilizers on the condition of rangelands in the Northeastern steppe zone of Kazakhstan. The parameters include the geobotanical composition of pastures, projective coverage, plant density, green and dry mass yields, and the nutritional composition of pasture grass. Bio-organic fertilizers were found to improve each examined indicator. Compared with the control, the application of WUXAL Aminoplant along with organic fertilizer "Kazuglegumus" increased green mass yield to 0.90 t/ha from 0.53 t/ha, dry mass yield to 0.27 t/ha from 0.16 t/ha, and digestible protein content to 0.013 t/ha from 0.007 t/ha. Humate + CO_2, along with Stoller Energy, also showed meaningful improvements. The paper concludes that bio-organic fertilizers increase forage yield, protein content, and energy values, specifically when restoring degraded pastures. However, the study's generalizability may be affected by its one-season and one-region limitation. Future research should expand to multi-year trials along with multi-regional trials, in addition to impacting long-term soil health, and also determining economic feasibility. Based on the conducted analysis, recommendations are proposed for improving the current condition of forage lands and ensuring a sustainable supply in the agricultural sector of Kazakhstan.

1. INTRODUCTION

Natural forage lands present an important reserve for strengthening the fodder base [1, 2]. Pastures occupy 67% of Kazakhstan. These lands (184.2 million ha) shape the ecological condition of the country. Covering a vast natural zone, pastures annually regenerate up to 28 million t of fodder units in the form of plant products that are free of cost and nutritionally valuable. The condition of these pastures affects the environment and human health [3] and the condition and development of animal husbandry [4-6].

Numerous studies indicate that pasture grass contains significantly more nutrients compared to hay prepared without leaf loss from the same grass. Fresh grass usually contains more moisture and nutrients, including proteins and vitamins, compared to hay, which can lose some nutrients during drying and storage [7-9]. In spring and summer, pasture herbage remains the primary food source for cattle. Summer grazing on pastures significantly improves the condition of livestock, promoting better reproduction and reducing the incidence of disease, e.g., endometritis (by 24.3%), compared to stall housing [10, 11].

Apart from the greater nutritional value, pasture fodder has economic advantages, as fodder produced on natural hayfields and pastures has the lowest cost. Financial efficiency is crucial for the sustainable development of agriculture because it ensures that resources are used efficiently to support economic, environmental, and social goals and strategies for further development [12, 13]. Due to the low cost of pasture fodder, pasture grazing becomes incomparably cheaper than stall housing and requires considerably less labor. Studies suggest that one unit of pasture fodder is 1.5–2.5 times cheaper than a unit of hay fodder, 2–3 times cheaper than grain feed, and 3.5–5 times cheaper than succulent feed [14].

Furthermore, agricultural ecosystems efficiently use natural resources such as solar energy and nitrogen fixation, which promote the use of bio-organic preparations and fertilizers [15, 16]. The ecological niche differentiation approach described by Shamsutdinov et al. [17] in arid pastures of Central Asia demonstrated that when plant species complement each other in the use of soil and climatic resources, the overall productivity of natural ecosystems increases, accelerating the recovery of degraded vegetation and lowering the cost of fodder production. Similarly, Satrija et al. [18] showed that grazing livestock on diverse natural forages not only improves the nutrient balance in their diets but also enhances health through natural bioactive compounds, reducing veterinary costs and improving overall physiological condition.

A higher share of pasture fodder in livestock diets will also lower costs per unit of animal production [19-21]. Abdullayev et al. [19] emphasized that strategic management of regional animal husbandry using efficient feeding systems and adaptive breeding directly increases profitability and reduces production expenses. Recent experimental work [20] confirmed that locally produced bio-organic feed mixtures, such as "Topirum" based on Rumex K-1 and Helianthus tuberosus, significantly improve weight gain and metabolic health in sheep while cutting feed costs in arid conditions. At a broader scale, Kuznetsova et al. [21] highlighted that strengthening human capital and modernizing agricultural management systems are essential for sustainable cost efficiency and profitability in livestock production.

In July 2024, Kazakhstan adopted the Model Plan for Pasture Management and Use, which centers on the rational use of pastures, sustainable fodder supply, and the prevention of degradation processes. The implementation of this plan will significantly increase fodder production, especially in summer, and reduce the cost prices of livestock products [22].

Although pasture fodder offers numerous advantages, the rangelands of North Kazakhstan remain in a critically degraded state. Large areas are overgrown with shrubs and uneven microrelief, while solonetz soils and seasonal swamping limit the growth of productive species [23, 24]. The average yield rarely exceeds 0.13–0.14 t/ha of fodder units, and most of the previously sown grasses have lost their vitality and regenerative capacity. Existing restoration methods have shown limited effectiveness under the region's arid and saline conditions. In recent years, considerable areas of land formerly used for cereals and other field crops have gone barren. In this light, the issues of improving forage lands are becoming particularly pressing [25, 26].

One possible solution to the outlined problem is treatment with bio-organic preparations and fertilizers, which improve soil fertility and increase crop yields, thereby strengthening the livestock fodder base and restoring natural pastures [27-29].

Thus, sustainable and productive fodder bases with high-quality feed play a crucial role in increasing the effectiveness of contemporary animal husbandry. This raises the need to develop techniques to restore the bioresource potential of degraded pastures in the steppe zone of North Kazakhstan [30], which can be accomplished using bio-organic preparations and fertilizers relying on the principles of organic farming. According to the International Federation of Organic Agriculture Movements [31], these principles include Health, Ecology, Fairness, and Care. All of them define organic agriculture as a system that sustains and enhances the health of soils, plants, animals, and humans as one whole. They call for the management of agroecosystems in harmony with natural cycles, responsible use of resources, and the exclusion of synthetic chemical inputs. Applying these principles promotes long-term soil fertility, biodiversity conservation, and resilience of steppe ecosystems.

Accordingly, the present study is aimed at developing techniques for restoring the bioresource potential of degraded pastures in the steppe zone of North Kazakhstan using bio-organic preparations and fertilizers based on the principles of organic farming.

2. METHODS

2.1 Location

The research was conducted at the North Kazakhstan Scientific Research Institute of Agriculture based on the B.A. Shaimerdenov Peasant Farm in the North Kazakhstan Region. Experimental studies were conducted on an unproductive degraded pasture measuring 1 ha. Experimental plots were established according to the study design in the Akkayin District, North Kazakhstan Region (coordinates: 54°30′08″ N, 69°05′26″ E). Each treatment was applied to three replicated plots (0.25 ha each), arranged in a randomized block design to ensure the statistical validity of the results.

2.2 Climatic background

The North Kazakhstan Region spans two natural zones, forest-steppe and steppe, which largely determine its landscapes, primary natural resources, soil, and climate. The region belongs to the zone of risky agriculture.

The region has three agroclimatic zones:

1. Low water availability, moderately warm, represented by forest-steppe landscapes, with a hydrothermal coefficient (HTC) of 1.0–1.1 and the sum of above-zero temperatures over 10°C at 2,000°C–2,100°C.

2. Arid, moderately warm, occupied by forest-steppes and steppes, with an HTC of 0.8–1.0 and an annual sum of active temperatures (above 0°C) totaling 2,100–2,200°C·days.

3. Arid, warm, spanning across steppe landscapes in the eastern and western parts of the south of the region, with an HTC of 0.7–0.9 and an annual sum of active temperatures (above 0°C) totaling 2,200 to 2,400 degree-days (°C·days).

The territory is easily invaded by cold Arctic and warm air masses from Central Asia. As a result, the weather changes frequently. In general, the climate is sharply continental with cold, long winters and hot summers. The period of stable snow cover lasts more than 6 months. The height of the snow cover ranges from 12 to 35 cm. Snow water reserves amount to about 50–69 mm, accounting for 22–23% of total water availability.

Daily temperatures average at –18.5°C to -19.1°C in the coldest month of January and +19.0°C to +19.5°C in the hottest month of July. In summer, on especially hot days, the air temperature climbs up to +41.0°C, and in winter it drops to around -35.0°C, sometimes reaching -45.0°C.

In January 2024, the average air temperature ranged from -16°C to -15°C, and the height of snow cover on the experimental plot was 42-44 cm. In February, the air temperature dropped to -15°C to -14°C, while the snow cover height decreased to 35–37 cm. The winter was marked by a relatively high snow cover, which contributed to moisture accumulation in the soil. In spring, snow started melting early, which additionally moistened the upper layers of soil and created favorable conditions for the beginning of crop vegetation. Average temperatures in March ranged from -9°C to -4°C. In the spring of 2024, soil moisture availability in North Kazakhstan was significantly affected by climatic conditions. Transition to above-zero daily temperatures occurred at the beginning of April, and 20–30 days later, average daily temperatures reached 10°C to 11°C.

Spring begins in the second half of April and lasts about 20–

30 days, with limited precipitation and average daily temperatures rising above 5°C in late April. Temperatures above 5°C are registered around April 20–22, and the 10°C mark is surpassed near May 8–10. Spring moisture reserves in soil are created mainly by autumn-winter precipitation and constitute the main source of water supply for plants in the early period of their vegetation. May and June often bring dry winds and dust storms. Average daily temperatures remain above 10°C for approximately 130–140 days, and the sum of temperatures above 10°C reaches 2,000–2,400°C·days.

In autumn, temperatures drop below 10°C by September 17–20. These dates also mark the end of the vegetation period. On average, the frost-free period lasts 120–130 days. Average annual precipitation ranges from 300 to 330 mm, with 60% occurring during the growing season. The greatest amount of precipitation falls in July and August (58 mm and 48 mm, respectively). Precipitation is also uneven across the years. Some years come short of the norm, while others exceed it by 1.5 to 2 times. June droughts are a characteristic feature of the zone.

Over the past 30 years of observation, 14 years (47%) showed relatively high annual precipitation (above 330–350 mm), 8 years (26.5%) had average precipitation (300–330 mm), and 8 years (26.5%) brought insufficient precipitation (220–300 mm).

The region's soil cover has several features determined mainly by its climate: sharp continentality, uneven snow distribution, frequent snowstorms, dry springs, weak bacterial processes in organic matter decomposition, the influence of winds on soil movement, and uneven moistening of soils due to their insufficient drainage [32]. Soil drainage in the region worsens closer to the north. The hydrophysical properties of soils, including forest soils, have little variation and are closely associated with soil salinity [33-35].

The most favorable conditions for crop cultivation are found in the first zone, which has more favorable moisture conditions and is dominated by ordinary chernozems and meadow-chernozem soils with a quality score of 70–75 out of 100. This zone primarily includes the Kyzylzhar District, Mamlyut District, Akkayin District, Esil District, Zhambyl District, and Magzhan Zhumabayev District.

The second and especially the third agroclimatic zones have harsher conditions for plants. Ordinary chernozems are replaced by carbonate and southern chernozems with solonetz complexes and bedrock coming up to the soil surface. The quality index of these soils ranges from 50 to 65, and precipitation reaches only 220 to 290 mm.

These zones primarily include the Taiynsha District, Akzhar District, Aiyrtau District, Timiryazev District, Ualikhanov District, Shal akyn District, and Gabit Musirepov District.

This description demonstrates that each farm needs to consider its agroclimatic conditions when working on its fodder base.

2.3 Methods

Counts and observations of the processes and results of the experiment were conducted according to the methodological guidelines of the All-Russian Williams Fodder Research Institute [33]. A detailed description of the experimental procedure is provided below. The design of the experiments is detailed below. The geobotanical composition of natural pastures was studied using a route survey to determine the composition of plant species. In addition, plant density was determined as an indicator largely determining the productivity of agrophytocoenoses [36, 37]. The data obtained were subjected to analysis of variance following the methodology described by Marchenko et al. [38].

2.4 Stages of the experiment

Prior to the experiment, productive moisture was measured in the 0–100 cm soil layer.

The counts and observations conducted after treatment with fertilizers (Table 1) included the following:

- monitoring meteorological conditions;
- determining the geobotanical composition of the pasture;
- determining the projective coverage of pastures;
- determining the height of pasture plants;
- determining the density of pasture plants;
- determining the yield of green and dry mass;
- determining the chemical composition of pasture grass.

Table 1. Scheme of field experiments aimed at developing methods to restore the bioresource potential of degraded pastures in the steppe zone of North Kazakhstan using bio-organic preparations and fertilizers

No.	Experiment Variant	Fertilizer Type and Composition	Time and Frequency of Application
1	Natural degraded pasture (control)	–	No treatment (baseline)
2	WUXAL Aminoplant + Organic fertilizer "Humate + CO_2"	Anti-stress biostimulant + liquid humate	Applied twice per vegetation season: 5 L/ha before grazing (1st decade of May) + 5 L/ha after grazing (1st decade of June)
3	Stoller Energy + Organic fertilizer "Humate + CO_2"	Biostimulant + liquid humate	Applied twice per vegetation season: 5 L/ha before grazing (May 1–10) + 5 L/ha after grazing (June 1–10)
4	WUXAL Aminoplant + Organic fertilizer "Kazuglegumus"	Anti-stress biostimulant + organic humus concentrate	Applied twice per vegetation season: 5 L/ha before grazing (May 1–10) + 5 L/ha after grazing (June 1–10)

Note: Each treatment was applied twice per vegetation season, before grazing in the first decade of May and after grazing in the first decade of June at a rate of 5 L/ha per application.

A natural degraded pasture was selected as the control variant because it represents the typical unmanaged condition of rangelands in Northern Kazakhstan. Using a naturally degraded site ensured ecological realism and allowed the effects of bio-organic fertilizers to be evaluated under the actual stress factors that characterize the region. Artificial degradation was not simulated, as it would not reproduce these complex field interactions [39].

Prior to treatment, composite soil samples were collected from the 0–30 cm layer of each experimental plot to determine the basic agrochemical parameters of the soil (Table 2).

Soil moisture plays a major role in the development of the shoots and roots of young plants [40]. Many chemical, biological, and physicochemical processes, as well as the availability of nutrients for plants, depend on soil moisture content [41, 42]. To determine productive moisture reserves in the 0–100 cm soil layer on the pasture plot, soil samples were collected before the first treatment with bio-organic preparations and fertilizers. Next, from February to March, snow retention was carried out twice using SVU-2.6 trailed snow plows and MTZ-80 tractors. A spring geobotanical analysis of pasture vegetation was conducted in the second decade of April. In the first decade of May, biologicals and fertilizers were applied according to the established scheme of experiments before grazing. The second round of treatment was performed in the first decade of June using a John Deere self-propelled sprayer.

To assess the quality and nutritional value of fodder, chemical analysis of samples from different variants of the experiment was conducted in the research and innovation complex of North Kazakhstan Research Institute of Agriculture with an InfraXact Express Analyzer (Denmark), a near-infrared spectrometer. The InfraXact express analyzer is designed to determine several parameters (protein, moisture, fat, starch, calcium, phosphorus, lactic acid, acetic acid, pH, fiber, etc.).

Table 2. Baseline agrochemical properties of the soil

Parameter	Unit	Mean ± SD	Interpretation
pH (H_2O)	-	7.2 ± 0.1	Neutral to slightly alkaline
Organic matter	%	3.1 ± 0.2	Moderate humus content
Total nitrogen (N)	%	0.19 ± 0.01	Medium
Available phosphorus (P_2O_5)	mg/kg	18.4 ± 1.2	Low–medium
Exchangeable potassium (K_2O)	mg/kg	210 ± 15	High
Bulk density	g/cm³	1.25 ± 0.03	Typical for ordinary chernozem
Electrical conductivity	dS/m	0.37 ± 0.04	Non-saline

Note: The soil of the experimental site corresponds to ordinary chernozem with moderate humus content and good structural stability. Values represent the average composition of degraded pasture soils in the Akkayin District according to monitoring data.

3. RESULTS

Table 3 summarizes the geobotanical composition of the studied natural pastures.

Table 3. Geobotanical composition of pasture herbage under different variants of treatment with biologicals and bio-organic fertilizers in the steppe zone of North Kazakhstan in 2024

Experiment Variant	Species Composition and Structure of Herbage, %		
	Volga fescue	Mugworts	Forb
Natural degraded pasture (control)	45	33	22
WUXAL Aminoplant (Anti-stress biostimulant) + Organic fertilizer "Humate + CO_2"	44	38	17
Stoller Energy + Organic fertilizer "Humate + CO_2"	46	37	17
WUXAL Aminoplant (Anti-stress biostimulant) + Organic fertilizer "Kazuglegumus"	43	35	22

Table 4. Productive moisture reserves of pastures under different variants of treatment with biologicals and bio-organic fertilizers in the steppe zone of North Kazakhstan in 2024, mm

Experiment Variant	Before Grazing
Natural degraded pasture (control)	62.0
WUXAL Aminoplant (Anti-stress biostimulant) + Organic fertilizer "Humate + CO_2"	57.5
Stoller Energy + Organic fertilizer "Humate + CO_2"	61.2
WUXAL Aminoplant (Anti-stress biostimulant) + Organic fertilizer "Kazuglegumus"	59.4

The projective coverage of pastures ranged from 50 to 60%. The pasture plots surveyed can be attributed to the Volga fescue-mugwort-forb type. This type is dominated by Volga fescue with subdominant species including mugworts, plantains, sea lavenders, and needle grasses. The analysis of geobotanical composition indicates that Volga fescue constitutes around 44.5% of pasture herbage, mugworts make up 35.7%, and forb accounts for 19.5%.

During the regrowth period, differences in productive moisture reserves in the 1 m soil layer were insignificant, averaging 55 mm. Precipitation in early spring improved soil moisture availability. However, later in the spring, precipitation in the region was non-uniform, which could have affected soil water holding capacity in the area. Overall, spring moisture in 2024 played an important role in initial plant development and determined the success of agricultural operations in the fields throughout the growing season (Table 4).

Studies suggest that undergrazing of pasture grasses reduces aboveground vegetative mass and significantly lowers the suction power of root systems, sometimes by 6–7 times. When grass is overgrown, the top layer becomes less dense, and animals grazing at a grass height of 25–30 cm eat only the tops of plants 6–8 cm long. The experiments show that the maximum amount of fodder is collected when grass height reaches 12–15 cm. Considering the botanical composition of the herbage, the height of the predominant grass species was measured before and after grazing. The period of most active growth was from late May to June in the vegetative period. Herbage growth was greatest in May with increasing temperatures. The soil dried and flowering initiated, so growth reduced in July and August. Field measurements of dominant species show average heights of 10-14 cm around early May and 19-22 cm around late June. The average height of the dominant plant species before and after grazing were as follows: in the control variant — 19 cm for Volga fescue, 15 cm for mugworts, and 16 cm for forb; in the variant with WUXAL Aminoplant (anti-stress biostimulant) and organic fertilizer "Humate + CO_2" — 20 cm, 17 cm, and 19 cm; in the variant with Stoller Energy and organic fertilizer "Humate + CO_2" — 21 cm, 19 cm, and 22 cm, respectively.

The data in Table 3 were used to plot the relationship between the reserve of productive moisture and the variant of treatment with biologicals and bio-organic fertilizers (Figure 1).

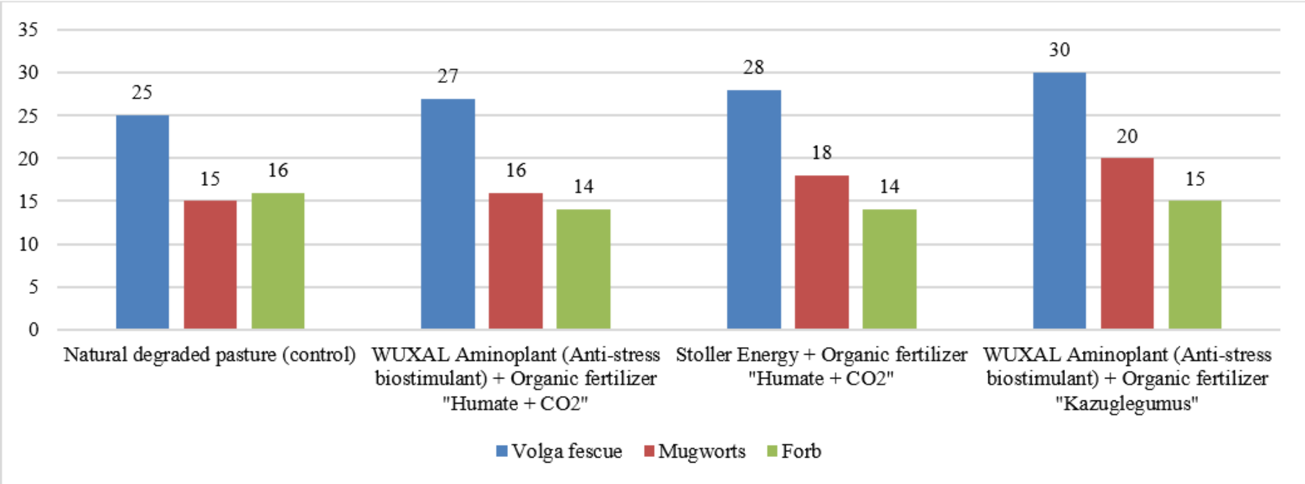


Figure 1. Productive moisture reserves of pastures under different variants of treatment with biologicals and bio-organic fertilizers

Table 5. Height of pasture herbage under different variants of treatment with biologicals and bio-organic fertilizers in the steppe zone of North Kazakhstan in 2024

Experiment Variant	Plant Height, cm		
	Volga fescue	Mugworts	Forb
Natural degraded pasture (control)	19	15	16
WUXAL Aminoplant (Anti-stress biostimulant) + Organic fertilizer "Humate + CO_2"	20	17	19
Stoller Energy + Organic fertilizer "Humate + CO_2"	21	19	22
WUXAL Aminoplant (Anti-stress biostimulant) + Organic fertilizer "Kazuglegumus"	22	23	27

The variant with WUXAL Aminoplant combined with organic fertilizer "Kazuglegumus" is marked by the greatest height of Volga fescue, mugworts, and forb: 22, 23, and 27 cm, respectively (Table 5).

The positive influence on the growth of pasture plants in these variant stems from one of the leading advantages of organic fertilizers: increased soil fertility, activation of soil micronutrients, intensified formation and recovery of humus, and improved soil structure and water-air regime (Table 6) [42]. The high efficiency of WUXAL Aminoplant + Kazuglegumus in fertilization systems is related to the chemical composition of the amino fertilizer "Kazuglegumus", including a high content of humic and fulvic acids, trace elements (Fe, Mn, Zn, Cu), and biologically active organic carbon. Humic substances increase the cation-exchange capacity of the soil, the solubility of plant nutrients, and improve the activities of the soil microflora.

Using the data in Table 6, we put together a graph of pasture plant height by different variants of treatment with biologicals and fertilizers (Figure 2).

The treatment of pastures with biologicals and bio-organic fertilizers greatly reduces variation in grass growth, as demonstrated by lower coefficients of variance both for Volga fescue – 5.4% (control) versus 4% (WUXAL Aminoplant (anti-stress biostimulant) + Organic fertilizer "Kazuglegumus"), for mugworts – 16% versus 13.5%, and for forb – 19.3% versus 16%. These results indicate a higher resistance of herbage to external factors and a greater stability of its development under the influence of agrochemical agents, which may be useful for increasing the productivity of pastures in the steppe zone of North Kazakhstan.

Plant height of pasture herbage was monitored at two growth stages – during the regrowth period and before winter – as presented in Table 7.

Table 6. Coefficient of variation of grass height on pastures under different variants of treatment with biologicals and fertilizers

Experiment Variant	Plant Height, cm		
	Volga fescue (CV%)	Mugworts (CV%)	Forb (CV%)
Natural degraded pasture (control)	5.4	16.0	19.3
WUXAL Aminoplant (Anti-stress biostimulant) + Organic fertilizer "Humate + CO_2"	4.8	15.0	18.0
Stoller Energy + Organic fertilizer "Humate + CO_2"	4.5	14.0	17.5
WUXAL Aminoplant (Anti-stress biostimulant) + Organic fertilizer "Kazuglegumus"	4.0	13.5	16.0

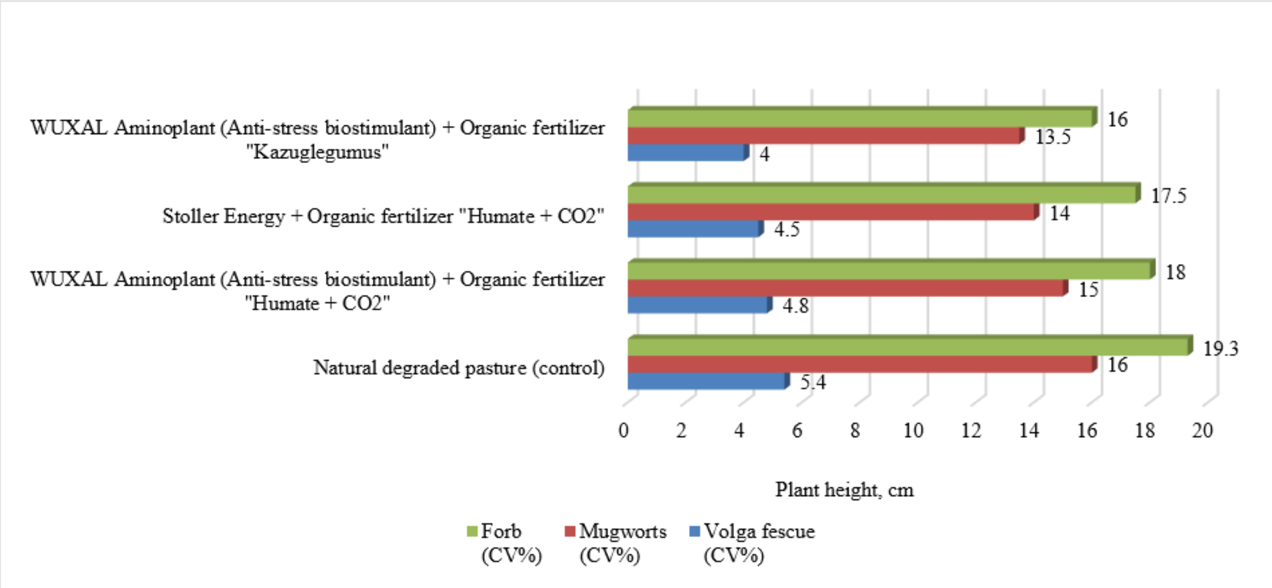


Figure 2. Coefficient of variation of grass height on pastures under different variants of treatment with biologicals and fertilizers

Table 7. Height of pasture herbage at different growth stages under various treatments with biologicals and bio-organic fertilizers in the steppe zone of North Kazakhstan in 2024, cm

Experiment Variant	Regrowth Period			Before Winter		
	Volga fescue	Mugworts	Forb	Volga fescue	Mugworts	Forb
Natural degraded pasture (control)	24	17	11	25	15	16
WUXAL Aminoplant (Anti-stress biostimulant) + Organic fertilizer "Humate + CO_2"	25	19	12	27	16	14
Stoller Energy + Organic fertilizer "Humate + CO_2"	27	17	13	28	18	14
WUXAL Aminoplant (Anti-stress biostimulant) + Organic fertilizer "Kazuglegumus"	29	19	15	30	20	15

During this period, plant height ranged from 24 to 29 cm in Volga fescue, from 17 to 19 cm in mugworts, and from 11 to 15 cm in forb. The dominant species in pasture herbage was Volga fescue, a semi-hardy plant with significant advantages in adaptation to environmental conditions (Figure 2).

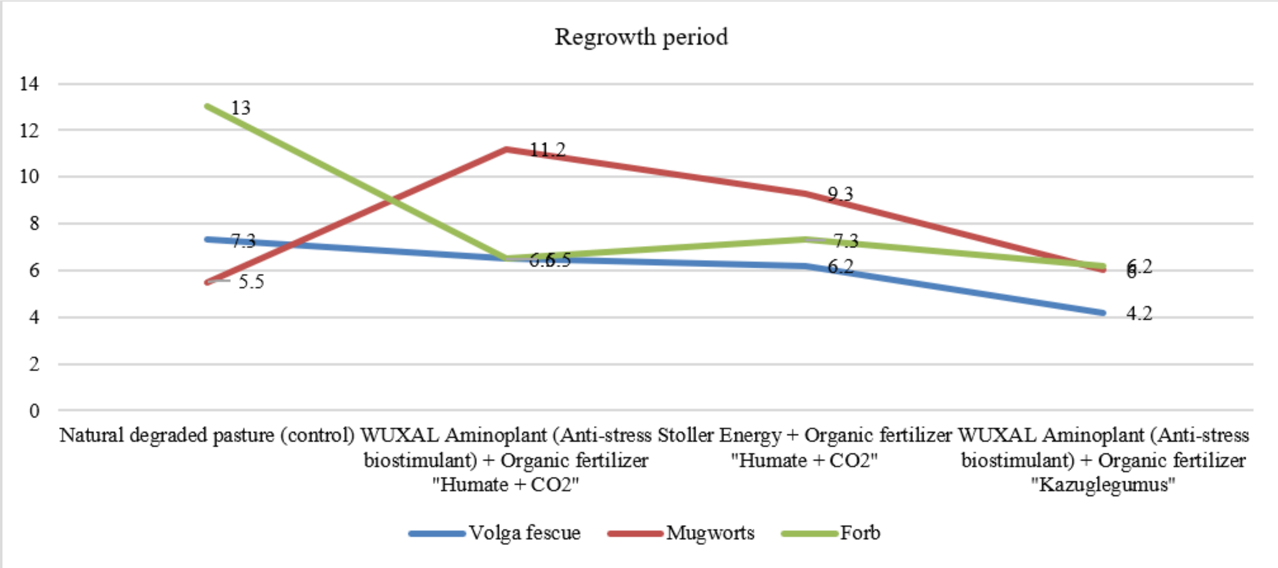
Before winter, the post-grazing height of plants reached 25–30 cm in Volga fescue, 15–20 cm in mugworts, and 14–16 cm in forb. The greatest plant height was obtained with the combination of WUXAL Aminoplant and "Kazuglegumus": 30 cm for Volga fescue, 20 cm for mugworts, and 15 cm for forb. The productivity of natural vegetation cover in the steppe zone of Northern Kazakhstan, measured in pasture potential, is 0.15 to 0.24 t/ha of dry mass. This level comes as a result of prolonged unsystematic use of natural resources, which has led to degradation exacerbated by stringent water regimes and low soil fertility.

Based on the data in Table 8, we created a graph of the coefficient of variation of grass height on pastures in relation to the variant of treatment with biologicals and fertilizers (Figure 3).

The application of WUXAL Aminoplant (anti-stress biostimulant) in combination with organic fertilizer "Kazuglegumus" reduces the variability of herbage density on pastures, which is confirmed by low coefficients of variation (4.10–6.10%) across all plant species in both periods (regrowth and pre-winter). Thus, the treatment enhances the stability of herbage, increasing its stress resistance and optimizing plant growth. In contrast, control plots show much greater variability, especially in forb and mugworts, which proves the effectiveness of biologicals in increasing the pasture productivity in the steppe zone of North Kazakhstan (Table 9).

Table 8. Coefficient of variation of plant density on pastures under different variants of treatment with biologicals and fertilizers (coefficient of variation – CV)

Experiment Variant	Regrowth Period			Before Winter		
	Volga fescue (CV%)	Mugworts (CV%)	Forb (CV%)	Volga fescue (CV%)	Mugworts (CV%)	Forb (CV%)
Natural degraded pasture (control)	7.31	5.5	13	6.5	11.3	6.6
WUXAL Aminoplant (Anti-stress biostimulant) + Organic fertilizer "Humate + CO_2"	6.5	11.2	6.5	6.5	11.4	6.5
Stoller Energy + Organic fertilizer "Humate + CO_2"	6.2	9.3	7.3	6.1	9.2	7.3
WUXAL Aminoplant (Anti-stress biostimulant) + Organic fertilizer "Kazuglegumus"	4.2	6	6.2	4.1	6.0	6.1



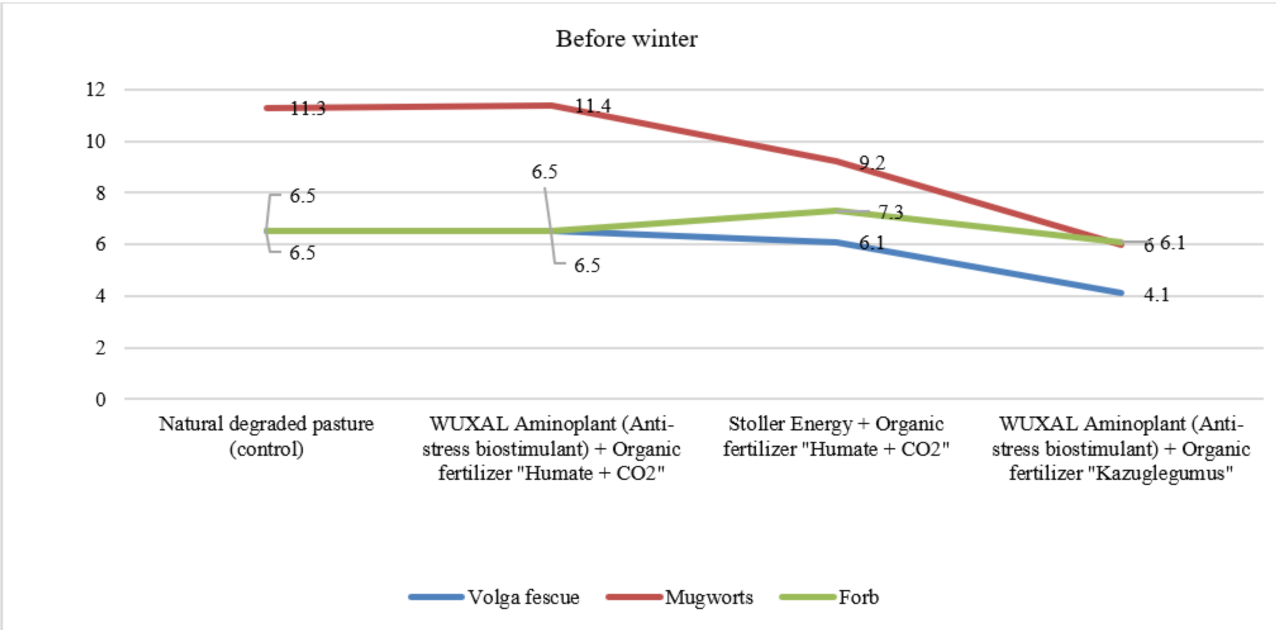


Figure 3. Coefficient of variation of plant density on pastures under different variants of treatment with biologicals and fertilizers

Table 9. Productivity, nutritional value, and energy-protein value of pasture herbage under different variants of treatment with biologicals and bio-organic fertilizers in the steppe zone of North Kazakhstan in 2024

Experiment Variant	Green Mass Yield, t/ha	Dry Mass Yield, t/ha	Digestible Protein Yield, t/ha	Fodder Unit Yield, t/ha	Metabolic Energy Yield, GJ/ha
Natural degraded pasture (control)	0.53[c]	0.16[c]	0.007[c]	0.062[c]	0.76[c]
WUXAL Aminoplant (Anti-stress biostimulant) + Organic fertilizer "Humate + CO_2"	0.81[b]	0.24[b]	0.010[b]	0.082[b]	0.98[b]
Stoller Energy + Organic fertilizer "Humate + CO_2"	0.72[b]	0.22[b]	0.009[b]	0.066[b]	0.80[b]
WUXAL Aminoplant (Anti-stress biostimulant) + Organic fertilizer "Kazuglegumus"	0.90[a]	0.27[a]	0.013[a]	0.113[a]	1.37[a]

Note: Means followed by the same letter within a column are not significantly different according to the LSD test at $p < 0.05$.

The greatest yield of green and dry mass was obtained with complex fertilizers, especially in the variant of WUXAL Aminoplant and organic fertilizer "Kazuglegumus", where yields amounted to 0.90 t/ha of green mass and 0.27 t/ha of dry mass (Table 9). The overall trend of improvement in nutritional indicators is further illustrated in Figure 4, where digestible protein and metabolic energy show consistent increases across all fertilizer variants. The combination of WUXAL Aminoplant and Kazuglegumus significantly ($p < 0.05$) increased green mass yield (0.90 t/ha) and dry mass yield (0.27 t/ha) compared with the control (0.53 and 0.16 t/ha). Digestible protein yield (0.013 t/ha) and metabolic energy (1.37 GJ/ha) were also significantly higher ($p < 0.05$).

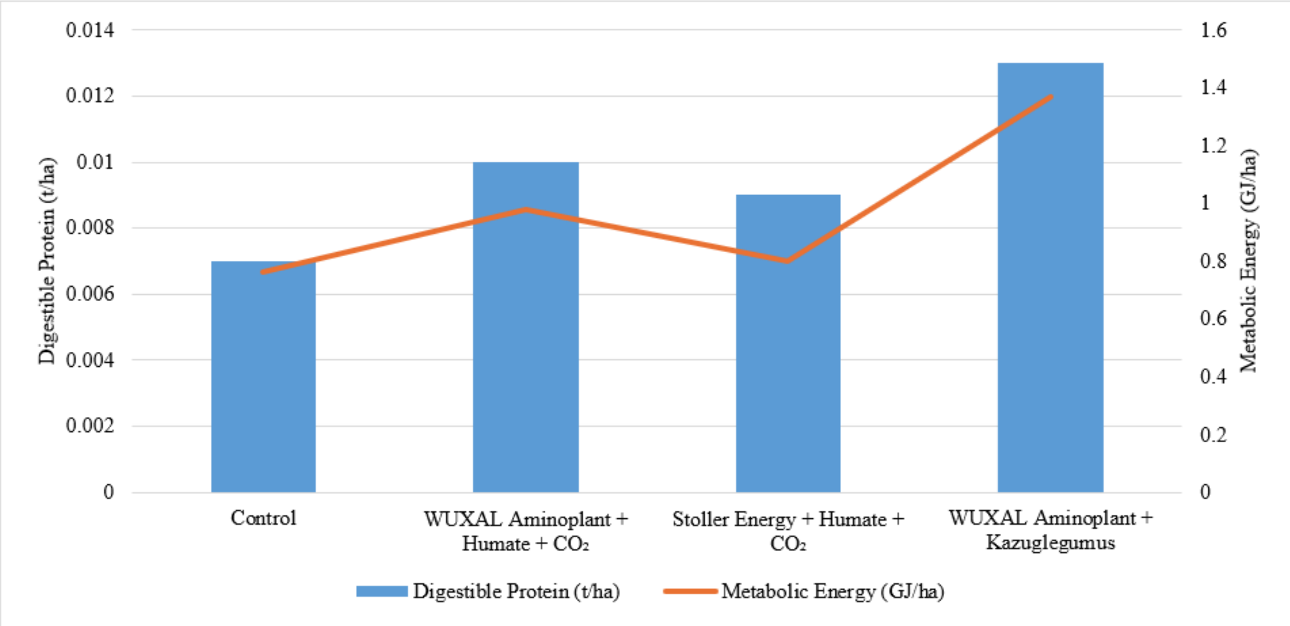


Figure 4. Trends of digestible protein and metabolic energy yield under different fertilizer treatments in 2024

Our studies demonstrate that the scheme of treatment with WUXAL Aminoplant (anti-stress biostimulant) + Organic fertilizer "Kazuglegumus" contributed to the improvement of bioresource potential on degraded pasture plots, increasing green mass yield from 0.53 to 0.90 t/ha, or by 1.7 times.

Biochemical analysis demonstrates that the herbage of natural pastures contained 43.4 g of digestible protein per kg of dry matter, 0.38 fodder units per kg of dry matter, and 4.66 MJ of metabolic energy per kg of dry matter. In the second variant involving treatment with WUXAL Aminoplant + Organic fertilizer (Humate + CO_2), the content of digestible protein reached 65.21 g/kg dry matter, the content of fodder units – 0.34 per kg dry matter, and metabolic energy – 4.12 MJ/kg dry matter. In the third variant with Stoller Energy + Organic fertilizer (Humate + CO_2), the obtained feed contained 38.61 g of digestible protein per kg of dry matter, 0.30 fodder units/kg dry matter, and 3.64 MJ/kg dry matter.

Finally, herbage in the fourth variant provided 49.40 g of digestible protein, 0.42 fodder units, and 5.08 MJ of metabolic energy.

In analyzing the nutritional value of pasture herbage, we considered the content of dry matter, protein, fiber, digestible protein, fodder units, and metabolic energy.

Chemical analysis conducted in the summer shows that digestible content ranged from 0.007 to 0.013 t/ha, the content of fodder units – from 0.062 to 0.113 t/ha, and metabolic energy yield – from 0.76 to 1.37 GJ/ha.

The highest levels were achieved with the combination of WUXAL Aminoplant (anti-stress biostimulant) and organic fertilizer "Kazuglegumus": 0.013 t/ha of digestible protein, 0.113 t/ha of fodder units, and 1.37 GJ/ha of metabolic energy.

Thus, in the steppe zone of the North Kazakhstan Region, biological and bio-organic fertilizers significantly contribute to the restoration of the resource potential of degraded pasture ecosystems.

4. DISCUSSION

Out of the three analyzed variants, the greatest height of predominant plant species was observed in the variant of WUXAL Aminoplant (anti-stress biostimulant) and organic fertilizer "Kazuglegumus". Specifically, the height of Volga fescue, mugworts, and forb reached 22, 23, and 27 cm, respectively, surpassing control by 3, 8, and 11 cm.

Chemical analysis conducted in the summer showed that the herbage of the studied pastures contained 0.007–0.013 t/ha of digestible protein0.062–0.113 t/ha of fodder units, and 0.76–1.37 GJ/ha of metabolic energy. The highest levels were observed in the variant with WUXAL Aminoplant (anti-stress biostimulant) and organic fertilizer "Kazuglegumus" with 0.013 t/ha of digestible protein, 0.113 t/ha of fodder units, and 1.37 GJ/ha of metabolic energy.

The parameters of yield varied across the different variants. During summer grazing, the yields of green and dry mass were as follows: in the control – 0.53 and 0.16 t/ha; in the variant of WUXAL Aminoplant (anti-stress biostimulant) and organic fertilizer "Humate + CO_2" – 0.81 and 0.24 t/ha; in the variant of Stoller Energy and organic fertilizer "Humate + CO_2" – 0.72 and 0.22 t/ha, respectively. The greatest green and dry mass yields were obtained using WUXAL Aminoplant (anti-stress biostimulant) and organic fertilizer "Kazuglegumus", amounting to 0.90 and 0.27 t/ha, respectively, which is 1.7 times higher than the control.

The findings of this study align with recent regional research emphasizing the role of sustainable agro-industrial and ecological management in maintaining food security and soil productivity in arid zones of Central Asia. Zhilyakov et al. [43] demonstrated that agricultural efficiency and food security in Central Asia depend largely on optimizing the use of internal agro-industrial resources and introducing sustainable production technologies. Their SWOT analysis confirmed that improving local soil fertility and vegetation productivity is central to regional food resilience, an approach consistent with our results showing that bio-organic fertilizers enhance pasture productivity and feed quality, thereby strengthening the agro-industrial base of Northern Kazakhstan. Likewise, Saparov et al. [44] highlighted that soil degradation, including contamination by heavy metals, remains a key constraint to sustainable land use in Kazakhstan. Their findings underscore the importance of soil remediation and fertility recovery measures, which correspond with our experimental evidence that the use of humate- and amino-based fertilizers improves soil structure and nutrient status in degraded steppe ecosystems. Similar conclusions were drawn by research [45], which revealed that drought and aridity in Central Asia significantly reduce biodiversity and pasture resilience. Their comparative floristic analysis identified drought-tolerant species of the Amaranthaceae and Asteraceae families as key structural components for vegetation recovery and soil stabilization in arid landscapes of Western Kazakhstan. Our results are consistent with these findings, that after bio-organic fertilization, the proportion of resilient steppe grasses and forbs increased, and the overall stability of the herbage improved, suggesting that organic soil amendments can accelerate the same ecological processes observed in naturally adapted floras. Likewise, study [46] experimentally proved that the application of chelated zinc during early wheat development enhances physiological resistance to moisture deficit, boosts protein synthesis, and improves root vigor—effects conceptually similar to those obtained in our pasture trials, where bio-organic inputs increased protein and energy values of forage plants.

Overall, these regional parallels demonstrate that integrating bio-organic fertilizers, micronutrient treatments, and biodiversity-based land management can effectively restore soil fertility and pasture productivity across Central Asia's arid ecosystems [47]. The present study thus contributes empirical evidence supporting sustainable agricultural intensification and ecological resilience under increasing climatic and resource constraints.

Thus, our investigation of the impact of bio-organic preparations and biological fertilizers on the restoration of degraded pastures proves these products promote an increase in the yields and productivity of natural pasture herbage.

5. CONCLUSION

The application of bio-organic fertilizers and biostimulants in the steppe zone of North Kazakhstan significantly improved the condition of degraded pastures. The combined treatment with WUXAL Aminoplant and the organic fertilizer "Kazuglegumus" produced the most pronounced results, increasing green mass yield from 0.0.53 to 0.90 t/ha, dry mass yield from 0.16 to 0.27 t/ha, and digestible protein content from 0.007 to 0.013 t/ha, and a 1.7-fold increase in productivity. These effects are attributed to the high content of humic and fulvic acids in "Kazuglegumus," which enhance nutrient availability, soil aggregation, and water retention, stimulating root development and plant metabolism.

The applied fertilizers had a favorable effect on soil structure and the productive coverage of pastures, thus increasing their resistance to degradation. Contributing to pasture restoration and the productivity of animal husbandry, organic fertilizers play a key role in ensuring food security and the sustainable development of agriculture.

Given the simplicity of application, local production of bio-organic inputs, and their low cost, the proposed approach is scalable and economically feasible for use in other degraded steppe and semi-arid grasslands of Central Asia, offering a sustainable pathway to strengthen forage supply, soil health, and regional food security.

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