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RESEARCH ARTICLE
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Selection and Assessment of Perennial Grass Mixtures for Enclosed Pastures in North Kazakhstan

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ABSTRACT

The article examines the efficiency of growing multi-component grass mixtures for enclosed pastures given the plants' resistance to trampling to obtain high-quality products with minimal material and energy resources. Field experiments were conducted in the steppe zone of North Kazakhstan. The results suggest that the superior grass mix is the Optima Yug multi-component pasture grass mixture, which includes 30% perennial ryegrass (*Lolium perenne*), 25% tall fescue (*Festuca arundinacea*), 15% smooth brome (*Bromopsis inermis*), 15% cock's-foot (*Dactylis glomerata*), 10% annual ryegrass (*Lolium multiflorum*), and 5% white clover (*Trifolium repens*). The yield of green mass from Optima Yug reaches 23.4 t/ha, 4 times greater than the control. Bioenergetic assessment of phytocenoses further confirms the advantage of Optima Yug, which provides 78.9GJ/ha of metabolic energy and 0.81 t/ha of digestible protein. The best two-component pasture grass mixtures are those combining Russian wild rye (*Psathyrostachys juncea*) with alfalfa (*Medicago sativa*) and Siberian wild rye (*Elymus sibiricus*) with alfalfa (*M. sativa*). Increased protein content in the grass mixtures translates into significantly more produced feed protein. The significance of this research is determined by its contribution to knowledge pertinent to solving the problems of developing efficient technologies to improve the productivity and rational use of pastures, which will allow utilizing the full potential of agrocenoses and stabilizing the development of animal husbandry in the steppe zone of North Kazakhstan.

Keywords: Multi-component grass mixture, Yield, Enclosed pastures, Nutritional value of feed.

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INTRODUCTION

The prime objective of sustainable development in animal husbandry is to create a solid feed base, including by increasing the productivity of pasture land. Today, the task of stabilizing the development of animal husbandry in the steppe zone of North Kazakhstan demands a significant improvement in the quality of feeds and, most importantly, their protein and carbohydrate balance. In Kazakhstan, where the area of pasture and hay land reaches 187500000ha, natural forage lands are the key source of cheap and biologically complete feed. In the steppe zone of North Kazakhstan, natural forage lands occupy 53000000ha, including 7.112600ha in the Akmola Region, of which 6.843.800ha are pastures (Serekpayev et al., 2015). In terms of farming and technical condition, 66.7% of Kazakhstan's land is not polluted and actively utilized, 10.0% is covered by shrubs and needle grass (*Stipa capillata*), and 7.7 million ha and more than 27% of pasture land is degraded (Ministry of Agriculture of the Republic of Kazakhstan, 2022). In recent years, however, noticeable changes have been made to restore pasture lands after the data on pasture lands had been fully digitized (Nasiyev et al., 2022).

Enclosed pastures can become one of the most effective solutions in raising the effectiveness of animal husbandry. Pasture grazing reduces the costs of fuel, lubricants, equipment, and labor by several times. The total cost of producing feed is cut by 2–3 times compared to housing in stalls. In addition, this grazing method improves animals' metabolic processes and reproductive functions. The use of both early and late grass mixtures extends

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optimal harvesting time from 12–15 to 20–25 days and reduces the need for haymaking machinery by 15–20% (Shayakhmetova, 2023; Nurgaziyev et al., 2024).

The development of animal husbandry requires improving the quantity and quality of feed. Insufficient production and low quality of feeds hinder the growth of livestock productivity (Pazla et al., 2024). According to Kazakhstan's Ministry of Agriculture, the shortage of fodder in the country totals 8.7 million t of fodder units. The measures proposed by researchers to increase feed production include renewing perennial grass crops and removing old-age crops with low yields (Mukhambetov et al., 2023). The improvement of grasses that can provide higher yields of green fodder and roughage can be accomplished through simple and accessible technological operations and organizational measures that do not require costly or energy-intensive work (Bekimova et al., 2021).

The preservation, restoration, and improvement of the productivity of Kazakhstan's natural fodder lands is a high priority because of the impact of these efforts on preserving the global ecosystem (Mussynov et al., 2014). Kazakhstan is among an environmentally vulnerable country (Zhyrgalova et al., 2024). It is experiencing intense desertification, including on pastures (Serekpayev et al., 2016). This state of affairs is caused by the fact that farms tend to solve their feed production problems mainly through field feed production, while natural pastures have largely been overlooked.

The primary source of all types of feed in the region is field feed production, 70–80% of which is made up of silo, haylage, grass meal, hay, and fodder root crops. Nevertheless, the shortage of high-quality fodder for livestock persists. The variety of fodder crops is limited, and the trend of using monocultures continues. The point of the matter is not just the amount of fodder crops but also their quality. The cultivated perennial grasses are rarely rejuvenated and are represented primarily by old smooth brome with weeds and low yields reaching only 0.3–0.5t/ha. The productivity of natural pastures is as low as 0.12–0.36t/ha. Furthermore, mixtures of perennial legumes, such as sand sainfoin and alfalfa, with cereal crops are virtually never used (Useinov et al., 2020). Summarized data on the productivity of natural herbage in the steppe zone of North Kazakhstan (pastoral potential) show large fluctuations in yield (0.1–0.24t/ha of dry mass), which comes as a result of many years of unsystematic use of the natural system leading to degradation (Stybayev & Baitelenova, 2019).

At the moment, the most widespread single-species crops in North Kazakhstan are the perennials cereals smooth brome (*Bromus inermis*) and wheatgrass (*Agropyron peintforme* Roem et Schult) and the perennial legumes alfalfa (*Medicago sativa*) and sand sainfoin (*Onobrychis arenaria*) (Vlasenko & Trubakova, 2022).

The most popular grass mixtures are two-component. In well-watered areas, preference is given to mixtures of smooth brome and alfalfa, and in arid areas — to crested wheatgrass (*Agropyron cristatum* L.) and sand sainfoin. In moderately moist steppe areas (average annual precipitation of about 400mm), various ryegrasses and cock's-foot are used. When sowing two-component (e.g., crested wheatgrass + alfalfa; intermediate wheatgrass + alfalfa) and three-component (crested wheatgrass + smooth brome + alfalfa; intermediate wheatgrass + smooth brome + alfalfa) grass mixtures, the seeding rate of each component is 30–50% of its rate as a monoculture. The nutrient content depends on the phase of use. For example, crested wheatgrass at the elongation stage contains 23.0% of crude protein and 19% of crude fiber 19.0%. By the full earing stage, protein content drops to 17.0% and crude fiber increases to 24.3%. During full flowering, these indicators equal 14.0 and 31.7%, respectively. Crude fat content also lowers at later developmental stages (5.0 to 2.5%). The chemical composition and productivity of pastures depend not only on the plants' growth cycles but also on the types of grasses. Multi-component grass mixtures provide green fodder of a much higher quality compared to one- and two-component mixtures (Deak et al., 2007; Baikalova et al., 2020). The share of legumes and cereals as grass mixture components also presents a significant factor in forming highly productive biomass to meet the needs of animal husbandry (Bozhanska et al., 2023). Grass mixtures containing 4–6 species ensure more stable dry substance (DS) yields under changeable conditions compared to two-component mixtures of cereals and legumes or cereal monocultures (Deak et al., 2010).

Multi-component grass mixtures also improve the nutritional value and quality of the feed because of the greater number of fodder units and higher digestible protein content in the green mass and hay of legumes and grasses. Furthermore, such mixtures have a higher content of vitamins, minerals, and essential amino acids compared to cereal grasses (Khatiwada et al., 2020). In addition, legume-cereal mixtures provide better-tasting grass (DeBoer et al., 2020). Grass mixtures also have an economic advantage over monocultures, surpassing them in terms of yield by 1.6–2.4 times reducing the cost of one fodder unit by 1.3–1.75 times. Another advantage is that grass mixtures give more stable fodder yields (Pavlyuchik et al., 2018). Legume-dominated mixtures consistently produce more biomass than cereal-dominated mixtures. The higher yield of legume-grass mixtures compared to monocultures is confirmed in similar pasture studies conducted in Europe and Canada (Sanderson et al. 2013; Finn et al., 2013). As reported by the Thünen Institute of Farm Economics, the cost of pasture fodder is 40% lower than that of silo made from grass and 2 times lower than the cost of hay.

The introduction of a new culture in the composition of grass species on the pasture and the creation of different grass combinations can have different effects on pasture productivity. For example, mixtures of grasses with alfalfa are a more advantageous alternative to monocultures to create effective cultivated pastures in arid regions. These mixtures produce higher yields and more biomass, ensure stable production, and control weeds (Fan et al., 2020). Numerous studies highlight white clover (*Trifolium repens*) as a species that develops actively and interacts well with perennial ryegrass (*Lolium perenne*). Importantly, clover-ryegrass mixtures do ensure high pasture productivity (Nie et al., 2004; Chapman et al., 2018). Mixtures of perennial cereal grasses with alfalfa demonstrate increased drought resistance and improve soil fertility (Hayes et al., 2018). Whereas monocultures are more susceptible to weeds, grass mixtures containing perennial ryegrass and tall fescue (*Festuca arundinacea*) suppress weed invasion (Tozer et al., 2017). In the case of complex mixtures of ryegrass, tall fescue and white clover, frequent mowing may reduce green mass yields, but the minor loss in total yield will be offset by increased digestibility of the forage available for grazing, especially during the critical summer period (Bailey et al., 2022).

Perennial legumes in grass mixtures are particularly suitable for temperate climates: legumes fix nitrogen, optimize nutritional value, improve forage productivity, and reduce the need for nitrogen fertilizers. Legumes used in grass mixtures enrich the soil with nitrogen and increase its content in cereal components (Zegler et al., 2018). The symbiosis of legumes with nodule bacteria, which assimilate molecular nitrogen and support the grass mixture, has a positive effect on the productivity of grass mixtures. On the other hand, the involvement of large reserves of symbiotic nitrogen makes it possible to reduce the energy costs of producing fodder from perennial grasses by 1.3–1.5 times.

Multi-component grass mixtures increase the nutritional value of feed, allow utilizing the available pasture resources efficiently, and have an economic value. As found by many farms, the costs of pasture feed are almost 1.5–2 times lower than bulky feed (Nasiyev et al., 2023). Enclosed pastures can become the most effective path in increasing the efficiency of animal husbandry. Pasture grazing reduces the costs of fuel, lubricants, equipment, and labor by several times. The total cost of fodder produced is cut by 2–3 times compared to stall housing (Kuts et al., 2024). In addition, pasture grazing has been found to improve animals' metabolic processes and reproductive functions (Soloshenko et al., 2016).

The above literature demonstrates that multi-component grass mixtures have many advantages compared to other crops, both economic and associated with using the nutrient resources of the soil rationally. Mixtures containing tall fescue, perennial ryegrass, smooth brome, alfalfa and white clover have great economic value in pasture agrocenoses in various areas. However, the issue of the exact composition of the multi-component feed in Northern Kazakhstan conditions is still understudied. Thus, the objective of our research is to identify an optimal grass mixture composed of specific grass varieties that exhibit longevity, adaptability, and high productivity while remaining the most cost-effective under the environmental conditions of the steppe zone in North Kazakhstan.

MATERIALS & METHODS

Study Location and Time Frame

The experiments on the development of effective technologies for cultivating perennial grass mixtures for enclosed pastures in the steppe zone of North Kazakhstan were conducted in 2023–2024 by order of the Ministry of Agriculture of the Republic of Kazakhstan as part of the project "Development of effective technologies for increasing productive potential and rational use of pastures in the steppe zone of North Kazakhstan" under the targeted research program BR22883585 "Development of effective technologies to increase the productive potential and rational use of pastures" for 2024–2026 (Nasiev, 2025) completed within the framework of budget program 267 "Increasing the availability of knowledge and scientific research", subprogram 101 "Program-targeted financing of scientific research and activities" (Ministry of Justice of the Republic of Kazakhstan, 2024).

The object of the study was the degraded natural pasture lands of the Zaisan peasant farm located in the Zerendi District, Akmola Region (coordinates: N52°93.3161; E69°29.9401). The mixtures of perennial grasses were sown on May 5.

Experimental Samples of Grass Mixtures

The mixtures of perennial grasses for enclosed pastures were sown considering their resistance to trampling. The scheme of experiments is provided in Table 1.

The perennial grasses used to create the agrocenosis were: Siberian wild rye, variety Guran; Alfalfa, variety Lazurnaya; Russian wild rye, variety Bozoisky; Kentucky bluegrass, varieties Markus and Zeptor; Perennial ryegrass, variety Libronco. Other grass mixtures used grass varieties from the German seed breeding concern DSV (Eurograss).

Characteristics of the Experimental Plot and Climatic Conditions

The experimental site had an area of 7.200m^2. The experiments were repeated four times. Each variant was given a 1.800m^2 plot and the repetitions were allocated 600m^2. The plots were arranged systematically. The experiments were conducted with drought-resistant grass mixtures designed for intensive pasture use. The grasses were sown without cover crops using the continuous sowing method without tillage. The period of use was 3–5 years. The sowing rate was set at 30–35kg/ha.

The soil of the experimental site was a chernozem with below-average humus content and low water holding capacity. Specifically, humus content amounted to 4.7%,

Table 1: Scheme of the field experiment. Development of effective technologies for the cultivation of perennial grass mixtures for enclosed pastures in the steppe zone of North Kazakhstan

№	Name of perennial grass mixture
1	Natural pastures (control)
2	Siberian wild rye (*E. sibiricus*) + alfalfa (*M. sativa*)
3	Russian wild rye (*P. juncea*) + alfalfa (*M. sativa*)
4	Three-component pasture grass mixture Sport Lyuks Yug: Tall fescue (*F. arundinacea*) — 70%, Perennial ryegrass (*L. perenne*), variety Libronco — 10%, Kentucky bluegrass (*P. pratensis*), varieties Markus and Zeptor — 20%.
5	Multi-component pasture grass mixture: Pastbishche Optima Yug: 30% — perennial ryegrass (*L. perenne*), 25% — tall fescue (*F. arundinacea*), 15% — smooth brome (*B. inermis*), 15% — cock's-foot (*D. glomerata*), 10% — annual ryegrass, (*L. multiflorum*), 5% — white clover (*T. repens*).

and the content of easily hydrolyzable nitrogen reached 41.0mg/kg. Mobile phosphorus was at a level of 15.0 mg/kg, and the content of exchangeable potassium was 350mg/kg. Soil pH was 7.3, indicating a neutral reaction of the soil environment.

Agrometeorological Conditions

According to data from the automatic weather station in Zerendi, the amount of precipitation in the zone of our experimental work in the 2023–2024 agricultural year reached 546 mm, exceeding the multi-year average of 340mm by 206mm, or 60% (Table 2).

Table 2: Indicators of weather conditions for 2023–2024 (Zerenda Weather Station)

Months	Precipitation (mm)		Air temperature (°C)	
	average long-term	2023–2024	average long-term	2023–2024
September	29	74.4	11.2	11.3
October	27	57.1	3.6	7.0
November	21	32.1	–5.7	–7.1
December	21	34.4	–11.9	–7.9
January	14	13.0	–18.2	–12.6
February	10	18.0	–17.0	–11.9
March	12	12.0	–11.1	–7.5
April	18	26.5	2.2	9.5
May	35	76.9	12.1	11.2
June	46	62.3	17.1	22.6
July	64	63.3	18.8	21.7
August	44	76.2	17.4	18.1
Total	546.2	340		

Soil moisture is one of the main factors determining crop environment, which makes rational water use a key problem, especially in a dry climate. The reserves of productive soil moisture amounted to 8.7–9.0mm in the 0–10cm layer, 55.0–60.0mm in the 0–50cm layer, and 120–125mm in the 0–100cm layer as a result of precipitation in the autumn months (September–November 2023) totaling 163.6mm, 2.1 times greater than the multi-year average for this period. Thus, during their emergence and all growth and development stages, the studied cultures in the composition of grass mixtures for enclosed pastures, as well as perennial and annual forage crops, had favorable moisture conditions additionally benefited by a comfortable temperature regime and abundant precipitation across the entire agricultural year.

Methods for Assessing Grass Stand Productivity

Yields were determined on randomly selected 1m^2 sample plots (1×1m frame) by cutting all types of plants on the plot with scissors and weighing them. Each repetition involved three separate measurements. The green mass was cut and weighed (imitation of zero-grazing) once the plants reached a height of 15–18cm during the shooting stage of legumes, followed by flattening the crops with land rollers. In the remaining cycles, the grass was cut as soon as it grew to harvest ripeness (the tillering stage). The cut plants were then placed in a desiccator for 48 hours at 70°C. After reaching a constant weight, the mass was weighed.

Methods for Calculating Feed Value

Biochemical tests were performed on dry substance (DS). Raw ash was determined by firing the samples in muffle furnaces at 500–600°C. The mass fraction of protein was determined using the Kjeldahl method (Aguirre, 2023). The mass fraction of crude protein was determined according to GOST 13496.4-2019 (Federal Agency for Technical Regulation and Metrology, 2019), mass fraction of fat — according to ST RK 1564-2006 (Committee for Technical Regulation and Metrology of the Republic of Kazakhstan, 2006), mass fraction of ash — also according to ST RK 1564-2006, mass fraction of fiber — according to GOST 13496.2-91 (State Committee of the USSR for Quality Management of Products and Standards, 1992), nitrates and nitrites — according to GOST 13496.19-2015 (Interstate Council for Standardization, Metrology and Certification, 2015), nitrogen-free extractives (NFE) — according to GOST 23153-78 (Gosstandart of the USSR, 1995), and metabolic energy — according to ST RK 1564-2006 (Committee for Technical Regulation and Metrology of the Republic of Kazakhstan, 2006). NFE were determined by subtracting the content of protein, fat, fiber, and microelements.

The nutritional value of feed was assessed based on gross and metabolic energy. The content of gross energy in the dry substance of the feed was calculated through chemical analysis using formula:

$$GEMJ/kg = 23.95 \times CP + 39.77 \times CFa + 20.05 \times CFi + 17.46 \times NFE$$

where: CP — crude protein (kg), CFa — crude fat, CFi — crude fiber, NFE — nitrogen-free extractives (NFE=100%–CP–CFa–CFi–CA), CA — crude ash.

Next, metabolic energy was calculated as:

$$ME\ MJ/kg = (0.73 \times GE)/DS \times (DS - CFi \times 1.05)$$

where: GE – gross energy, DS – dry substance content.

In addition, the assessment of the nutritional value of feed based on cluster chemical analysis paid attention to other substances not related to protein energy value: phosphorus, calcium, carotene, and sugar.

Statistical Processing of Experimental Data

Statistical data analysis was conducted using STATISTICA version 10 by StatSoft, Inc. (2011). The introduction to correlation levels is presented in Table 3.

Table 3: Correlation data in StatSoft, Inc. (2011)

Correlation strength	Correlation coefficient value	
	Direct (+)	Inverse (–)
Zero	0	0
Weak	From 0.01 to 0.29	From –0.01 to –0.29
Moderate	From 0.30 to 0.69	From –0.30 to –0.69
Strong	From 0.70 to 0.99	From –0.70 to –0.99
Perfect	1	–1

RESULTS

Phenological Observations of the Growth and Development of the Components of Grass Mixtures for Enclosed Pastures

The "sowing–emergence" inter-stage period (Fig. 1) was virtually the same for all studied cultures and amounted to 15 days. The Siberian wild rye + alfalfa grass mixture demonstrated comparatively slow development in the first year with its "emergence–tillering" inter-stage Period lasting 30 days. The "elongation–seed head emergence, earing, budding" inter-stage period took 15

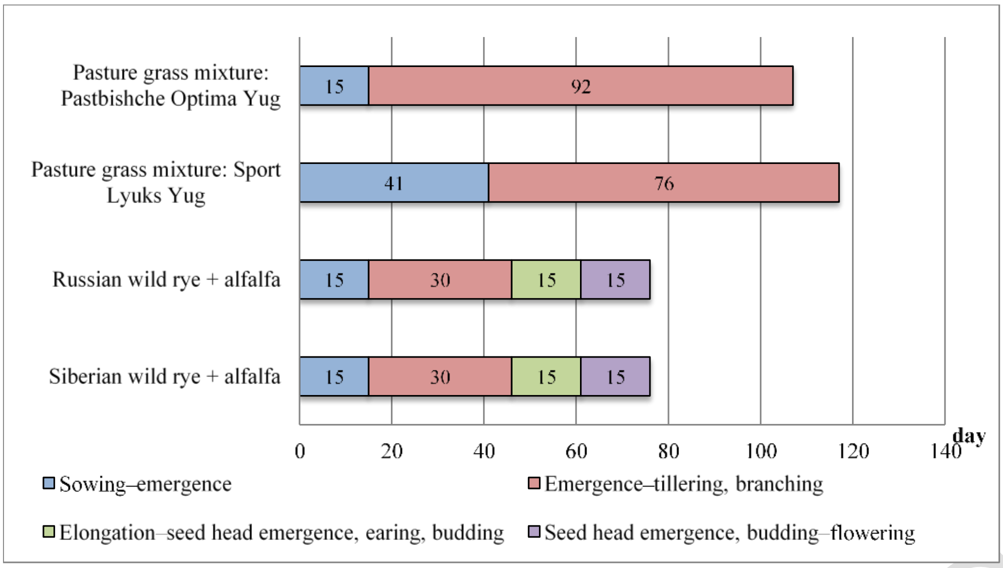

Fig. 1: Duration of inter-stage periods by grass mixtures.

days. The "seed head emergence, budding–flowering" stage started on July 5 and lasted until July 20. The condition of the grass stands before heading into winter in this variant of the experiment was rated with 5 points.

Russian wild rye and branching alfalfa in the "Russian wild rye + alfalfa" mixture both entered the tillering stage on May 20. Russian wild rye remained in this stage until the end of vegetation, failing to form productive stems, whereas alfalfa went through the budding stage from June 15 to July 5 and then entered the flowering stage, which lasted 15 days. The condition of the grass stands before going into winter in this variant was also rated with 5 points.

In the "Sport Lyuks Yug" pasture grass mixture, the dominant grass was tall fescue, which accounted for 20% of the mix. The "sowing–emergence" period lasted 15 days. The grasses fully emerged by May 20 and developed in the single-stem form up until June 15. After June 15, following heavy rains, the plants entered the tillering stage and remained in it until the end of the vegetation period. The condition of the grass stand before going into winter was rated with 5 points.

The composition of the "Pastbishche Optima Yug 5%" grass mixture is more optimized, including about equal proportions of tall fescue (25%) and perennial ryegrass (30%), as well as smooth brome and cock's-foot (15% each). The grasses fully emerged 15 days after sowing, on May 20. The tillering stage started on May 30, with the strongest tillering demonstrated by smooth brome and cock's-foot. Overall, the grass mixture showed great tillering, which affected green mass yield, and the condition of the grass stand before heading into winter was excellent.

Thus, the growth and development of the studied mixtures fluctuated. Siberian wild rye + alfalfa demonstrated slow early development, with a prolonged "emergence–tillering" period (30 days), though in the afterwards rapid progression through later stages was observed. The Russian wild rye + alfalfa mixture showed limited productivity, as Russian wild rye remained in the tillering stage until the end of vegetation without forming productive stems, while alfalfa successfully created flowers. In contrast, the "Sport Lyuks Yug" mixture dominated by tall fescue (20%) demonstrated delayed tillering (post-June 15). The "Pastbishche Optima Yug 5%" mixture displayed the most balanced composition, with strong tillering without significant fluctuations on all stages of growth. While all mixtures received a winter readiness rating of 5 points, "Pastbishche Optima Yug 5%" demonstrated the best development potential, making it the most promising choice for enclosed pasture use.

Biometric Indicators of the Growth and Development of the Components of Grass Mixtures for Enclosed Pastures

Field germination rates were generally high, ranging from 89.5 to 97.5%. The Russian wild rye + alfalfa grass mixture showed the lowest germination rate of 89.5%. The survival rate in this variant was 82.9%. In the "emergence–tillering" period, grass height ranged from 12 to 15cm. By the harvesting period, plant height had changed, increasing by an average of 26 cm for alfalfa and 28cm for Russian wild rye. The field germination rate of the Siberian wild rye + alfalfa grass mixture reached 93%. By autumn, only 6.5% of the initial number of plants had been lost, the survival rate equaling 88.5%. The height of plants averaged 12–15cm at the "emergence–tillering" stage and 41–51cm before harvest. The composition of the herbage was uniform, no suppression of one plant by another was observed.

The "Sport Lyuks Yug" pasture grass mixture demonstrated a high field germination rate of 96.4%. In the "emergence–tillering" period, the plants stood 10–12cm tall and grew to 22–25cm by autumn. The "Pastbishche Optima Yug" pasture grass mixture was also marked by a high field germination rate of 97.5%, while the survival rate reached 94.4%, from this perspective outperforming other mixtures. The plants in this grass mixture developed with vigor: at the "emergence–tillering" stage, the grass stood 10–15cm tall and by virtue of its great tillering reached a height of 28–34cm by autumn (Fig. 2). Although Siberian wild rye + alfalfa performed better showing greater height development (12–15cm at tillering, 41–51cm before harvest) that the survival rate in the context of Northern Kazakhstan is more important because if grasses survive the overwintering in North Kazakhstan, it will open an opportunity to cultivate them in agroecological niches to create pastures, as they are characterized by high resistance to trampling.

Fig. 2: Pastbishche Optima Yug and Sport Lyuks Yug grass mixtures at the tillering stage.

Productivity, Nutritional Value and Energy-protein Content of Perennial Grass Mixtures for Enclosed Pastures in the First Year of Life

The greatest yields of green and dry mass, which is a critical regulated parameter of livestock diets, were achieved in the variant of the "Pastbishche Optima Yug" multi-component pasture grass mixture — 23.4t/ha of green mass and 7.7t/ha of dry substance (Table 4).

The cultures involved in other experiment variants rank by the accumulation of green mass as follows. The Siberian wild rye + alfalfa mixture comes second with 15.3 t/ha of green mass and 6.4t/ha of dry mass; third place is taken by the Russian wild rye + alfalfa mixture with 14.4 of green mass and 6.0t/ha of dry mass. Alfalfa accounts for 20% of the herbage in the mixture with Siberian wild rye (*Elymus sibiricus*) and for up to 25% in the mixture with Russian wild rye (*Psathyrostachys juncea*). The three-component pasture grass mixture "Sport Lyuks Yug" composed of tall fescue (70%), perennial ryegrass, variety Libronco (10%), and Kentucky bluegrass, varieties Markus and Zeptor (20% each), yielded around 12.7t/ha of green mass with 42.0t/ha of dry mass. The lowest green and dry mass yields were obtained in the control variant with natural pastures — 5.8 and 1.7t/ha, respectively.

Cock's-foot (*Dactylis glomerata*) had a good growth pace but is too early. This culture entered the earning stage earlier than all other crops. When cultivating white clover and alfalfa, it is assumed that nitrogen is obtained biologically. Tall fescue grows back well after cutting, can be used in a mixture with perennial ryegrass, and improves yields in the first year. Thus, the results obtained in the first year of the study show that all studied perennial grass mixtures for enclosed pastures in the arid zone of North Kazakhstan surpassed the control variant of natural pastures in the first year of their life. The highest green and dry mass yields were achieved with the multi-component pasture grass mixture Pastbishche Optima Yug, which outperformed control by an average of 17.6t/ha for green mass and 6.0t/ha for dry mass. The lowest indicators were demonstrated by the three-component pasture grass mixture "Sport Lyuks Yug", which surpassed the control variant by 6.9 and 2.5t/ha, respectively. The rest of the variants fell in the middle. Thus, if these grass species overwinter successfully, they could be cultivated in agroecological niches to create enclosed pastures in North Kazakhstan.

Apart from yields, a decisive factor is the nutritional value or quality of the feed. The consensus is that metabolic energy accounts for 50%, protein — for 20–30%, and other feed components — for 20–30%. The obtained yields were analyzed to determine the parameters of fodder units, digestible protein, and metabolic energy. Here we should note that in considering the composition of animal diets, researchers refer specifically to simple proteins. The content of protein required to meet animals' need for digestible protein is 100–120g per fodder unit. Thus, feeds with less than 100g of digestible protein per fodder unit cannot be considered complete by protein content. In all studied grass mixtures, digestible protein content is higher than 100g per fodder unit, making them a complete feed (Fig. 3).

In addition, we determined the economic and bioenergy efficiency of cultivating mixed perennial fodder crops in the steppe zone of North Kazakhstan (Fig. 4). The analyzed grass mixtures contain 2.4–3.0% of crude fat and 4.6–10.2% of crude ash, and cluster analysis shows a high correlation between the two indicators. It further proves that phosphorus interacts strongly with calcium (Table 5). In the animal body, phosphorus performs functions in energy metabolism and affects the absorption of calcium, which is essential for bone formation (Fig. 5). To avoid triggering metabolic disorders, the feed must contain the necessary amount of energy so that protein is not consumed for energy purposes. In our grass mixtures, the nutrients in the green forage of perennial legumes and grasses are available in an easily digestible form. To be specific, crude protein content reaches 20.6–24.7%, digestible protein is 84–811kg/ha, crude fiber content is 30.8–25.8%, and the content of nitrogen-free extractives (NFE) is 33.1–40.1%.

The highest content of metabolic energy is observed in the "Pastbishche Optima Yug" grass mix — 74.9GJ/ha. In the two-component mixtures of Siberian wild rye + alfalfa and Russian wild rye + alfalfa, metabolic energy content reaches 62.9 and 56.2GJ/ha, respectively. The levels of digestible protein achieved by grass mixtures that include perennial legumes improve the productivity of pasture lands. Given that well-dried grass loses up to 30% of its

Table 4: Yields of pasture grass mixes depending on species composition in the first year (t/ha)

№	Variants	Yield, t/ha		Deviation from control	
		green mass	dry mass	green mass	dry mass
1	Natural pastures (control)	5.8	1.7	–	–
2	Siberian wild rye + alfalfa	15.3	6.4	+9.5	+4.7
3	Russian wild rye + alfalfa	14.4	6.0	+8.6	+4.3
4	Three-component grass mixture Sport Lyuks Yug	12.7	4.2	+6.9	+2.5
5	Multi-component grass mixture Pastbishche Optima Yug	23.4	7.7	+17.6	7.0
	LSD 0.05	3.6			

Table 5: Correlation analysis of biochemical indicators

	Crude ash, %	Crude fat, %	Crude fiber, %	Nitrogen-free extractives	Starch, %	Sugar, %	Carotene, mg	Calcium, %	Phosphorus, %	Digestible protein, kg/ha	Metabolic energy, GJ/ha
Crude ash, %	1										
Crude fat, %	–0.61	1									
Crude fiber, %	0.85	–0.86	1								
Nitrogen-free extractives	–0.75	0.96	–0.86	1							
Starch, %	–0.97	0.77	–0.91	0.88	1						
Sugar, %	–0.97	0.64	–0.89	0.74	0.93	1					
Carotene,mg	0.71	–0.50	0.71	–0.55	–0.65	–0.86	1				
Calcium, %	0.52	–0.91	0.69	–0.90	–0.65	–0.59	0.62	1			
Phosphorus, %	0.15	–0.27	0.48	–0.12	–0.20	–0.18	0.01	–0.10	1		
Digestible protein, kg/ha	–0.43	–0.06	–0.08	0.11	0.28	0.49	–0.67	–0.24	0.65	1	
Metabolic energy, GJ/ha	–0.44	0.00	–0.12	0.16	0.30	0.52	–0.71	–0.30	0.64	1.00	1

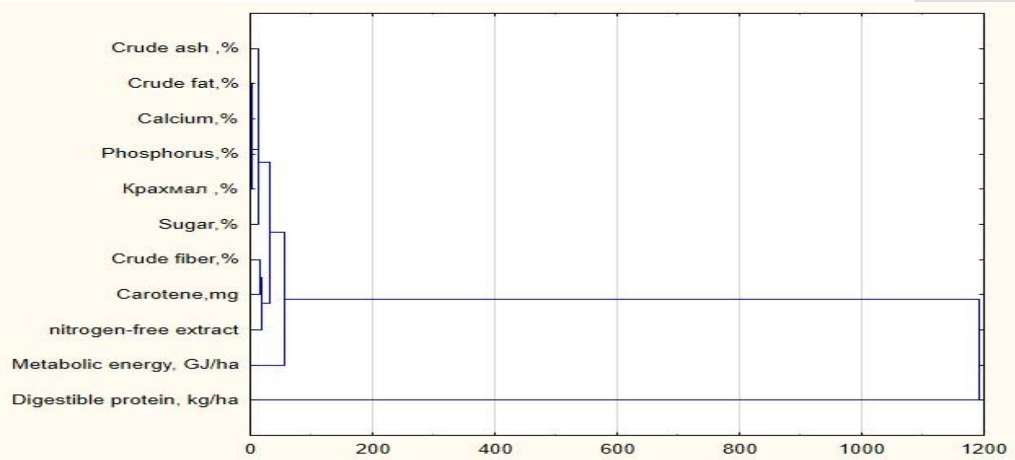

Fig. 3: Cluster analysis.

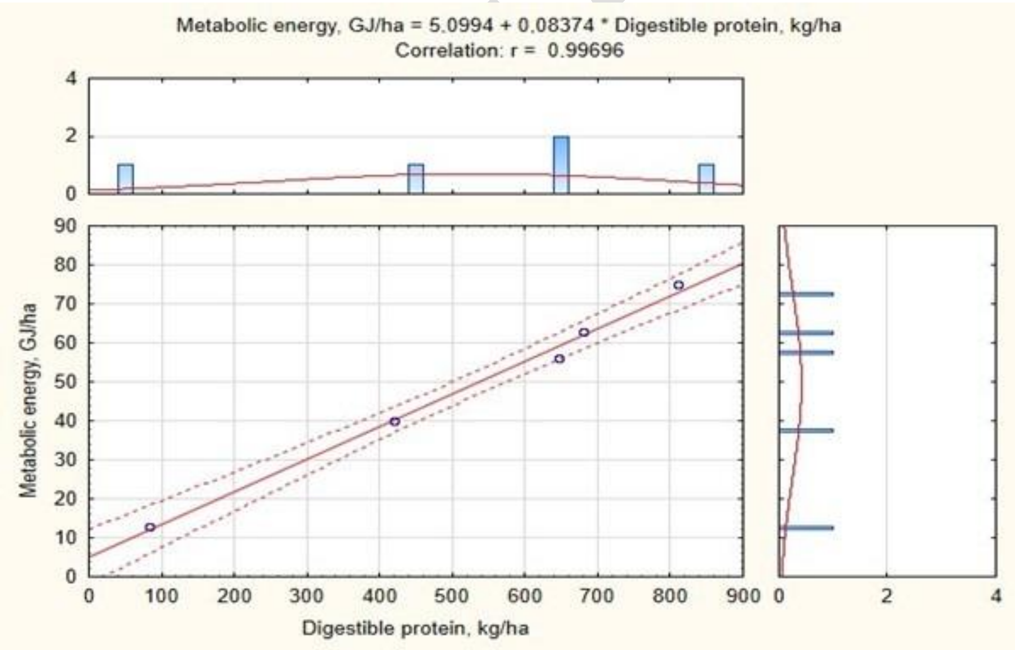

Fig. 4: Relationship between digestible protein and metabolic energy.

nutrients compared to unmowed grass, the considered indicators will be much higher with grazing (Fig. 5).

In our analysis of the grass mixtures, we also determined the content of mineral substances, a deficiency in which impairs animals' proper growth and development. These minerals are available in the examined pasture grass in necessary quantities: calcium content is 1.0–1.86% and phosphorus ranges within 0.20–0.25% (Fig. 6).

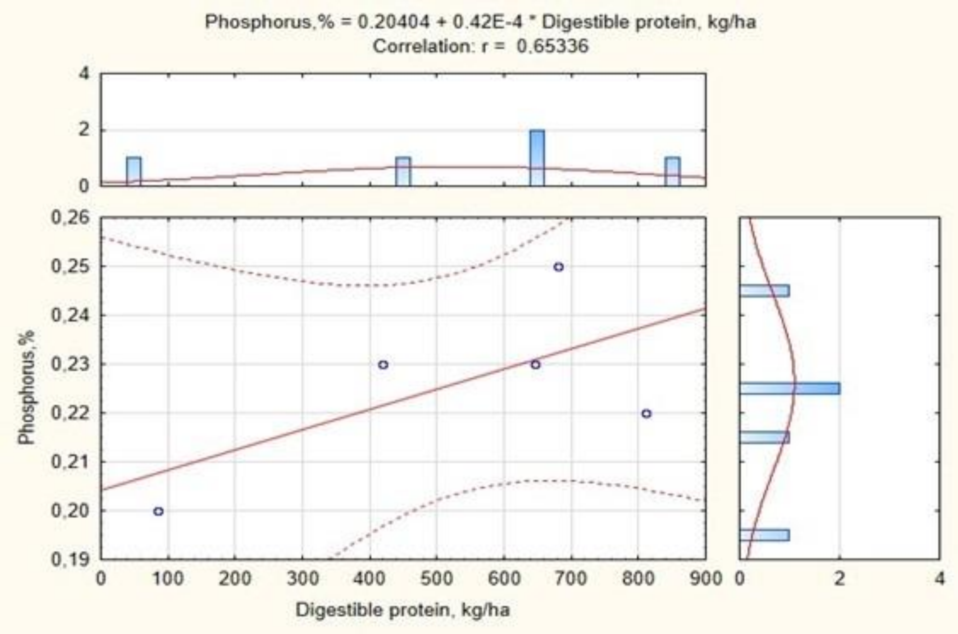

Fig. 5: Relationship between digestible protein and phosphorus content.

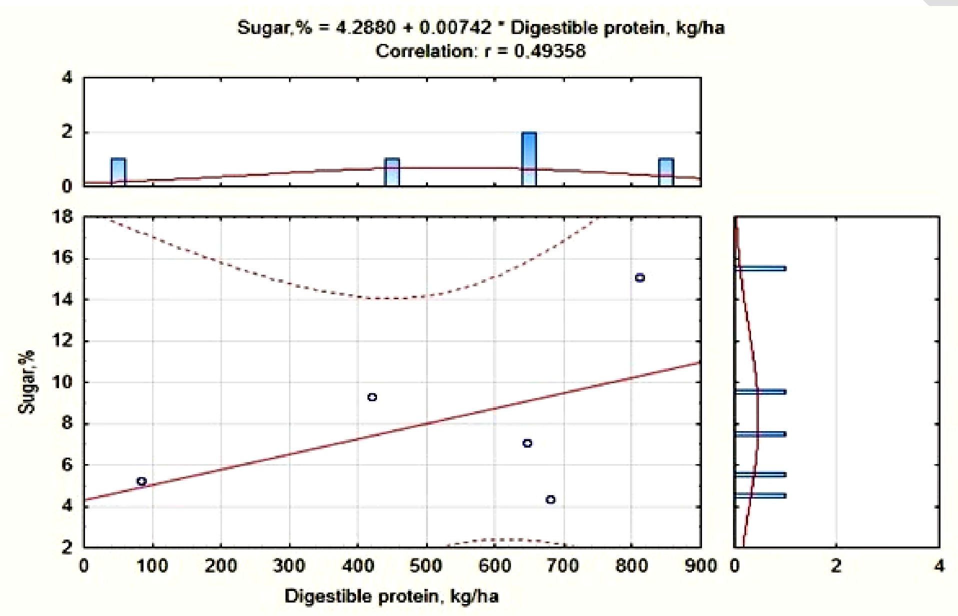

Fig. 6: Relationship between digestible protein and sugar content.

The efficiency of protein utilization depends on the content of sugars, the lack of which makes protein poorly digested. The use of cereal-legume grass mixtures is considered to be effective in increasing biomass yield in the steppe zone of North Kazakhstan, as they provide a green mass yield of around 15.3–23.4t/ha, a dry mass yield of 6.4–7.7t/ha, and 62.9–74.9GJ/ha of metabolic energy.

DISCUSSION

Our studies prove the advantages of multi-component grass mixtures. The findings obtained are consistent with current research trends on multi-component grass mixtures and animal husbandry in Northern Kazakhstan and its effectiveness in increasing available forage and resisting adverse climatic conditions (Baidalina et al., 2023). The study shows that complex species combinations increase herbage productivity in the long term and this agrees with the findings of Shayakhmetova (2023), who documented that increased productivity in land use and animal work rate at a reduced cost was an advantage of implementing multi-component grass mixtures. The productivity of managed permanent pastures depends greatly on the species composition of the mixtures sown. Environmental theory suggests that increased diversity of plant species helps improve productivity and quality (Budiyanto et al., 2024; Karymsakov et al., 2024). In recent years, multi-component mixtures have been used more actively in connection with climate change (Kitczak et al., 2021). The superior grass mixtures include 5–6 components, as they enhance the nutritional value and quality of the obtained feed due to greater amounts of fodder units and higher digestible protein content in the green mass and hay of legumes and grasses. Furthermore, these mixtures have a higher content of vitamins, minerals, and essential amino acids compared to cereal grasses. Importantly, the technologies used to produce grazing pasture forage are inexpensive, making the feed cheap. In this study, we propose the use of high-yielding grass mixtures marked by high productivity, nutritional value, and stability of herbage.

By creating agrophitocenoses of perennial and annual forage crops with high yield potential to produce nutritious fodder on forage lands of the steppe zone of North Kazakhstan, it is possible to accelerate restorative succession, restore biodiversity and increase the forage productivity of degraded pasture ecosystems many times over while optimizing the environment for the local population in the region (Kabylbekova et al., 2023). Furthermore, the agrophitocenoses of perennial and annual forage crops on pastures will make it possible to increase the number of farm animals (Bitewi et al., 2021; Pimnon et al., 2024). The target audience of the obtained results are small and medium-sized farms and peasant farms, agricultural cooperatives, and partnerships engaged in pasture-based animal husbandry in the regions of Kazakhstan.

The greatest influence on yields in the study year was demonstrated by weather conditions, which involved excessive precipitation during the vegetation period (Al-Khaza'leh et al., 2020). The shares of cock's-foot and tall fescue in multi-component mixtures increased in subsequent years, while the proportion of meadow fescue and perennial ryegrass decreased the fastest. Cock's-foot eventually becomes the dominant species regardless of its initial percentage in the mixture (Martinson et al., 2016). In the case of complex mixtures of perennial ryegrass, tall fescue, and white clover, green mass yields might decrease with frequent mowing. These minor losses in overall yield are offset by higher digestibility of the forage available for grazing, especially during the critical summer period. Notably, perennial ryegrass delivers low yields when mixed with Kentucky bluegrass because of the suppressive effect of the latter (Lowe & Bowdler, 2009b).

The role of soil health and nutrient cycling is another key aspect of recent studies. Among the studied grass mixtures created based on new varieties, the best productivity indicators are demonstrated by variants that include legumes, which is consistent with the findings of Makmur et al. (2020). Current research has shown that grass mixtures containing at least one legume performed better in biomass yield due to factors such as production of nitrogen (Sollenberger & Dubeux, 2022; Tahir et al., 2022; Wu et al., 2022) ultimately reducing the need for synthetic fertilizers. In particular, superior nutritional value was observed in the variants of Siberian wild rye + alfalfa, Russian wild rye + alfalfa, and the multi-component grass mixture "Pastbishche Optima Yug" which contained containing alfalfa and clover, and exhibited improved metabolic energy and digestible protein content. This suggests that long-term pasture management strategies should incorporate legume-rich mixtures to enhance sustainability. Our finding is also consistent with Baidalina et al. (2023) who obtained similar results with a combination of red fescue, common meadowgrass, Russian wild rye, alfalfa, Hungarian sainfoin. This underscores the importance of incorporating rye and alfalfa to forage mixtures (Phillips et al., 2021; Nugmanov et al., 2022). The high field germination rate and survival rate recorded in "Pastbishche Optima Yug" grass mixture and also in the study of Baidalina et al. (2023) shows the correlation between a diverse composition and increase in germination rate, productivity, nutritional value and survival rate. More research is recommended to test the limitations of these correlations and the possible parameters that influence it. On the other hand, mixed multi-component herbage uses soil resources more efficiently because of an improved vertical arrangement of the root mass in soil horizons, which allows plants to assimilate nutrients better and form more durable and highly productive grass stands (Bozhanska et al., 2023). Moreover, deep-rooted plant species (e.g., *Bromus valdivianus*) can avoid periods when soil water is scarce by extracting water from deeper layers of the soil (Ordóñez et al., 2024). The study also partially contradicts Tahir et al. (2022) conclusion, which stated that In terms of production and nutritional quality, the low-diversified combination performed better than the highly-diversified mixtures which does not align with our results as the highly diversified "Pastbishche Optima Yug" grass mixture produced the best performance. On the other hand, the results agree with another conclusion that states that the dominating species in the combinations plays a critical role on their productivity. This also gives room for more studies on how similar mixtures would perform with equal distribution of its components. Another important consideration is the economic feasibility of multi-component mixtures. Our findings suggest a positive outcome as the higher biomass yield observed in our study translates to lower production costs per unit of feed.

Our study testifies to the advantages of multi-component grass mixtures, which provide highly nutritious feed, stable yields, and economic benefits with a balanced proportion of legumes and cereals. These species combinations additionally improve the quality of soils by fixing nitrogen and ensure greater stability and productivity under changing climatic conditions. Moving forward, long-term studies should be conducted to track species composition changes over multiple years to further refine optimal grass mixtures for enclosed pastures in the steppe zone of North Kazakhstan.

Conclusion

As a result of the study, we selected mixtures of early- and late-maturing grasses to create agrophitocenoses that are promising for the considered region. In our experiments, pasture herbage accumulated a large biomass from early spring to late fall. The studied grasses did not require much warmth to develop, but they were supplied with sufficient moisture and minerals. Our recommendation is to use semi-complex grass mixtures that follow the scheme of 1 leguminous + 3–4 cereal crops. The studied pasture grass mixtures demonstrated considerable advantages in productivity and nutritional value (2.5–3.0 times higher) over the control variant. Complexes of perennial grasses show greater resistance to diseases, temperature changes, and drought. In variants including legumes, the soil was additionally saturated with nitrogen. The protein, carotene, and macronutrient content in the green mass is higher, and the fiber content is optimal. Agrophitocenoses of perennial and annual forage crops with high yield potential created on forage lands in the steppe zone of North Kazakhstan to produce nutritious fodder can accelerate restorative succession, restore biodiversity, and increase the forage productivity of degraded pasture ecosystems many times over while optimizing the environment for residents. These grass mixtures will provide an opportunity to increase the number of farm animals.

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