















Effects of Seasonal and Intra-Seasonal Grazing on Semi-Desert Pasture Vegetation, Forage Quality, and Soil Degradation in West Kazakhstan

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ABSTRACT

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class of degradation, intra-seasonal pasture areas, nutritional value, pastures, productivity, quality of pasture grasses, soil indicators

This research focused on seasonal pastures as an influential technology and tool to prevent degradation and improve the sustainability of pastures in the semi-desert zone of West Kazakhstan. To assess these effects, seasonal and intra-seasonal grazing variants were compared against two key benchmarks: an intensive continuous grazing area (control variant) representing standard high-pressure management, and a reference variant with no grazing, representing undisturbed natural conditions. The obtained data established a positive influence of seasonal and intra-seasonal use on biometric and productive indicators. As a result of the redistribution of grazing pressure and the presence of seasonal rest periods, the yield of pasture green mass increased by 0.25-0.59 t/ha (39.68-60.82%) relative to the intensive grazing control area, which yielded only 0.38 t/ha. The recommended grazing variants also increased the collection of feed units by 0.06–0.15 t/ha, digestible protein by 0.002-0.02 t/ha, and exchange energy by 0.77-1.92 GJ/ha. Furthermore, pasture grass collected from seasonal and intra-seasonal areas was distinguished by a higher content of crude fat (5.19-7.79%), crude protein (6.45-10.85%), and carotene (12.82-16.03 mg/kg) with a lower content of crude fiber (30.45-32.55%). The intensive use of pastures had a significant negative effect on the health of light chestnut soils. Compared to the no-grazing reference variant, humus stocks under intensive grazing dropped by 26.73%, characterizing the soil as degradation class 2. Additionally, the increase in soil density due to continuous livestock trampling caused further deterioration to degradation class 3. The findings demonstrate that seasonal grazing technology makes it possible to prevent these degradation processes and improve the sustainability of pasture ecosystems. These effects are achieved through a uniform distribution of pasture load, allowing plants and soil to recover, thereby ensuring greater vegetation productivity and improved soil health.

1. INTRODUCTION

Pastures are among the largest terrestrial ecosystems and play a critical role in livestock production, biodiversity conservation, and ecosystem functioning [1-3]. In semi-arid regions, including Kazakhstan, pasture systems are increasingly affected by degradation driven by climate change and intensive land use. Currently, of the 188.9 million hectares of pasture in Kazakhstan, 26.6 million hectares are severely degraded [4], leading to substantial losses in forage resources (4.3 million tons of feed units) [5]. Degradation is most pronounced near settlements, watering points, and frequently used grazing areas [4].

Pasture degradation is typically assessed through changes in soil and vegetation properties [6]. Numerous studies indicate that livestock grazing is a key driver of these changes [7-9]. Grazing alters soil structure and function by increasing compaction [10], reducing macroporosity [11] and water-holding capacity [12], and intensifying surface runoff [13]. These processes contribute to nutrient loss [14], reduced carbon storage [15], and declining vegetation cover [16]. Overgrazing further accelerates erosion, reduces plant biodiversity, and facilitates the spread of less desirable or invasive species [17, 18].

The intensity and management of grazing play a decisive role in determining the extent of these impacts. Unregulated

grazing significantly affects above-ground biomass, soil organic matter, aggregate stability, nitrogen cycling, and soil moisture [19]. To mitigate these effects and prevent further desertification, immediate measures should focus on restorative management approaches [20, 21]. In this context, adaptive grazing strategies, particularly seasonal and rotational systems, are increasingly recognized as effective tools for reducing degradation risks [22, 23].

Seasonal grazing, which includes defined grazing and resting periods, allows pastures to recover and restore ecological functions. Evidence suggests that even short-term rest can significantly improve vegetation cover and soil properties [24, 25]. Long-term grazing exclusion has been shown to increase biomass, vegetation cover, and soil nutrient content, including nitrogen and phosphorus [26]. These recovery processes are especially important in semi-arid environments, where water availability and soil resilience are limited [27]. Rested pastures not only support biodiversity conservation but also provide economic benefits by maintaining pasture productivity and carrying capacity [28].

Despite the growing body of research on grazing management, there remains a need to better understand how seasonal grazing specifically influences soil and vegetation dynamics under semi-arid conditions and the mechanisms that govern degradation and recovery processes. In particular, the role of recovery windows and their effectiveness in restoring pasture ecosystems requires further investigation.

The purpose of the present study is to evaluate seasonal grazing as a management strategy and to assess its effects on vegetation and soil properties, with a focus on its potential to reduce degradation and enhance the sustainability of pasture-based livestock production.

2. MATERIALS AND METHODS

2.1 Description of the study sites

Studies on seasonal grazing were conducted on the pastures of the “Miras” peasant farm located in the Bokeiordinsky District of the semi-desert zone of West Kazakhstan.

The three fixed seasonal grazing plots were designated for spring, summer, and autumn grazing. The same herd of 120 cattle was moved between these plots according to the seasonal grazing schedule. For standardization of grazing pressure, one adult cattle head with an average live weight of 450-500 kg was accepted as 1.0 livestock unit (LSU). The seasonal grazing system had a stocking density of 0.21 head/ha, or 0.21 LSU/ha. Grazing lasted 60 days in spring, 90 days in summer, and 60 days in autumn. Grazing intensity was calculated as animal unit months per hectare (AUM/ha) using the following equation:

$$\text{AUM/ha} = (\text{number of animals} \times \text{LSU coefficient} \times \text{grazing days}) / (30 \times \text{pasture area, ha})$$

Accordingly, grazing intensity in the seasonal grazing variant was 0.43 AUM/ha in spring, 0.64 AUM/ha in summer, and 0.43 AUM/ha in autumn. The cumulative grazing intensity over the spring–autumn grazing period was 1.50 AUM/ha.

In addition to the seasonal grazing areas, the study included three intra-seasonal pasture areas assigned to spring, summer, and autumn, each covering 235 ha. Each intra-seasonal area was used to graze 50 heads of cattle during the corresponding

season. This corresponded to a stocking density of 0.21 head/ha, or 0.21 LSU/ha. Grazing lasted 60 days in the spring intra-seasonal area, 90 days in the summer intra-seasonal area, and 60 days in the autumn intra-seasonal area. The calculated grazing intensity was 0.43 AUM/ha in spring, 0.64 AUM/ha in summer, and 0.43 AUM/ha in autumn. The cumulative grazing intensity over the spring–autumn period was 1.50 AUM/ha.

The control area was comparable to the seasonal grazing variant in total area and herd size: both variants included 560 ha and 120 cattle, corresponding to 0.21 head/ha, or 0.21 LSU/ha. However, the control pasture was used continuously without seasonal rest, whereas the seasonal grazing system redistributed grazing pressure among seasonal plots and allowed recovery periods. Therefore, the control was considered an intensive continuous-grazing benchmark. In the control variant, grazing lasted 210 days during the spring–autumn period. The calculated grazing intensity was 1.50 AUM/ha. Winter grazing in favorable years was not included in the comparative AUM calculation because it was irregular and depended on annual weather conditions.

Watering points were located at the periphery of the grazing areas and outside the permanent vegetation transects and soil sampling points. The distance from sampling transects to watering points was maintained at not less than 500 m to avoid localized effects of trampling and animal concentration. Supplementary feeding was not provided within the vegetation sampling plots during the main grazing period. When mineral supplementation was used, salt licks were placed near watering points rather than inside the accounting transects. Livestock movement followed established farm routes between grazing plots and watering points. These routes were kept outside the permanent transects and soil sampling locations.

2.2 Vegetation studies

The following measurements and analyses were performed at the experimental sites:

- (1) Identification and description of the pasture plant community;
- (2) Pasture productivity assessment;
- (3) Determination of the nutritional value and energy component of feed obtained from the pastures.

The indirect study of pastures was effectively carried out using the method of transects (profiles). In each grazing technology variant, three permanent transects measuring 100 × 50 m were established within visually homogeneous pasture areas representative of the corresponding grazing regime. Transects were located away from roads, watering points, feeding sites, livestock resting places, and other local disturbance sources in order to avoid edge effects and localized trampling effects. In each transect, five accounting quadrats of 1 × 1 m were placed systematically along the transect line and in the central part of the transect. Thus, 15 accounting quadrats were assessed for each grazing variant during the corresponding season.

The condition of natural pasture vegetation was assessed using species composition, projective cover, plant height, and above-ground green biomass as the main indicators. This technique targets such parameters as the species composition of the grass, the percentage of land surface covered with plants, the height of the grass, and the volume of green biomass obtained.

Projective coverage was determined by eye on a 10-point scale (10-100% with a 10% step). The possibility of visual determination of projective coverage by a person with an accuracy of 10% had been confirmed.

Before field assessment, observers were calibrated using reference plots with contrasting vegetation cover. The same observers conducted all field assessments during the study period. To reduce subjectivity, projective cover was assessed repeatedly in the same accounting quadrats, and the final value was calculated as the mean of repeated observations. If the difference between observer estimates exceeded 10%, the plot was reassessed jointly, and the agreed value was used in the dataset.

Plant height was measured in each accounting quadrat using a measuring ruler. The height of the dominant vegetation layer was recorded at five points within each quadrat, and the mean value was used for statistical analysis. Species composition was determined directly in the field, with particular attention to dominant, forage-value, weed, and poisonous species.

Green biomass was determined by harvesting above-ground plant material from 1 × 1 m accounting quadrats. Plants were cut at a standard mowing height of 3–5 cm above the soil surface. The harvested green mass was weighed immediately in the field to determine fresh biomass. A representative subsample from each quadrat was then taken for laboratory drying. The subsamples were dried in a ventilated drying oven at 65 °C to constant weight. Dry matter content was calculated as the ratio of dry mass to fresh mass, and this coefficient was used to convert fresh biomass into dry biomass. Pasture productivity was then recalculated per hectare.

The nutritional and energy-protein value of pasture vegetation was determined in accordance with current methods and state standards (GOST) based on the quantitative indicators of crude nitrogen, crude fat, crude fiber, and crude ash content. The agrochemical analysis of plant samples was carried out at an accredited laboratory of Zhangir Khan West Kazakhstan Agrarian and Technical University.

2.3 Soil sampling

To analyze the impact of different grazing technology variants on soil quality, samples were taken from pastures at the soil depths of 0-10 cm, 10-20 cm, and 20-30 cm. In addition, soil samples were also taken from the reference area (no grazing) from the same depths to compare and identify the changes caused by livestock grazing. Four samples were collected from each depth in each pasture area.

Soil sampling points were located within the same pasture variants as the vegetation transects but outside direct livestock paths, watering points, feeding sites, and resting areas. This sampling design was used to characterize the general effect of grazing technology on pasture soil rather than the localized effect of trampling near livestock concentration zones.

Judging by their morphological features, the soils of peasant farm pastures in West Kazakhstan belong to the light chestnut type (Calcic Kastanozems) and are typical of the semi-desert zone of the region.

The quality of pasture soils in the semi-desert zone of West Kazakhstan was studied in an accredited laboratory of Zhangir Khan West Kazakhstan Agrarian and Technical University.

The main focus of the study was to identify degradation processes caused by livestock grazing using the criteria approved by Order of the Minister of Agriculture of the Republic of Kazakhstan No. 185 of April 27, 2017 [29].

The criteria used to assess the condition of pasture soils were the reduction of humus content in the upper soil layer (0-30 cm) compared to the control area (in %); the decrease in mobile phosphorus relative to the control area (in %); the increase in exchangeable sodium (in % of total cation-exchange capacity); the increase in soil density in the 0-30 cm layer compared to the control area (in %); and the content of structural aggregates favorable for agriculture (in %).

2.4 Physical and chemical soil analyses

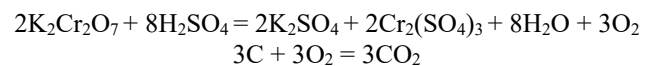
Soil density was determined by the Kachinsky method using cylinders. Soil samples from the 0-10, 10-20, and 20-30 cm layers were collected in the field with a cylinder drill with a volume of about 500 cm³ (manufacturer: Smart Pribor, Russia). In parallel with density sampling, additional samples for determining soil moisture were collected into aluminum weighing bottles (manufacturer: Smart Pribor, Russia).

In the course of laboratory tests, the soil was dried in an oven at 105 °C to constant weight. The mass of absolutely dry soil was calculated by subtracting the weight of the empty weighing bottle from the weight of the weighing bottle with dried soil. Next, soil density was determined by dividing the mass of dry soil by the volume occupied by it in the ring [30].

The dry sieving method was applied to determine the structural condition of the soil and quantify agronomically valuable aggregates. Such aggregates included water-resistant lumpy-granular formations ranging from 10 to 0.25 mm in size. Laboratory analysis consisted of sieving the soil samples through sieves with different mesh sizes (Smart Pribor, Russia) [30].

Soil humus content was determined by the laboratory method of I.V. Tyurin. The essence of the method consists of the oxidation of the organic component of the soil using chromic acid, which causes the release of carbon dioxide [30]. The oxidizing agent was a solution of potassium dichromate (K₂Cr₂O₇) prepared from sulfuric acid.

Oxidation formula:



The laboratory determination of mobile phosphorus compounds in the soil was carried out using the photometric method of I. Machigin. The method consists of the following: mobile phosphorus compounds are extracted from the soil with a solution of ammonium carbonate (NH₄)₂CO₃ at a concentration of 10 g/dm³, the ratio of soil to solution being 1:20. The content of phosphorus as a blue phosphorus-molybdenum complex is then determined photometrically with a photoelectrocolorimeter (Zagorsk Optical-Mechanical Plant, Russia) [30].

Following the photometric method, exchangeable and soluble sodium was extracted with a 1 mol/dm³ solution of ammonium acetate (CH₃COONH₄) with a pH of 6.7-7.0. The ratio of soil sample weight to solution volume was 1:20. The content of sodium in the extract was determined using a flame photometer (Unico-Sis, Russia). At the same time, the content of soluble sodium was measured in the aqueous extract, and exchangeable sodium was calculated as the difference. Based on the content of exchangeable sodium in the cation-exchange capacity, the degree of soil solonetzity (salinity) was determined [30].

Soil solonetzity (salinity) was calculated by the formula:

$$C_s = \frac{Na \cdot 100}{CEC}$$

where,

- C_s – solonetzity relative to cation-exchange capacity, %;
- Na – exchangeable sodium content, cmol/kg;
- 100 – percentage conversion factor;
- CEC – cation-exchange capacity, cmol/kg [31].

2.5 Data analysis

The effects of grazing technology on vegetation and soil indicators were analyzed using one-way analysis of variance (ANOVA). When ANOVA indicated a significant treatment effect, post hoc multiple comparisons were performed. Tukey's HSD test was used for pairwise comparisons among all grazing variants, while Dunnett's test was applied for planned comparisons with the control or reference no-grazing area.

The assumptions of normality and homogeneity of variances were checked using the Shapiro-Wilk test and Levene's test, respectively. Statistical significance was accepted at $p < 0.05$. Box plots were used to visualize the distribution of values and differences among grazing technology variants. Statistical analyses and visualizations were performed using JASP® software, version 0.96.0.

3. RESULTS AND ANALYSIS

3.1 Impact of seasonal pastures on the productivity and quality of pasture vegetation

Monitoring results demonstrate that the biometric characteristics of semi-desert pastures are directly connected to the applied livestock grazing technology [32, 33].

In particular, on pastures used seasonally (in spring, summer, and autumn), the projective coverage of plants reaches 62-77%, while intensive grazing areas (control) have only 38% (Table 1).

As demonstrated by the data, a lower intensity of pasture use contributes to a better condition of vegetation. In pasture areas under seasonal grazing, the projected cover of grass ranges from 62% to 77%.

Scientific studies demonstrate that seasonal pasture use has a beneficial effect on their characteristics, especially on the height of the grass cover. This parameter is an important component in assessing the health of pasture ecosystems [31, 34]. The findings suggest that grass height throughout the year is predetermined by grazing methods. After spring grazing, the height of plants reaches 25.50 cm. The maximum height of the grass cover (from 25.50 to 28.60 cm) is observed in pasture areas used seasonally, in spring and autumn.

According to the observation, plant height generally varies from 23.8 to 31.2 cm throughout the year. Meanwhile, vegetation in intensive grazing areas reaches only 18.70 cm.

The results also demonstrate a positive effect of seasonal pastures on the foliage of pasture grasses. While in the control variant of intensive grazing, grass foliage amounts to 16.77%, the use of pastures in the spring, summer, and autumn seasons increased this indicator to 25.12-44.77%, and grazing in pastures with intra-seasonal areas resulted in a rise of the specific weight of leaves in the crop structure to 25.92-46.47%. These data indicate the advantage of the proposed

grazing technology on pastures in the semi-desert zone.

One-way ANOVA confirmed a significant effect of grazing technology on the quantitative and qualitative indicators of pasture vegetation cover ($p < 0.001$).

The species diversity of pasture ecosystems also shows variability. In spring, pastures under intensive grazing had around 16 species, including ephemera (e.g., *Poa bulbosa*). Nevertheless, the vegetation cover of these pastures is dominated by poorly eaten, low-value fodder plants. There is a significant diversity and high abundance of plants such as *Artemisia lerchiana*, *Artemisia austriaca*, *Ceratocarpus arenarius*, *Chenopodium album*, *Poa bulbosa*, *Tanacetum achilleifolium*, *Lepidium perfoliatum*, and *Gypsophila paniculata*. Among weedy species, the most notable are *Thlaspi arvense*, *Fritillaria*, *Alyssum turkestanicum*, and *Galium aparine*, which are also quite abundant. *Polygonum aviculare* and *Lappula squarrosa* are moderately abundant. Intensive grazing led to the disappearance of valuable forage species from the vegetation cover, for example, *Kochia prostrata*, *Festuca valesiaca*, *Leymus ramosus*, *Koeleria cristata*, and *Agropyron desertorum*. The ephemeral *Tulipa* is also absent from these pastures. Meanwhile, intensively grazed areas have an abundance of ephemerals, *Poa bulbosa* and *Fritillaria*.

Table 1. Quantitative and qualitative indicators of pasture vegetation cover depending on grazing technology

Grazing Technology Variant	Projective Coverage, %	Number of Species	Height of Plants, cm	Plant Foliage*, %
Intensive grazing area (control)	38	16	18.70	16.77
Spring grazing area	72	15	25.50	36.14
Summer grazing area	62	16	22.20	25.12
Autumn grazing area	77	14	28.60	44.77
Intra-seasonal pasture areas (spring)	72	15	27.70	37.34
Intra-seasonal pasture areas (summer)	62	16	23.80	25.92
Intra-seasonal pasture areas (autumn)	77	14	31.20	46.47
ANOVA p-value	< 0.001	< 0.001	< 0.001	< 0.001

$p < 0.05$, *Leaf-to-stem biomass ratio

The best quality of pasture land was recorded in areas reserved for seasonal grazing in spring, summer, and autumn, as well as on intra-seasonal pastures. Areas used during the three seasons have a higher concentration of the most valuable cereal plants, among which are *Agropyron desertorum*, *Stipa capillata*, *Festuca valesiaca*, *Leymus ramosus*, *Koeleria cristata*, and *Kochia prostrata*.

An analysis of changes in plant abundance indicates that pastures are characterized by a variety of species from different botanical groups [33]. Thus, in autumn, seasonal pastures are dominated by annual grasses (ephemera and ephemeroïds), covering 14% of the territory, and cereal plants make up 46% of the plant community, consistent with the detailed study of vegetation.

In the spring-summer period, seasonal pastures had a total projective coverage of 62-72% with the following species composition: ephemera and ephemeroïds accounted for 11-12%, grasses made up 27-40%, wormwoods occupied 11-14% of the total vegetation, forbs amounted to 9-10%, and the share of weeds and poisonous plants was 2-3% (Table 2).

Table 2. Dynamics of total projective vegetation cover (%) and projective cover (%) of economic-botanical groups of pasture plants

Economic-Botanical Group	Grazing Technology Variant			
	Intensive Grazing Pastures (control)	Spring Season Grazing Area	Summer Season Grazing Area	Autumn Season Grazing Area
Total projective coverage	38	72	62	77
Ephemera and ephemeroïd plants	8	12	11	14
Grasses	5	40	27	46
Mugworts	15	11	14	9
Forbs	10	9	10	8
Weeds and poisonous plants	6	2	3	1

The study further shows that *Artemisia lerchiana* and *Artemisia austriaca* occupy from 9 to 15% of the grass layer of meadows and that their percentage is determined by the farming methods deployed in these territories. The highest occurrence of wormwoods, up to 15%, was observed on pastures with high grazing intensity. The reduction of grazing impact causes a consistent decrease in wormwood to 9-14%. Areas under intensive and summer grazing were marked with the highest content of forbs (10%), including weeds and poisonous species. During the summer and autumn seasons, forbs are included in the composition of pasture phytocenosis and account for approximately 8-9% of its total mass. At the same time, the share of undesirable weeds in the same pastures amounts to 1-2%. It is also worth noting a positive downward trend in the presence of poisonous plants, particularly *Tanacetum achilleifolium*, *Lepidium perfoliatum*, *Anabasis aphylla*, *Datura*, *Xanthium strumarium*, *Alhagi pseudalhagi*, and *Euphórbia*, in the composition of forbs characteristic of seasonal pastures.

A key indicator of pasture quality is the yield of green mass, which is directly contingent on the grazing technology used. Our experiments show that the grazing method significantly affects the state of pasture ecosystems, both quantitatively and qualitatively. Due to increased load, intensive grazing compromises grass productivity [35]. In our study, intensive grazing (control variant) produced the lowest yield of 0.38 t/ha. Seasonal grazing, due to the redistribution of grazing pressure and the presence of rest periods, achieved a significant increase: by 0.25 t/ha (summer, 0.63 t/ha), 0.44 t/ha

(spring, 0.82 t/ha), and 0.55 t/ha (autumn, 0.93 t/ha). Intra-seasonal grazing also performed better than intensive with the yields of 0.84 t/ha (spring), 0.65 t/ha (summer), and 0.97 t/ha (autumn), surpassing control by 0.46, 0.27, and 0.59 t/ha, respectively.

Grazing technology has a significant impact on green mass yields. One-way ANOVA revealed a significant overall effect of grazing technology on green mass yield ($p < 0.001$). Post hoc comparisons showed that seasonal and intra-seasonal grazing variants produced higher green mass yield than the intensive grazing control. A visual confirmation of this effect is presented in the box plot below (Figure 1).

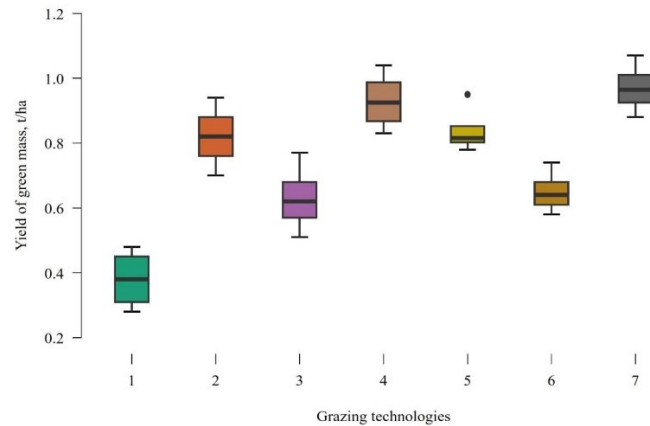


Figure 1. Impact of grazing technologies on the yield of green mass from pasture vegetation: 1-Intensive grazing area (control); 2-Spring season grazing area; 3-Summer season grazing area; 4-Autumn season grazing area; 5-Intra-seasonal pasture areas (spring); 6-Intra-seasonal pasture areas (summer); 7-Intra-seasonal pasture areas (autumn)

Effective pasture management is key to securing both the required volume and nutritional value of feed resources. If the pasture is mowed too low, the leaf mass of plants decreases, as does the consumption of feed by livestock [36], and the growing season is elongated [37]. The research conducted from 2023 to 2025 demonstrates a strong relationship between pasture feed quality and the applied grazing technology. This relationship, in turn, determines the nutritional and energy value of the feed. The collection of feed units per hectare varied depending on the grazing season, reaching 0.17 t/ha in spring, 0.12 t/ha in summer, and 0.20 t/ha in autumn under seasonal grazing. In contrast, intensive continuous grazing reduced this indicator to 0.06 t/ha, confirming the lower feed productivity of pastures under heavier grazing pressure. With the introduction of intra-seasonal pasture use, the collection of feed units increased by 0.07, 0.11, and 0.15 t/ha, reaching higher rates compared to intensive grazing.

One-way ANOVA confirmed a significant effect of grazing technology on the accumulation of feed units per hectare ($p < 0.001$). The lowest values were recorded under intensive grazing, whereas seasonal and intra-seasonal grazing increased feed unit collection, which can be clearly seen in the box plots in Figure 2.

With the use of pastures in different seasons, the yield of digestible protein ranged from 0.005 to 0.022 t/ha. The intra-seasonal grazing technology provided 0.009, 0.018, and 0.023 t/ha of digestible protein, outperforming the control variant by 0.006, 0.015, and 0.020 tons, respectively. The ratio of feed units to digestible protein fell in the range of 107-110 g.

Under intensive grazing, the collection of digestible protein per hectare was the lowest (0.003 t/ha) among all the methods. The content of digestible protein in the feed in this variant also dropped to 60 g.

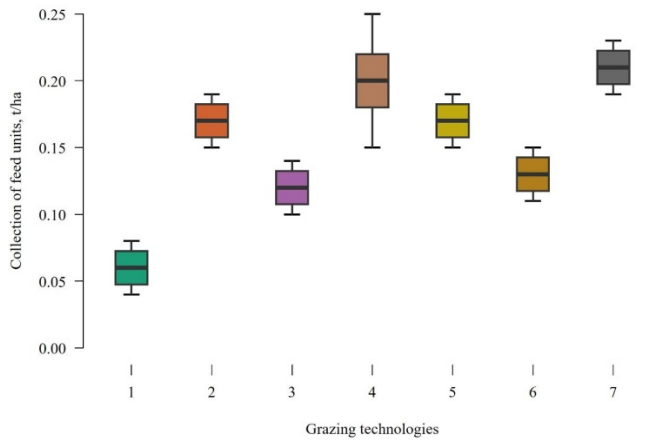


Figure 2. Impact of grazing technologies on the accumulation of feed units in pasture vegetation: 1-intensive grazing area (control); 2-spring season grazing area; 3-summer season grazing area; 4-autumn season grazing area; 5-intra-seasonal pasture areas (spring); 6-intra-seasonal pasture areas (summer); 7-intra-seasonal pasture areas (autumn)

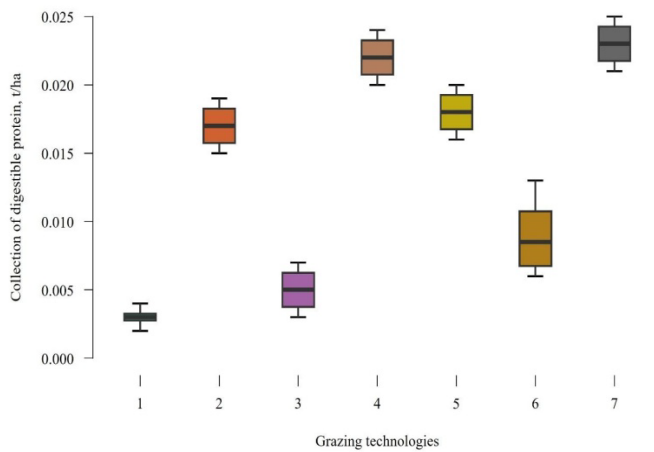


Figure 3. Optimization of digestible protein levels in pasture vegetation under different grazing technologies: 1-intensive grazing area (control); 2-spring season grazing area; 3-summer season grazing area; 4-autumn season grazing area; 5-intra-seasonal pasture areas (spring); 6-intra-seasonal pasture areas (summer); 7-intra-seasonal pasture areas (autumn)

One-way ANOVA showed significant differences in digestible protein yield among grazing technologies ($p < 0.001$). The intensive grazing control had the lowest digestible protein yield, while the intra-seasonal and seasonal grazing variants showed higher values. The observed differences are visualized in the boxplots in Figure 3.

Pasture productivity assessment needs to consider not only the biomass but also the energy value of pasture feed. Pacheco et al. [38] noted that differences in plant height between the pastures of different ages entail variability in the nutritional value of different plant species, which can be further aggravated by the degradation of pasture ecosystems. Our

findings support these patterns. The collection of exchange energy from pasture feed was found to rise with the use of seasonal and intra-seasonal grazing [39, 40]. The most advantageous variants in terms of exchange energy yield were seasonal grazing and intra-seasonal pasture use. According to Figure 4, intensive continuous grazing produced the lowest exchange energy yield, approximately 0.87 GJ/ha. Under seasonal grazing, this indicator increased to 1.67–2.67 GJ/ha, which was 0.80–1.80 GJ/ha higher than under intensive grazing. In the intra-seasonal pasture plots, exchange energy yield reached 1.79–2.79 GJ/ha, exceeding the intensive grazing control by 0.92–1.92 GJ/ha.

One-way ANOVA confirmed a significant effect of grazing technology on exchange energy yield from pasture vegetation ($p < 0.001$). Seasonal and intra-seasonal grazing increased exchange energy output compared with intensive continuous grazing (Figure 4).

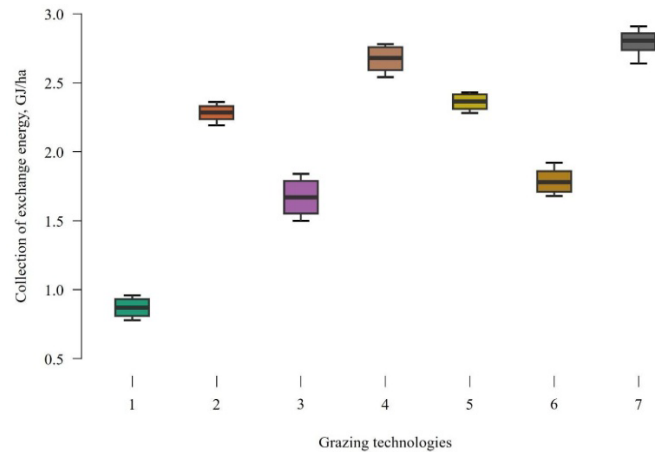


Figure 4. Impact of grazing technologies on exchange energy yield from pasture vegetation: 1-intensive grazing area (control); 2-spring season grazing area; 3-summer season grazing area; 4-autumn season grazing area; 5-intra-seasonal pasture areas (spring); 6-intra-seasonal pasture areas (summer); 7-intra-seasonal pasture areas (autumn)

Our results are consistent with the conclusions drawn in a 2021 study by Bell et al. [41], which also reports an improvement of the nutritional value of pasture feed as a result of optimized grazing practices and pasture management.

Thus, in order to improve the indicators of vegetation, feed productivity, and energy protein value of pasture phytocenoses in the semi-desert zone of West Kazakhstan, we can recommend seasonal and intra-seasonal livestock grazing in the spring-autumn months. This approach is the optimal technology to sustainably manage pasture ecosystems and reduce their degradation.

3.2 Pasture soil health depending on grazing technology

Overgrazing has been found to produce a significant impact on the dynamics of pasture ecosystems, causing changes in soil properties [42]. Our results support this pattern, demonstrating that intensive grazing on pastures in the semi-desert zone of West Kazakhstan aggravated both the physical and chemical parameters of the light chestnut soil. According to the agrochemical analysis, humus content in the 0-30 cm soil layer of the reference pasture area equals 1.30% with a stock of humus of 47.58 t/ha. The research of Dong et al. [43]

suggests that excessive trampling by livestock leads to the compaction of soil, destroys its structure, and promotes salinization, which in turn contributes to the pasture degradation. In our study, the content and stock of humus decreased significantly under intensive grazing and amounted to 0.83% (a decrease of 0.47%) and 34.86 t/ha (a decrease of 12.72 t/ha), respectively. Thus, the difference between humus content in intensive grazing pastures and in the reference variant corresponds to degradation class 2 (a decrease of 26.73%), whereas the minimal reduction in humus content in

seasonal pastures indicates a lack of pasture degradation according to this indicator.

Seasonal pasture use in spring, summer, and autumn had an insignificant effect on humus indicators compared to the reference area. Specifically, humus content in the spring, summer, and autumn season grazing areas lowered, respectively, by 0.06-0.09%. The stock of humus in the 0-30 cm soil layer in these variants was 45.76, 45.74%, and 45.76 t/ha, respectively (Table 3).

Table 3. Agrochemical indicators of the light chestnut soils of pastures in the semi-desert zone of West Kazakhstan depending on grazing technology, average for 2023-2025, 0-30 cm soil layer

Grazing Technology Variant	Humus, %	Stock of Humus, t/ha	Available Phosphorus, mg/kg	Exchangeable Sodium, % of CEC
Reference area, no grazing	1.30a	47.58a	10.7a	8.88a
Intensive grazing area	0.83b	34.86c	6.6c	10.53b
Spring season grazing area	1.23a	45.76b	9.5ab	9.18 a
Summer season grazing area	1.21a	45.74b	9.2b	9.26 a
Autumn season grazing area	1.24a	45.76b	9.7ab	9.06a
ANOVA F-value	56.91	251.13	28.28	13.56
ANOVA p-value	< 0.001	< 0.001	< 0.001	< 0.001

Values are presented as means. Different lowercase superscript letters within each column indicate significant differences among grazing variants according to Tukey's HSD test at $p < 0.05$. Dunnett's test was used for planned comparisons with the reference no-grazing area. Available phosphorus values were converted from mg/100 g to mg/kg by multiplying by 10.

Humus stock was calculated as an integrated indicator based on humus content, bulk density, and the depth of the analyzed soil layer using the following relationship: humus stock (t/ha) = humus content (%) \times bulk density (g/cm³) \times soil depth (cm). Therefore, humus stock reflects not only the percentage concentration of humus but also the mass of soil in the 0–30 cm layer. In the spring season grazing area, humus content did not differ significantly from the reference variant, whereas humus stock showed a significant reduction. This difference reflects the derived nature of the stock indicator and the variance structure of the calculated values rather than a contradiction in the dataset. Therefore, this result should be interpreted together with humus concentration and soil density.

One-way ANOVA showed a significant overall effect of grazing technology on all agrochemical indicators of light chestnut soils in the 0–30 cm layer ($p < 0.001$). The strongest deterioration was observed under intensive continuous grazing, where humus content, humus stock, and available phosphorus were lower, while exchangeable sodium was higher than in the reference no-grazing area. Post hoc comparisons showed that seasonal grazing variants remained much closer to the reference conditions than the intensive grazing variant.

Fenetahun et al. [44] defined the chemical properties of the soil as characteristics determined by soil management, dependent on soil structure and air and water permeability and largely on the employed grazing practice. In this study, livestock grazing had only a minor influence on the chemical properties of soil in pasture areas [45]. Our results support this trend, revealing higher available phosphorus content in seasonal grazing areas, ranging from 9.2 to 9.7 mg/kg, compared with 6.6 mg/kg under intensive grazing. As suggested by Wang et al. [46], the main reason behind increased mobile phosphorus levels in seasonal grazing areas is the greater volume of grass biomass, which improves the availability of soil nutrients once it decomposes. However, as pasture lands are transferred to continuous grazing and experience degradation (intensive grazing), we can observe a

decrease in the biomass of above-ground grass. This, along with a reduction in humus content to 0.83%, caused available phosphorus to decrease to 6.6 mg/kg.

Intensive grazing also caused a transition of soil solonetzicity from a weak to a medium level, as evidenced by an increase in the proportion of exchangeable sodium in CEC from 8.88% in the reference no-grazing area to 10.53% under intensive grazing (Table 3). Other study [47] also indicate changes in cation-exchange capacity and nutrient stores associated with the leaching of clay particles and higher soil density due to overgrazing.

Compared to continuous grazing, the method using seasonal areas had only a limited effect on soil solonetzicity [48]. In the seasonal grazing areas, the proportion of exchangeable sodium in CEC increased only slightly, from 8.88% in the reference no-grazing area to 9.06-9.26%. According to post hoc comparisons, these differences were not significant at $p < 0.05$. In contrast, intensive continuous grazing increased the proportion of exchangeable sodium in CEC to 10.53%, indicating a stronger shift toward soil solonetzicity under continuous livestock pressure.

An analysis of the influence of livestock grazing on pasture ecosystems has demonstrated that the detrimental effect on soil structure caused by the dynamic impact of livestock is directly proportionate to livestock density and the intensity of grazing [32]. As an outcome of intensive grazing, soil density climbed to 1.40 g/cm³, which is 14.75% higher than the control area (no grazing) and corresponds to soil degradation class 3 [42]. Soil density indicators also experienced changes in connection to grazing technology. In comparison with the 1.22 g/cm³ density of soil in the 0-30 cm layer in the reference area, under intensive grazing, soil density increased by 14.75%, amounting to 1.40 g/cm³ and corresponding to degradation class 3. The seasonal pasture grazing technology brought only a minor increase of 0.82-3.28% in the density of light chestnut soil in the 0-30 cm layer. These data indicate a lack of soil degradation under the influence of livestock.

The content of agronomically valuable aggregates in the 0–30 cm layer of light chestnut soil in the reference area was

75.05%, corresponding to the “good” category, and the coefficient of structurality was 3.14, also interpreted as “good”. In intensive grazing pastures, the content of agronomically valuable structural aggregates decreased to 52.76%, while the structurality coefficient declined to 1.15, corresponding to the “satisfactory” category. Seasonal grazing

in spring, summer, and autumn maintained a better structural state of the soil: the content of valuable aggregates reached 67.82%, 67.04%, and 68.70%, respectively, and the coefficient of structurality was 2.13, 2.04, and 2.21, respectively (Table 4).

Table 4. Agrophysical indicators of the light chestnut soils of pastures in the semi-desert zone of West Kazakhstan depending on grazing technology, average for 2023–2025, 0–30 cm soil layer

Grazing Technology Variant	Soil Density, g/cm ³	Coefficient of Structurality	Agronomically Valuable Structural Aggregates, %
Reference area, no grazing	1.22a	3.14a	75.05a
Intensive grazing area	1.40b	1.15c	52.76c
Spring season grazing area	1.24a	2.13b	67.82b
Summer season grazing area	1.26a	2.04b	67.04b
Autumn season grazing area	1.23a	2.21b	68.70b
ANOVA F-value	11.58	75.28	184.28
ANOVA p-value	< 0.001	< 0.001	< 0.001

Values are presented as means. Different lowercase superscript letters within each column indicate significant differences among grazing variants according to Tukey’s HSD test at $p < 0.05$. Dunnett’s test was used for planned comparisons with the reference no-grazing area.

One-way ANOVA confirmed a significant overall effect of grazing technology on all agrophysical soil indicators ($p < 0.001$). Intensive continuous grazing caused the greatest increase in soil density and the strongest decline in the coefficient of structurality and the content of agronomically valuable structural aggregates. Post hoc comparisons showed that soil density in the seasonal grazing variants did not differ significantly from the reference no-grazing area, whereas soil structure indicators were lower than in the reference variant but remained substantially better than under intensive grazing.

To summarize, intensive grazing contributes to a deterioration of pasture soil health and ultimately leads to its degradation, specifically, to class 2 due to a decrease in the stock of humus and class 3 based on the increase in the density of light chestnut soils in the semi-desert zone of West Kazakhstan.

4. DISCUSSION

4.1 Relationship between the biometric and productive indicators of pastures

Scientific research points to the primary role of plant height among the biometric characteristics of pastures. A plant height of 20–30 cm has been found to correlate with an increase in livestock productivity. At the same time, researchers state that intensive pasture use with the withdrawal of a significant proportion of biomass, despite the improvement of individual indicators of livestock and carcass quality, is associated with a decrease in key biometric indicators of pastures, including the height of the grass stand [49, 50].

Our studies support these conclusions: under intensive grazing, plant height lowered to 18.70 cm, which resulted in a drop of green mass yield to 0.38 t/ha. This rate is 0.25–0.55 t/ha (or 39.68–59.14%) lower than in the variants of seasonal grazing (in spring, summer, and autumn), where plant height reached 22.20, 25.50, and 28.60 cm, respectively, outperforming intensive grazing by 3.50, 6.80, and 9.90 cm. Furthermore, our research confirms the effectiveness of intra-seasonal grazing. In these variants, plant height amounted to 23.80, 27.70, and 31.20 cm, which is 5.10, 9.00, and 12.50 cm higher than under intensive grazing. The yield of green mass

was also greater at 0.65, 0.84, and 0.97 t/ha, which is 0.27, 0.46, and 0.59 t/ha (or 41.54, 54.76, and 60.83%) above the level of intensive grazing. These results are associated with improved pasture biometrics (plant height and projective coverage) due to the redistribution of grazing pressure and the presence of recovery periods during pasture rotation [44]. This also confirms the relationship between grass height and yield, consistent with the research of Comasseto et al. [51], which established a linear relationship between these parameters.

The results of statistical analysis show that the yield of green mass increases with the height of the grass stand. The level of yield can also be seen to depend on the method of pasture use. The rate of the increase is described by a linear regression equation. The general regression equation is: Yield, t/ha = $-0.22 + 0.03 \times \text{Height, cm}$. Hence, it can be stated that with an increase in plant height by 1 cm, the yield of green mass grows by an average of 0.03 t/ha. The model showed a moderate relationship between plant height and green mass yield. According to Figure 5, the correlation coefficient was $R = 0.56$, corresponding to a coefficient of determination of $R^2 = 0.31$. The model was statistically significant at $p < 0.001$.

The management of pasture ecosystems is a fundamental aspect determining the productivity and nutritional value of the vegetation cover. If the height of the stover on pastures is too low, the ratio of leaf mass to total plant biomass significantly decreases, the feed becomes less palatable to livestock [52], and the general productivity of pastures suffers as a result [53].

The study has established a negative impact of intensive grazing on pastures, as the proportion of leaves under this technology was lower compared to seasonal and intra-seasonal methods. This aspect is critical, because the leaf mass is the main driver of pasture feed yield [54]. As a result of the longer and more active removal of biomass with intensive grazing, the foliage of plants decreased to 16.77%. This, combined with changes in biometric indicators (plant height and projective coverage), led to the lowest pasture yield of only 0.38 t/ha. These results are highly consistent with other studies in the semi-arid regions of West Kazakhstan, which reported yield increases of approximately 0.43 t/ha, representing a two-fold improvement over unsystematic grazing [55]. Similarly, in the dry steppe zones of Northern Kazakhstan, rotational management has been shown to produce green mass yields

between 6.1 and 12.6 c/ha, significantly outperforming intensive continuous systems [45]. The comparability of these findings across regional contexts suggests that the recovery of

dominant species like fescue and wormwood follows a predictable trajectory when unregulated intensive pressure is removed [50].

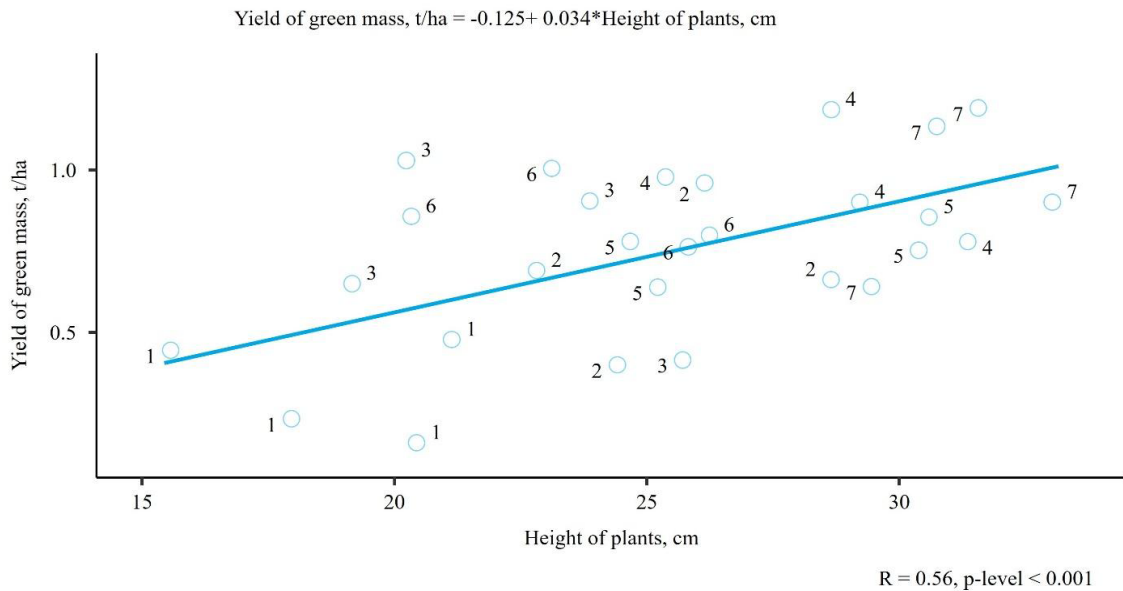


Figure 5. Dependence of the productivity of pasture ecosystems (yield of green mass) on plant development (height of plants) under different grazing technologies: 1-intensive grazing area (control); 2-spring season grazing area; 3-summer season grazing area; 4-autumn season grazing area; 5-intra-seasonal pasture areas (spring); 6-intra-seasonal pasture areas (summer); 7-intra-seasonal pasture areas (autumn)

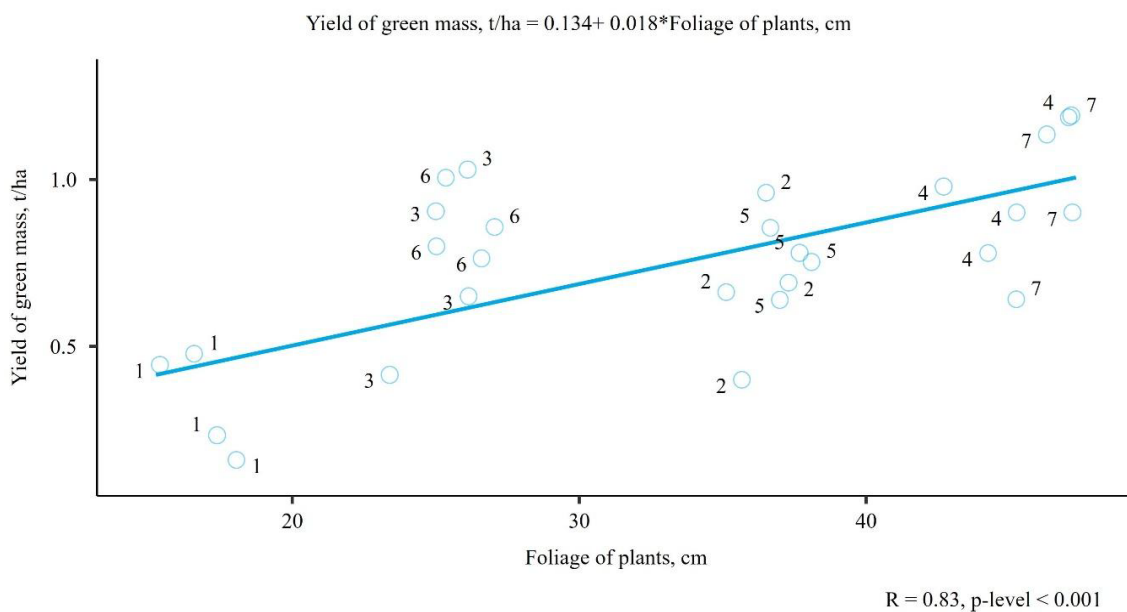


Figure 6. Relationship between green mass yield and plant foliage obtained under different grazing technologies: 1-intensive grazing area (control); 2-spring season grazing area; 3-summer season grazing area; 4-autumn season grazing area; 5-intra-seasonal pasture areas (spring); 6-intra-seasonal pasture areas (summer); 7-intra-seasonal pasture areas (autumn)

The findings of Tomich et al. [56] indicate a relationship between plant height and leaf-to-stem ratio. In our study, the use of grazing strategies involving pasture rest periods (seasonal and intra-seasonal) facilitated grass growth and an increase in the proportion of leaves in the yield. Specifically, foliage reached 25.12-44.77% on seasonal pastures and 25.92-46.47% on intra-seasonal ones, with some variation between the seasons. Our results also confirm that higher foliage is directly linked with increased pasture yield. For instance, on seasonal pastures, where foliage grew from 16.7% to 25.12-

44.77% (an 8.35-28.00% increase), green mass yield rose by 0.25-0.55 t/ha (or by 39.68-59.14%) relative to the control group (intensive grazing).

The results of the study thus demonstrate that the foliage of plants has a significant impact on the productivity of pasture vegetation, the effect being the most pronounced on the intra-seasonal pastures. In these variants, with a rise in foliage from 16.77% to the range of 25.92-46.47% (a 9.15-29.70% increase compared to intensive grazing as the control), pasture grass yields climbed to 0.65-0.97 t/ha. These levels surpass the yield

of control pastures by 41.54-60.82%. These effects are explained not only by the spatial redistribution of grazing pressure and seasonal rest periods but also by plant physiological mechanisms. Grazing damages leaf structures, reducing photosynthesis and carbohydrate accumulation [56]. Under seasonal grazing, plants reallocate nutrients (primarily nitrogen and phosphorus) to restore functional balance between above- and below-ground organs before rebuilding biomass [56]. This promotes a tolerance strategy, in which plants increase biomass allocation to leaves, enhancing regrowth and carbon assimilation efficiency [56]. Thus, the results indicate that plant height and foliage jointly determine pasture productivity, while seasonal and intra-seasonal grazing systems enhance these parameters by balancing biomass removal and recovery processes. According to Anghinoni et al. [57], optimized grazing intensity contributes to a balanced distribution of roots, shoots, and leaves and improves soil organic matter within integrated systems.

Statistical analysis shows (see Figure 6) that the yield of green mass increases depending on the height of plants indicator. The graph also shows the dependence of yield on pasture use methods. The linear regression equation is: Yield, t/ha = 0.134 + 0.018 × Foliage, %. Therefore, it can be asserted that with an increase in the foliage of plants by 1%, the yield

of green pasture mass grows on average by 0.018 t/ha. The model is quite close to real data, having an 83% determination coefficient and a significance level of $p < 0.001$.

4.2 Correlation between grazing technology and pasture soil parameters

The study discovered a statistically significant correlation between soil density and humus content. This inverse correlation is consistent with the results of Chestnykh and Zamolodchikov [58], who noted the possibility of approximating this dependence to both linear and nonlinear functions.

According to our statistical analysis (see Figure 7), soil density decreases depending on grazing intensity and humus content. The rate of decline is consistent with a regression equation. The general regression equation is: Soil density, $g/cm^3 = 1.69 - 0.37 \times \text{Humus, \%}$. The resulting model has a determination coefficient of 86% and a significance level of $p\text{-level} < 0.001$. The regression analysis established a linear coefficient describing the dependence of soil density on humus content (-0.37). Accordingly, with a 1% increase in humus content, soil density lowers by $0.37 g/cm^3$.

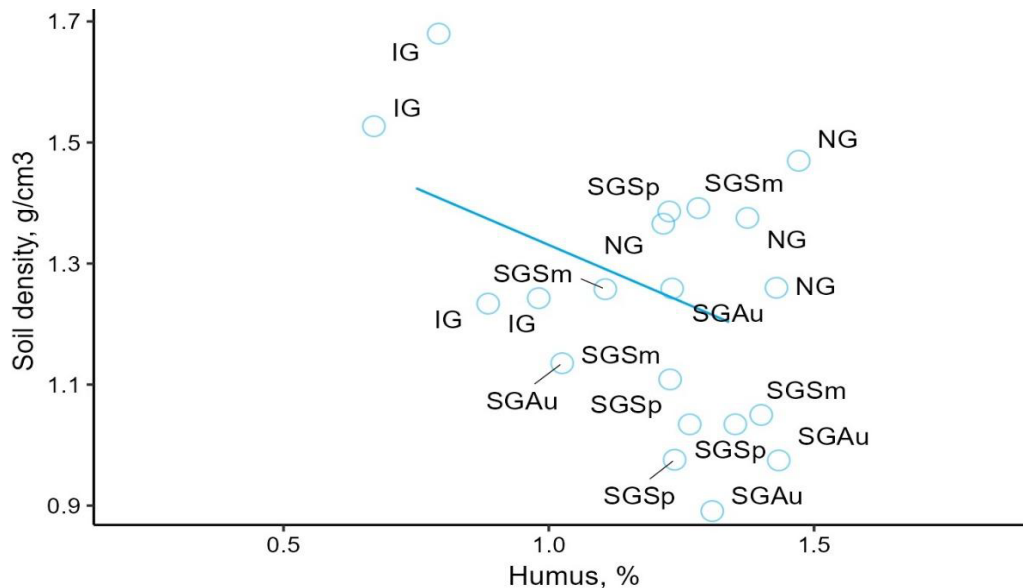


Figure 7. Impact of different grazing technologies (NG-no grazing; SGSp-seasonal grazing, spring; SGSm-seasonal grazing, summer; SGAu-seasonal grazing, autumn; IG-intensive grazing) on the relationship between soil density (g/cm^3) and humus content (%) in the light chestnut soils of the semi-desert zone of West Kazakhstan

Wang et al. [59] established that as the condition of pasture lands deteriorates, the soil becomes denser, which potentially affects its chemical properties. In turn, Koptsik et al. [60] demonstrated that humus content has a significant impact on both the density and the ability of soil to aggregate. A significant pattern emerged in the present soil analysis: the coefficient of structurality differed significantly from the reference across all grazing treatments ($p < 0.001$), whereas soil density was significantly elevated only under intensive continuous grazing. This suggests that soil structure, particularly the stability and arrangement of macroaggregates, is more sensitive to livestock impact than bulk density as a physical indicator [61].

In our study, the decline in humus content to 0.83% and the rise in soil density in the 0-30 cm layer to $1.40 g/cm^3$ observed

in intensive grazing variants contributed to the degradation of the soil to class 3. This pattern is consistent with evidence that soil bulk density responds primarily to high cumulative stocking pressure or prolonged grazing on moist soils, whereas structural degradation of macropores and aggregate stability occurs earlier in the degradation sequence [62, 63]. In contrast, seasonal grazing maintained soil density values closer to the reference conditions, indicating partial mitigation of compaction processes [42].

Furthermore, the fact that even seasonal grazing significantly altered the structurality coefficient indicates that any livestock presence disrupts the formation of stable agronomically valuable aggregates compared to undisturbed control conditions, although the magnitude of degradation remains considerably lower than under continuous grazing

regimes [61].

The analysis has established that an increase in the stock of humus by 1 t/ha leads to a 1.5% increase in the content of agronomically valuable structural aggregates.

Thus, the study demonstrates that the content of agronomically valuable structural aggregates grows with an

increase in the stock of humus. The observations were further subjected to linear regression analysis: Agronomically valuable structural aggregates, % = $-0.283 + 1.515 \times \text{Stock of humus, t/ha}$. The determination coefficient of the model is 90% with a significance level of $p < 0.001$ (Figure 8).

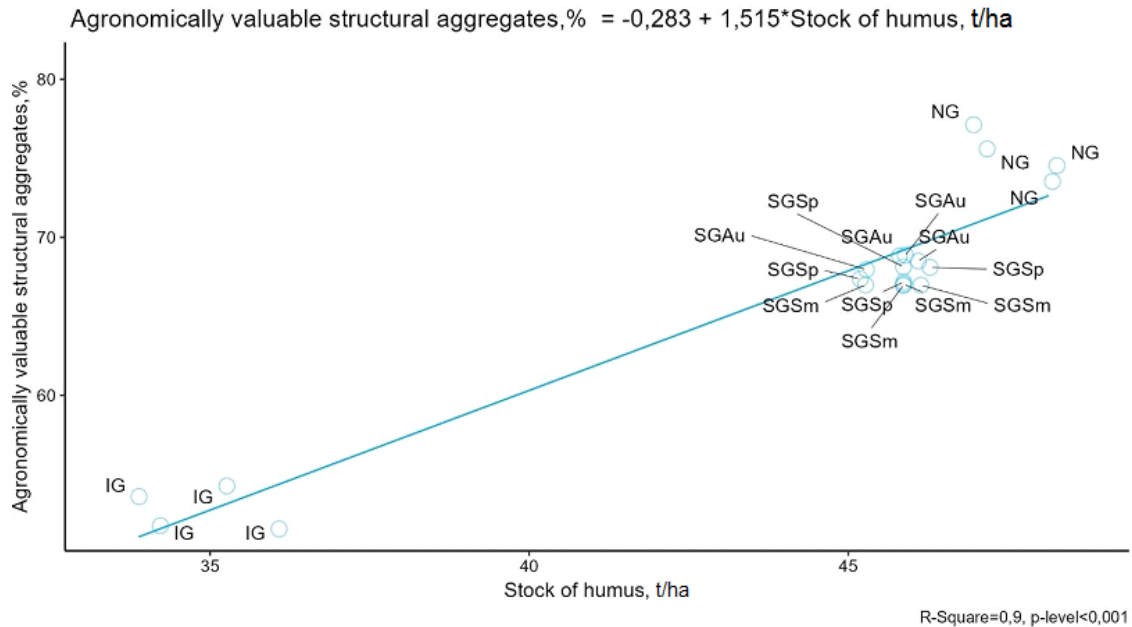


Figure 8. Impact of different grazing technologies (NG-no grazing; SGSp-seasonal grazing, spring; SGSm-seasonal grazing, summer; SGAu-seasonal grazing, autumn; IG-intensive grazing) on the relationship between agronomically valuable structural aggregates (%) and the stock of humus (t/ha) in the light chestnut soils of the semi-desert zone of West Kazakhstan

The regression analysis provided a linear coefficient characterizing the relationship between the content of agronomically valuable structural aggregates and the stock of humus in light chestnut soils. The results reveal a positive correlation between the content of agronomically valuable structural aggregates and the coefficient of soil structure with increasing distance from intensive grazing areas towards the control no-grazing areas. This trend is likely connected with the lowering of anthropogenic impact on the soil in the absence of grazing, which contributed to its long-term stability. These conditions were conducive to the formation of favorable hydrodynamic regimes and stimulated the synthesis of humus substances, which play a key role in the aggregation of soil particles [64]. In contrast, intensive grazing pastures experienced soil degradation to class 2 due to the decrease of humus stocks. The most favorable levels of the content (1.21-1.24%) and stock of humus (45.74-45.76 t/ha) together with optimal soil structure (67.04-68.70%) were observed in the variants of seasonal grazing on spring, summer, and autumn areas. Fonseca et al. [65] stressed that effective spatiotemporal pasture management can aid in increasing biodiversity, optimizing the distribution of nutrients in the soil, and improving its quality characteristics.

4.3 Methodological considerations and future research

Although grazing duration, stocking density, and AUM/ha were standardized and reported in the revised methodology, the study was conducted under real farm conditions, where animal movement, daily forage intake, and localized trampling pressure could not be fully controlled. Therefore, the observed

effects should be interpreted as the combined result of grazing timing, spatial redistribution of livestock pressure, and rest periods rather than as the effect of stocking density alone. In pasture research, grazing intensity can influence herbage removal and soil compaction independently of seasonal rotation [66, 67]; therefore, future studies should further separate the effects of stocking rate, grazing duration, and seasonal rest.

To refine future research and improve the scalability of these findings, it is recommended that studies standardize their metrics by reporting forage allowance and comparative stocking rates [66]. Using units such as "animal-days per ha" would allow researchers to disentangle the specific effects of seasonal timing from those of absolute livestock pressure [66]. Such standardization is essential for developing precise management protocols that can be replicated across the diverse semi-desert ecosystems of Kazakhstan.

5. CONCLUSIONS

The obtained findings give grounds to conclude that seasonal pasture use has several positive aspects in the framework of sustainable land use. Firstly, this approach prevents overgrazing, which induces soil degradation and the loss of productivity. The regular rotation of grazing areas gives the plants time to recover, supporting their growth and reproduction. The increase in plant diversity and productivity then translates into improved livestock feed quality. Furthermore, denser vegetation cover protects the soil from wind and water erosion. It also prevents soil degradation by

allowing it to recover and avoiding excessive compaction. Overall, seasonal grazing allows pasture areas to rest, with the break providing pasture plants time for regrowth and recovery, which is critical to maintaining a healthy soil ecosystem.

Concentrated grazing in the same area causes soil to compact by 14.75%, making it difficult for water and air to penetrate and leading the pasture soil to be degraded to class 3. Seasonal and intra-seasonal grazing reduce this impact by redistributing grazing pressure and allowing pasture vegetation and soil to recover between grazing periods. The improved soil structure with up to 67.04–68.70% of valuable aggregates and high plant biomass reaching 0.63–0.97 t/ha coupled with great foliage of pasture plants up to 25.12–46.47% facilitate the accumulation of organic matter, which increases soil fertility in the long term, thereby preventing soil degradation. In contrast, intensive grazing, which reduced pasture grass biomass to 0.38 t/ha and resulted in low foliage (16.77%) and low plant height (18.70 cm), contributed to soil degradation to class 2 due to a decrease in humus stocks to 26.73%.

The process of pasture degradation directly impacts the sustainability of the system. In addition to environmental damage, it can lead to economic losses, since degradation affects the productivity of the pastoral industry. Thus, stopping pasture degradation is beneficial not only from an environmental but also from an economic standpoint. The studied and proposed technology of seasonal pastures is both implementable and scalable for other regions of Kazakhstan, Central Asia, Mongolia and Kalmykia (Russia) with similar vegetation, soil, and climate conditions. Seasonal grazing can be integrated into national programs to combat degradation and desertification and is already used in the framework of SDG 15: "Conserve terrestrial ecosystems", which calls to combat desertification, restore land and forests, and conserve biodiversity. The fight against land degradation is an integral part of the wider SDG targets, such as tackling climate change, ending hunger, and ensuring sustainable land use.

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