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Assessing Variability of Soil Quality in Western Kazakhstan: Dynamic Effects of Grazing Practices

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ABSTRACT

Preserving the quality of pastoral ecosystem soil is crucially important for the production of nutritionally complete feed for the livestock industry as part of ensuring national food security. In Kazakhstan, such useful tools include soil assessment and evaluation of dynamic changes in soil properties in connection with agricultural grazing. The purpose of the study is to assess the current conditions of pasture soil in Western Kazakhstan using classical field research methods and popular methods of laboratory analysis. The study conducted in the semi-desert zone of Western Kazakhstan based on the Miras peasant farm demonstrates that rotational grazing is more optimal for maintaining and preserving soil quality compared to intensive agricultural grazing without breaks. Results demonstrate that rotational grazing maintains soil quality more effectively than intensive grazing. Specifically, under intensive grazing, humus content significantly decreased by 0.47%, while rotational grazing showed minimal changes (decrease of 0.09% in field 1 and 0.05% in field 2). Humus stock was also better preserved in rotational grazing fields, with only a 3.07-4.68% reduction, compared to a 27.05% decrease under intensive grazing. These findings suggest that rotational grazing can significantly mitigate the degradation effects of agricultural grazing on soil properties. The physical (density, structure) and chemical (humus content, humus stock, mobile phosphorous, exchangeable sodium) properties were found to be optimal on pastures where rotational grazing was employed. The conducted research is useful for assessing pasture soil properties and in taking measures to prevent potential degradation of pasture soil in the region. In addition, the findings will be useful in the evaluation of agricultural land in connection with its economic use in many countries with similar methods of pasture ecosystem management.

1. INTRODUCTION

By 2050, the world's population is expected to reach 9.1 billion people, significantly increasing the demand for agricultural products and highlighting the importance of sustainable agricultural practices. Pasture ecosystems, which cover nearly half of the Earth's land surface, are critical for the livestock industry, providing essential ecosystem services such as water regulation, nutrient cycling, and carbon sequestration. However, these ecosystems face threats from overgrazing, which can lead to severe soil degradation, impacting soil quality and ecosystem stability.

One of the levers for meeting the population's food needs is the development of the forage and livestock sectors [1-3].

Global demand for agricultural products demands that farmers employ technologies considering the mass degradation and aggravation of the ecological condition and functional capacities of forage land, which provide for the production of nutritionally complete feed with high energy-protein content [4-6]. Animal feed is produced on forage lands, which are estimated to occupy 26% of dry land and 70% of agricultural land worldwide [7, 8]. A great role in food production belongs to global pastures, which take up as much as half of the Earth's surface, or 3.4 billion ha [9-11]. Pasture lands also provide numerous ecosystem services, including the regulation and storage of water flows [12-14] and nutrient cycling [15-17]. Across the globe, pasture lands play a key part in climate change due to their enormous carbon stocks and flows [18, 19].

Recent trends in extreme phenomena (e.g., severe droughts) point to the fact that climate change is already affecting pasture lands. Model forecasts suggest that these systems, as well as millions of people in all parts of the world who depend on them, will continue to experience this impact [20, 21].

Pasture ecosystems provide livelihoods for millions of people on almost half of the globe, and soils are the foundation of the stability and resilience of these systems [22]. In Kazakhstan, pastures play an important role in the national economy and environmental sustainability, the effects of different grazing practices on soil properties are not well-documented, particularly in the semi-desert zones of Western Kazakhstan. This knowledge gap hinders effective pasture management and conservation strategies that could prevent further degradation and promote recovery of these landscapes.

As everywhere else, in Kazakhstan, the leading factor in soil degradation along with the climate is agricultural grazing (anthropogenic factor) [23]. The intensity of animal grazing is an indicator of the cumulative influence of agricultural animals on feed and soil resources and possibly one of the strongest predictors of agricultural and environmental outcomes, including the functional capacity and health of the soil [23]. Kazakhstan has few studies assessing pasture soil quality. Hence, the investigation of this issue is a topical and urgent task.

In the context of climate change and advancing degradation, it is important to have an understanding of changes in soil quality to increase the sustainability of pasture ecosystems [24, 25].

Soil is vital for humans because it not only affects the quality and quantity of food products and fiber production but also supports the biodiversity and functions of ecosystems [26]. Considering that agricultural lands sustain most of the world's population, the sustainable use of soil resources is critical for the long-term health of people [26-28]. Maintaining soil productivity for as long as possible without the reduction of its quality and thus soil degradation is a prerequisite for sustainable soil use [29]. Quantitative and qualitative protection of soils is necessary not just to ensure food security but to support other functions of soil, such as preservation of biodiversity, storage and filtration of water, and carbon sequestration [12, 15]. Soil protection can be achieved through sustainable agricultural land management, which prevents soil degradation, guarantees food production, and preserves soil functions [18, 30]. Therefore, to maintain a multifunctional productive soil, it is important to reduce negative influences on soil quality [8, 31].

The degradation of soils on pasture lands as a result of animal grazing due to defoliation, trampling, and excretion is a major issue in many countries [31-33]. The negative impact of trampling on the physical properties of soil is of particular interest, as intensive livestock production systems continue to develop all over the world [24, 34]. Ignoring soil degradation from livestock grazing can be a critical omission, since permanent pastures account for, for example, 40% of agricultural land in Western Europe [35] and 70% in Kazakhstan [36, 37]. These pastures are used exclusively for animal grazing. It is believed that about 20% of the world's pasture lands have degraded as a result of overgrazing and associated erosion and compaction [35, 38]. However, most of these degraded pastures are located in arid regions, so their degradation is associated mostly with wind and water erosion. Nevertheless, it has been calculated [39] that 0.83 million km2 of pasture lands in the world have physically degraded because of overgrazing. Experts in Kazakhstan estimate that as a result of irrational use, mainly due to intensive grazing, the area of degraded pastures in the country has reached more than 48 million ha (25.5% of the total area of pastures) [40, 41]. These degraded lands are characterized by deterioration of soil structure and functions and are prone to erosion and desertification [42].

The intensity of grazing is the chief decisive and dominating factor that controls the operation of pastures and overall nutrient cycling [43, 44]. Uninterrupted high-intensity grazing is typically believed to have a detrimental impact on pasture soil [45]. Intensive livestock production and grazing gradually change the characteristics of soil, particularly organic carbon content, total nitrogen, available phosphorus, exchangeable potassium, sodium, texture, bulk density, and pH [46]. Excessive animal grazing increases soil heterogeneity [47] and reduces soil moisture content, mainly through increased trampling [48]. This entails higher denitrification losses [49] and causes soil erosion, thereby reducing pasture productivity and in the long-term leading to the loss of productive and environmental services and social losses in the community due to malnutrition and poverty [50-52].

Grazing time and density, time between grazing activities, and the types of livestock are decisive factors in the sustainable management of pasture lands that play a role in the preservation or improvement of soil quality to prevent land degradation and increase biomass output over time [53].

Biogeochemical and physical soil responses to grazing are governed by complex and often interacting factors: grazing practices [54], climate [55], soil structure [55], the duration of management regime introduction [35], and plant community structure [56-59].

Steffens et al. [32] reported that agricultural grazing aggravates the physical and chemical parameters of soils and suggest that pastures can be improved by reducing the intensity of grazing or excluding the pasture from it [60]. Furthermore, the densification of soil due to trampling by agricultural animals changes soil characteristics, possibly raising the susceptibility of the soil to the loss of water and soil nutrients and thus reducing the amount of water available to plants and hence pasture productivity [61, 62].

Such management methods as rotational grazing can promote the restoration of pasture soil quality [63, 64], simultaneously requiring less work and managerial decisions [65, 66], as well as facilitate livestock productivity [43]. In studies [67, 68] the rotation of desert pastures with an 8-year rest period increased the content of total nitrogen (110%) and total phosphorus (114%) in the 0-10 cm soil layer. Pastures allowed to rest using rotation also offer environmental advantages, including the preservation of biodiversity [69, 70].

The strategies of grazing, particularly rotational grazing, are drawing increasing interest both at the national and global levels as potential climatically conscious tools for improving soil health in a broader sense [71, 72]. Therefore, understanding the properties of soils is pivotal for managing pasture lands, as these characteristics are among the primary factors that determine the forage production potential of a territory in a specific climate [73, 74].

The ecosystems of pasture lands in Kazakhstan, which play a key role in food production, are experiencing major problems due to the global change of climate and degradation [75]. For this reason, as part of efforts to protect pasture ecosystems and develop a strategy for their rational use, Kazakhstan adopted the Law "On Pastures" [76]. The norms enshrined in this law oblige farmers to protect the soil of pastures by using efficient methods of farm animal grazing [75, 77].

For many years, pastures in the semi-desert zone of Western Kazakhstan have been used by local pastoralists as a vital tool for food security. Yet, to date, there is no documented research data on the impact of grazing practices on soil properties in the region under study. This constitutes a critical gap in the sustainable management of pasture lands through balancing pasture capacity and maintaining pasture and livestock productivity. Thus, the goal of the present study is to assess the variability of soil as a result of the dynamic effects of livestock grazing on pastures in the semi-desert zone of Western Kazakhstan.

2. MATERIALS AND METHODS

2.1 Description of the study sites

In line with the research goal, by the state order of the Ministry of Science and Higher Education of Kazakhstan, over the period from 2019 to 2023, studies were conducted at the Zhangir Khan West Kazakhstan Agro-Technical University on pastures of the Miras peasant farm, which is located in the semi-desert zone of Western Kazakhstan, to assess the effects of agricultural grazing methods on pasture soil quality. The terrain of the Miras peasant farm is flat, located on the Caspian Depression. The climate is continental, with cold winters and moderately hot summers. Average temperatures are -12 to -14℃ in January and 27 to 29℃ in July, with annual precipitation ranging from 180 to 250 mm.

The soils on the farm, characteristic of the semi-desert zone of Western Kazakhstan, are light chestnut soils, classified as Calcic Kastanozems. This is based on the morphological features of genetic horizons observed in the soil profile.

Table 1. Scheme of the field experiment to study soil quality on pastures of the semi-desert zone of Western Kazakhstan with different methods of agricultural grazing

Grazing Method	Conditions of Experimental Field Use
No grazing (control)	No grazing – an untouched land plot located outside the peasant form and chosen as a reference for comparison of pasture soil quality. Grazing is absent here.
Rotational grazing – field 1	Grazing of 120 head of cattle is carried out in a rotational grazing system (field 1) on an area of 560 ha. Grazing takes place during the spring and summer seasons, while the field rests in autumn and winter.
Rotational grazing – field 2	Grazing of 80 head of cattle also uses a rotational grazing system (field 2), occurring over the same area of 560 hectares. Here, grazing is done in the spring and autumn, with the field resting during summer and winter.
Intensive grazing	Grazing of 120 head of cattle is carried out without rest in spring, summer, and autumn periods on an area of 560 ha. This means the field does not get a rest period during these seasons.

The vegetation structure in this semi-desert zone is dominated by communities of Artemisia lerchiana. The grass cover of these communities primarily consists of Artemisia lerchiana. Perennial grasses such as Stipa lessingiana, Stipa capillata, Festuca valesiaca, and Agropyron desertorum are moderately common. In the spring, ephemerals and ephemeroids like Poa bulbosa, Tulipa schrenkii, and Alyssum turkestanicum flourish extensively.

The primary livestock in the farm comprises Kazakh Whiteheaded cattle. The grazing patterns and schedules for the farm animals are outlined in Table 1.

2.2 Soil sampling

To conduct soil quality assessment, soil samples were collected at pastures with different grazing methods from the 0-10, 10-20, and 20-30 cm layers. Soil samples were collected once from all four experimental variations. In total, 48 soil samples were gathered.

To determine changes in soil quality as a result of agricultural grazing, soil samples were also collected at a reference plot (control, no grazing) from the 0-10, 10-20, and 20-30 cm soil layers. The soil sampling was conducted in four replications of the experiment.

According to morphological features of genetic horizons in the profile, pasture soils of the studied peasant farm are characteristic of the semi-desert zone of Western Kazakhstan – Calcic Kastanozems.

Agrochemical tests of the quality of pasture soil in the semi-desert zone of Western Kazakhstan were performed in an accredited laboratory at Zhangir Khan University.

A particular emphasis in the studies was placed on establishing soil degradation processes as a result of agricultural grazing. For this purpose, we referred to the criteria established by the Order of the Minister of Agriculture of the Republic of Kazakhstan No.185 of April 27, 2017 [78].

These criteria include:

1) Reduction of humus stock in the 0-30 cm soil layer relative to the control plot, in percent (%);

2) Reduction of mobile phosphorous content relative to the control plot, in percent (%);

3) Increase in exchangeable sodium content, in percent (%) of Cation Exchange Capacity;

4) Increase in soil density in g/cm^3 in the 0-30 cm soil layer relative to the control plot, in percent (%);

5) Soil structure (by content of agronomically valuable aggregates), %.

For this reason, our studies to assess pasture soils used these exact indicators.

Physical and chemical soil analyses

Soil density was determined using N.A. Kachinsky's cylinder method. To determine soil density, soil samples were collected in field conditions from the 0-10, 10-20, and 20-30 cm soil layers with a cylinder bore (manufacturer: Smart Pribor, Russia) of about 500 cm^3 in volume. Simultaneously, soil samples were collected into aluminum weighing bottles (manufacturer: Smart Pribor, Russia) to determine moisture content (Figure 1).

In the laboratory-chamber stage of the research, soil was dried at 105℃ to a constant weight. The mass of air-dry soil was found from the known mass of the weighing bottle with soil and an empty weighing bottle. Next, soil density was found by dividing the mass of dry soil by its volume (ring volume) [79].

The dry sieving method to determine soil structure. The content of agronomically valuable aggregates in soil (lumpy-grained water-resistant aggregates ranging from 10 to 0.25 mm) was established by laboratory analysis of the structural condition of the soil using sieves of different sizes (manufacturer: Smart Pribor, Russia) [79].

Figure 1. Studies of soils in the pastures

Humus content in soil was determined in laboratory conditions following I.V. Tiurin's method, which is based on oxidation of soil organic matter by chromic acid to carbon dioxide formation [79]. The oxidant employed was a solution of $K_2Cr_2O_7$ in sulfuric acid.

The oxidation formula:

$$2K_2Cr_2O_7+8H_2SO_4=2K_2SO_4+2Cr_2(SO_4)_3+8H_2O+3O_2$$
$$3C+3O_2=3CO_2$$

Knowing humus content and soil density, humus stock in the 0-30 cm soil layer was established.

Mobile phosphorus compounds in soil were determined in laboratory conditions using I. Machigin's photometric method. The method consists in extracting mobile phosphorous compounds from soil using a solution of ammonium carbonate $(NH_4)_2CO_3$ at a concentration of 10 g/dm^3 with soil to solution ratio of 1:20, followed by the determination of phosphorous as blue phosphorus-molybdenum complex on a photoelectrocolorimeter (manufacturer: Zagorsk Optical and Mechanical Plant, Russia) [79].

Exchangeable sodium content in soil was determined using the photometric method by extracting exchangeable and soluble sodium with ammonium acetate solution (NH_4CH_3COO) =1 mol/dm with pH at 6.7-7.0 and at a concentration of 1 mol/dm^3 with a 1:20 ratio of soil sample weight to solution volume and then determining sodium in the extract on a flame photometer (manufacturer: Iuniko-Sis, Russia). Soluble sodium was detected in the water extract and exchangeable sodium content was calculated as the difference. Soil salinity was determined based on the content of exchangeable sodium in cation exchange capacity [79].

Soil salinity was calculated using the following formula:

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

where, D_s – degree of salinity from absorption capacity, %;

Na – exchangeable sodium content, cmol/kg^{-1};

100 – percentage conversion factor;

CEC – Cation Exchange Capacity, cmol/kg^{-1} [79].

2.3 Data analysis

Parameters of pasture soil composition were statistically processed using one-way analysis of variance (ANOVA).

Changes in the average values of the indicators were visualized via Box Plot graphs. The construction of diagrams and analysis of variance were performed in JASP® software. During the analysis of the experiment, no other methods were used because the statistical analysis of the data with one-way ANOVA (Analysis of Variance) was sufficient to establish significant differences between the experimental variations.

3. RESULTS

3.1 Variability of soil quality under the dynamic effects of grazing

Quantitative assessment in the conditions of different soil management methods in agricultural grazing is important to identify problematic areas, detect early warning signs of unfavorable trends, and assess the sustainable management of soil use [79]. To establish the impact of agricultural grazing on soil health, the present study was conducted in the semi-desert zone of Western Kazakhstan. The obtained results support the conclusions of other researchers that the increased intensity of agricultural grazing damages the health of pasture soils [44-50].

According to soil sample tests, humus content on the reference plot equaled 1.29%. Under intensive grazing, humus content significantly decreased compared to control by 0.47%, reaching 0.82%. Rotational use of pastures had a minor effect on the humus compared to the control. Specifically, field 1 rotational pastures showed a 0.09% decrease in humus content, and field 2 rotational pastures – a 0.05% reduction, ultimately amounting to 1.20-1.24%, respectively.

The results of one-way ANOVA (Figure 2) confirmed the hypothesis that average humus content in percent does depend on the variants of pasture use. The statistical significance of the respective differences across experiment variants equaled $p < 0.001$. Thus, we concluded that the methods of agricultural grazing produce a significant impact on the outcome indicator of humus content.

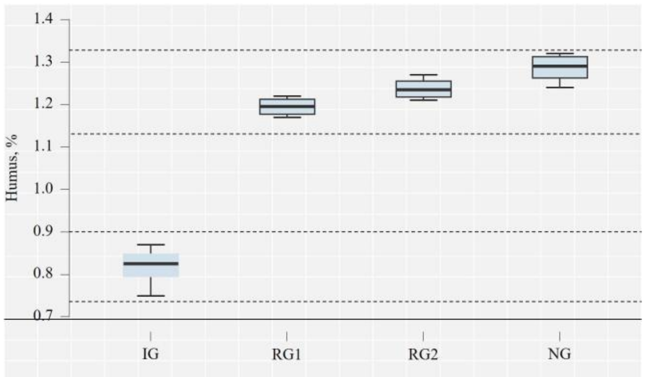

Figure 2. Changes in humus content in Calcic Kastanozems depending on the method of agricultural grazing on pastures in the semi-desert zone of Western Kazakhstan

IG – Intensive grazing; RG1 – rotational grazing – field 1, RG2 – rotational grazing – field 2, NG – no grazing.

According to the accepted assessment criteria, humus stock is a decisive sign of the degradation of Kazakhstan's pasture soils [78]. The study of the reference plot in the 0-30 cm soil layer indicated a humus stock of 47.21 t/ha. With intensive grazing, humus stock was significantly lower, by 27.05%, amounting to 34.44 t/ha. Per the assessment criteria, the soil of pastures under intensive grazing demonstrated 2nd-degree degradation based on humus stock. In contrast, on rotational grazing fields, humus stock was only slightly reduced compared to the control (3.07-4.68%), equaling 45.00 and 45.76 t/ha, respectively. Therefore, the examined rotational grazing fields experienced no degradation by the indicator of humus stock.

One-way ANOVA further confirms the influence of the variants of pasture use on humus stock (t/ha). The differences in mean values are significant at the level of $p<0.01$.

The results of our analysis (Figure 3) indicate that the greatest deviation from the control variant (no grazing) was observed under intensive grazing. The significance of the assessment is reduced by the presence of outliers in the data on field 1 and field 2 rotational pastures.

At the significance level of $p<0.001$, we can assume that humus content in soil is dependent on the method of agricultural grazing.

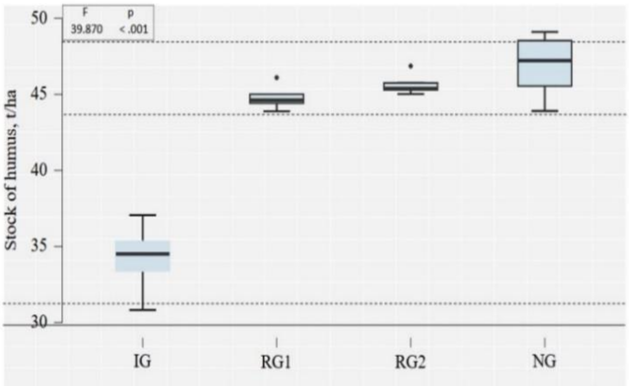

Figure 3. Changes in humus stock in Calcic Kastanozems depending on the method of agricultural grazing on pastures in the semi-desert zone of Western Kazakhstan
IG – intensive grazing; RG1 – rotational grazing – field 1, RG2 – rotational grazing – field 2, NG – no grazing

Soil densification due to trampling by agricultural animals is a physical impact that causes a direct negative influence on the majority of physical characteristics of soils, including density and structure, resulting in its degradation [80], which is supported by our findings. With the density of soil on the reference plot being 1.22 g/cm^3, intensive agricultural grazing resulted in a 14.75% rise in soil density, which ultimately reached 1.40 g/cm^3, indicating 3rd-degree degradation per the established criteria [78]. An increase of 2.46 and 0.82% in soil density was recorded in rotational grazing pastures of field 1 (1.25 g/cm^3) and field 2 (1.23 g/cm^3), respectively, which indicates the absence of soil degradation due to agricultural grazing.

The conducted studies of the density of pasture soil indicate statistically significant differences in average soil density values across the variants of the experiment as the significance level of $p<0.001$. In other words, average soil density does change depending on the variant of pasture use.

Analyzing field experiment data (Figure 4), we conclude that intensive agricultural grazing is associated with a much higher density of pasture soil compared to other variants. Minor differences in average soil density were found in the variants of rotational grazing (field 2) and the reference plot. The groups of rotational grazing, field 1, and rotational grazing, field 2, had the lowest variation of the indicator, showing stability.

Overly intense trampling by the hooves of grazing animals causes the soil to densify, which may compromise its structure [60, 80]. The content of agronomically valuable structural aggregates on the reference plot was 75.05%, corresponding to a "good" level, and the structure coefficient amounted to 3.14, also indicating a "good" level. Pastures where intensive agricultural grazing had been deployed had only 52.91% of agronomically valuable structural aggregates and, accordingly, the structure coefficient was down to 1.27. These values correspond to a "satisfactory" level of the indicators. In contrast to intensive grazing, rotational use of pastures had no significant effect on the content of agronomically valuable structural aggregates. On field 1 and field 2 rotational pastures, this indicator was found to be "good", reaching 66.45 and 67.79%, respectively. The structure coefficient amounted to 2.03 for field 1 pastures and 2.06 for field 2 pastures. Both values fall into the "good" range, the same as the reference plot.

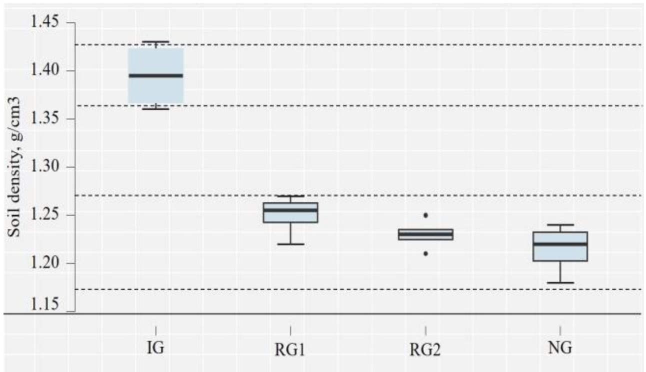

Figure 4. Changes in soil density in Calcic Kastanozems depending on the method of agricultural grazing on pastures in the semi-desert zone of Western Kazakhstan
IG – intensive grazing; RG1 – rotational grazing – field 1, RG2 – rotational grazing – field 2, NG – no grazing

The F-test demonstrates that the variant of pasture use has an effect on the content of agronomically valuable aggregates at the level of significance of $p <0.001$. Therefore, the method of agricultural grazing (NG, RG1, RG2, IG) has a significant impact on the content of agronomically valuable aggregates in pasture soil (Table 2).

Livestock grazing significantly lowers the agrochemical parameters of soil. This is associated with reducing vegetation height, cover, and biomass with increasing grazing intensity [80]. In confirmation, our studies showed that the method of agricultural animals grazing on pastures influences the content of mobile phosphorus in the soil. On pastures where intensive grazing was carried out mobile phosphorous content was 0.64 mg/100 g, which is 0.43 mg/100 g lower compared to the reference plot. The difference in phosphorus content between field 1 and field 2 rotational pastures with the reference plot was 0.17 and 0.12 mg/100 g, respectively.

Dispersion analysis proves that the variants of pasture use do affect mobile phosphorous content, in mg/100 g of soil (F). The statistical significance of differences in mean values between the experiment variants is indicated in the F-test p-value column in Table 2. The significance of the dependence of mobile phosphorus content on the method of grazing is $p < 0.001$.

Table 2. Indicators of the quality of Calcic Kastanozem soils on pastures in the semi-desert zone of Western Kazakhstan depending on the method of agricultural grazing, mean values over the 2019-2023 period, 0-30 cm soil layer

Soil Quality Indicators	Exper-Iment Variant	Observations	Mean	Standard Deviation	Dispersion	Maximum	F-test p-level*
Structure, %	**IG**	4	52.91	0.80	0.63	53.59	<0.001
	RG1	4	66.45	0.70	0.49	67.27	
	RG2	4	67.79	1.40	1.96	69.04	
	NG	4	75.05	1.59	2.52	77.04	
Mobile phosphorous content, mg/100 g	**IG**	4	0.64	0.03	0.00	0.67	<0.001
	RG1	4	0.90	0.03	0.00	0.94	
	RG2	4	0.95	0.02	0.00	0.97	
	NG	4	1.07	0.05	0.00	1.10	
Exchangeable sodium content, cmol/kg	**IG**	4	1.67	0.03	0.00	1.70	<0.001
	RG1	4	1.42	0.04	0.00	1.45	
	RG2	4	1.39	0.03	0.00	1.42	
	NG	4	1.29	0.03	0.00	1.32	

*Significance of deviation from the mean for one-way ANOVA
Content of agronomically valuable aggregates, %; mobile phosphorus content, mg/100 g soil (F); exchangeable sodium exchanger, cmol/kg of soil (Na)

The deterioration of soil agrophysical and agrochemical characteristics due to intensive grazing contributes to a rise of exchangeable sodium content in the light-chestnut soils [81]. Thus, due to the rise of exchangeable sodium content to 1.67 cmol/kg and the content of exchangeable sodium in CEC to 10.6%, the intensive grazing method contributed to a transition of the soil from slight salinity to moderate salinity.

Rotational grazing on field 1 and field 2 pastures is associated with only a slight increase in exchangeable sodium content in CEC. Specifically, the content of exchangeable sodium in field 1 pastures was 1.42 cmol/kg, and in field 2 pastures – 1.39 cmol/kg, while in the control plot with slightly saline soil, exchangeable sodium content amounts to 1.29 cmol/kg. This difference in exchangeable sodium content found in rotational pasture soils did not influence the degree of salinity.

As demonstrated by statistical analysis data in Table 2, F-test p-value column, the significance of the response of the outcome indicator (NA) to the grazing method options is at the level of p <0.001. Therefore, the different methods of pasture use (NG, RG1, RG2, IG) have a significant impact on exchangeable sodium content (Na). In the studied sample, the variants of grazing elicited a significant response from the quantitative indicator of exchangeable sodium content (Na).

4. DISCUSSION

4.1 Soil quality depending on the method of agricultural grazing on pastures

Overgrazing has a profound effect on pasture ecosystem dynamics, changing soil properties [81, 82], which is supported by our findings that intensive grazing is associated with aggravation of both the physical and chemical characteristics of Calcic Kastanozems on pastures in the semi-desert zone of Western Kazakhstan.

Studies on the impact of agricultural grazing methods on pastures show that the harmful dynamic influence of farm animals on soil density tends to become more severe as the grazing load per unit area and grazing intensity increase [82]. Our study found the density of pasture soil to increase to 1.40 g/cm^3, or by 14.75%, compared to control (no grazing) and the soil to reach 3rd degree degradation by density increase in the variant of intensive agricultural grazing [83].

Our studies discovered a relationship between soil density and humus content, which is supported by previous research findings. In particular, Silva et al. [84] found the relationship between soil density and humus content to be inverse and both linear and non-linear.

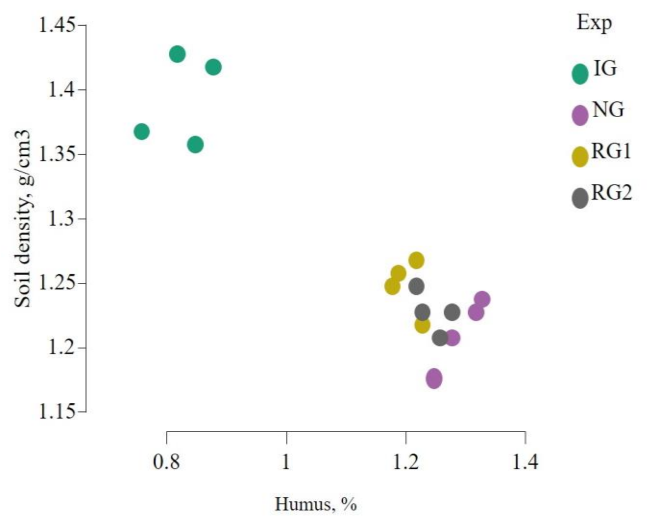

Figure 5. Relationship between soil density (g/cm^3) and humus content (%) in Calcic Kastanozems depending on the method of agricultural grazing on pastures in the semi-desert zone of Western Kazakhstan
IG – intensive grazing; RG1 – rotational grazing – field 1, RG2 – rotational grazing – field 2, NG – no grazing

Figure 5 shows that soil density decreases depending on the intensity of grazing and humus content. The rate of this decrease is characterized by a regression equation. The general regression equation is Soil density, g/cm^3=1.69-0.37 Humus, %. The coefficient of determination for this model is 86%. The model is significant at the level of p<0.001. Using regression analysis, a linear coefficient characterizing the dependence of soil density on humus content was established (-0.37). Thus, soil density decreases by 0.37 g/cm^3 with a 1% increase in humus content. In semi-desert conditions, optimal soil density (1.23-1.25 g/cm^3) with 1.20-1.24% humus content was found on pastures under rotational grazing (field 1 and field 2).

Muhammad et al. [85] conclude that soil density rises along the course of pastureland degradation and thus can affect other chemical processes in soil. Furthermore, Faizulina et al. [86]

found that humus content has a clear influence not only on the density but also on the aggregation of soil [86-88].

Our analysis shows that the content of agronomically valuable structural aggregates in soil increases by 1.35% with a 1 t/ha increase in humus stock.

The scatter plot in Figure 6 shows that the content of agronomically valuable structural aggregates increases with humus stock. Applying a linear regression model to the data, we obtained an equation of the form: Agronomically valuable structural aggregates, %=7.89+1.34*Stock of humus, t/ha. The determination coefficient for this model is 78%. In general, the model is statistically significant at the level of $p<0.001$. With a much higher probability, we can speculate that the initial value of the row level for this model will be 65.55%.

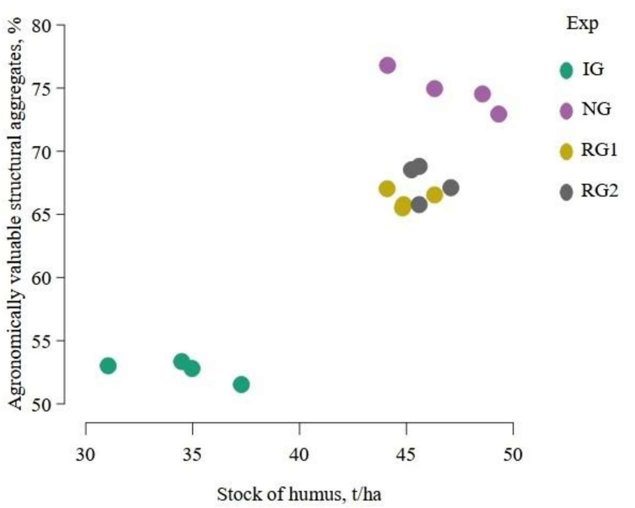

Figure 6. Relationship between agronomically valuable structural aggregates (%) and humus stock (t/ha) in Calcic Kastanozems depending on the method of agricultural grazing on pastures in the semi-desert zone of Western Kazakhstan

IG – intensive grazing; RG1 – rotational grazing, field 1, RG2 – rotational grazing, field 2, NG – no grazing

It is important to highlight that the content of agronomically valuable structural aggregates and the structure coefficient rise along the vector from intensive grazing pastures to the control variant (no grazing). This could be attributed to the fact that in the absence of grazing, soil experienced less negative impact and rested for a longer period of time. This created hydrodynamic conditions that boosted the production of humus substances, which perfectly penetrate soil aggregates [89]. On pastures under intensive grazing, as a result of decreased humus stock, the soil degraded to the 2nd level. The smallest difference in humus content (0.05-0.09%) and stock (3.07-4.68%), as well as optimal soil structure (66.45-67.79%), was observed in the variants of rotational grazing on field 1 and field 2 ($p<0.001$). As explained by Almanova et al. [89], well-managed pastures can provide better biodiversity, distribution of nutrients in the soil, and improved soil quality across territories and over time.

The chemical properties of soil are characteristics of soil management determined by soil structure and air and water conductivity and are highly dependent on livestock grazing management. Their study found livestock grazing to have only a minor effect on the concentration of chemical soil properties on the pasture plot [87]. This agrees with our results showing a higher content of mobile phosphorous on pastures under rotational grazing – 0.90-0.95 g/100 g of soil. As suggested by Akhazhanov et al. [88] the primary reason behind a higher distribution of mobile P on the regulated plot with rotational grazing is associated with a higher biomass of grass, which increases the accessibility of nutrients in soil during its decay. In contrast, when pasture lands were subjected to uninterrupted grazing and turned into a zone of degradation (intensive grazing), above-ground grass biomass decreased, which affected both humus (0.82%) and mobile P (0.64 mg/100 g of soil).

Almanova et al. [89] argue that trampling by livestock does increase the density of soil, destroy soil aggregates, and lead to soil salinization, contributing to the degradation of pastures. Studies of intensive livestock grazing show soils to transition from slight to moderate salinity due to a rise in CEC from 14.53 (reference-control) to 15.75 cmol/kg and an increase in exchangeable sodium content in CEC from 8.88 (reference-control) to 10.60%. Research by Sherimova et al. [90], Raketsky et al. [91] and Dukenov et al. [92] also demonstrate that changes in CEC and soil nutrients primarily owe to the removal of nutrient-rich clay particles from soil, which comes as a result of the degradation and increased density of soils due to livestock overgrazing in pastures.

The impact of rotational grazing on the soil condition is insignificant compared to intensive grazing [93]. Compared to the control (no grazing), the content of exchangeable sodium in CEC under rotational grazing (field 1 and field 2) showed a minor increase, reaching 1.39-1.42 cmol/kg-1 ($p<0.001$), or 7.75-10.08%, and the soil maintained a slight degree of salinity.

5. CONCLUSIONS

Our findings confirm the hypothesis about the promise of using the rotational method of agricultural grazing on pastures in the semi-desert zone of Western Kazakhstan. Compared to intensive use, regulated grazing using pasture rotation supports the quality of soils of pasture ecosystems. With pasture rotation, humus content stays at the level of 1.20-1.24% with humus stock of 45.00-45.76 t/ha, pasture soil maintains a "good" structure (66.45-67.79%) and a soil structure coefficient (2.03-2.06) close to the reference, as well as optimal density (1.23-1.25 g/cm^3) and salinity (slightly saline). In contrast, intensive agricultural grazing, as a result of increased load on pastures due to overgrazing coupled with a reduction of humus content and increased soil density, results in soil degradation to the 2nd-3rd level. Furthermore, as sodium content in CEC increases, the soil starts to show signs of salinity.

To protect pasture soils from degradation, we recommend optimizing the methods of their management with active employment of rotational grazing on pastures in accordance with regional climate and the types of pasture lands.

Rotational agricultural grazing is also relevant in adapting pasture management methods aimed at minimizing the negative effects of global warming and improving soil quality in the face of ubiquitous land degradation.

The results obtained can be applied in a practical context in Kazakhstan and other regions with a similar climate by organizing optimal grazing of agricultural animals through seasonal pasture rotation. This method enhances soil quality, increases the productivity of pasture vegetation, and ultimately improves the economic efficiency of livestock farming.

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