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Improving Degraded Pastures in Northern Kazakhstan Through Moldboard Plowing and Grass Seed Mixtures

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ABSTRACT

This research addresses the escalating issue of pasture land productivity decline in Northern Kazakhstan, attributed largely to anthropogenic impacts and misuse. One of the factors in improving the conditions and productivity of degraded pastures is tillage techniques. The objective of the study was to evaluate the influence of different tillage methods on enhancing soil conditions and boosting the productivity of degraded pastures. The study was conducted on the leached chernozem soils of degraded pastures at the Zhaysan farm in the steppe zone of Kazakhstan. Two broad tillage approaches were compared: surface (disk and rotary tillage) and root (moldboard and sweep plowing), combined with the sowing of alfalfa (Medicago L.) and brome (Bromus L) grass mixtures. Superior results were obtained through the application of moldboard plowing at depths of 25-27 cm, accompanied by double disk and double rotary tillage at depths of 10-12 and 14-16 cm. Analyses revealed an optimal soil density of 0.96-1.00 g/cm^3 for the leached chernozem soil, along with a high content of productive moisture (37.7-75.8%) within the 0-100 cm soil layer. Higher quantities of nitrate nitrogen, ranging from 2.11-2.75 g/100 g of soil, were detected in the upper soil horizons (0-30 cm). Moldboard plowing at 25-27 cm against the background of double disk tillage and double rotary tillage at 10-12 and 14-16 cm increased the yield of the dry mass of alfalfa and brome mixture to 29.9-32.4 c/ha, which is more than the variant without tillage by 16.2-18.7 c/ha. The findings suggest that a combination of moldboard plowing and two-fold rotary tillage effectively improves soil conditions and increases pasture land productivity in Northern Kazakhstan.

1. INTRODUCTION

Tillage significantly influences soil properties and crop yields, accounting for up to 20% of crop production factors [1-4]. It further governs the sustainable utilization of soil resources via its impact on soil attributes [5]. When employed judiciously, different tillage methods can overcome edaphic constraints, whereas improper tillage has the potential to yield several adverse effects such as soil structure destruction, accelerated erosion, organic matter and fertility loss, and the disruption of water, organic carbon, and nutrient cycles for plants [6].

Optimal tillage practices are tailored to specific soil-climatic conditions, cultivated crops, and types and varieties of crop rotations [7, 8]. Such practices modify the physical and mechanical properties of the soil, thereby fostering favorable conditions for microbiological processes and the transformation of inaccessible nitrates (NO_3) into a form assimilable by plants [9-11]. The influence of tillage leading to an increased content of nitrate nitrogen in the arable layer has been noted in previous studies [12-14].

However, unregulated tillage makes soil vulnerable to erosion and the intensive use of machinery contributes to increased soil density [15, 16]. This heightened soil density can initiate degradation due to compaction, posing a challenge to agricultural productivity [17, 18]. The transition to resource-saving tillage technologies has been necessitated by the escalating costs of industrial material and technical means, along with rising fuel prices [19, 20].

Two primary methods for improving natural hayfields and pastures, contingent on their reclamation state and herbage composition, are surface and root methods. Surface methods involve actions to enhance the composition and productivity of natural herbage, without disrupting or with only partially tilling the natural turf. It is advisable to carry out a surface improvement in two cases. In the first case, this is done if the area covered with shrubs and hummocks does not exceed 20-30%. In the second case, the herbage should contain at least 30% of valuable types of herbs that respond well to agrotechnical techniques. Meanwhile, root improvement gives way to newly seeded hayfields or pastures in place of the former herbage, specifically suited to lands with dense cereal and shrub herbage or a high prevalence of different grasses, sedges, and mosses.

Surface improvement methods have the potential to effectuate a radical transformation of degraded steppe pastures into highly productive forage areas [21]. These methods are typically applied towards the end of May, marking the initiation of grass meadow formation. When cultivation is challenging or infeasible, disk tools are employed. For areas in Northern Kazakhstan characterized by erosive, light soils with sparse vegetation cover, meadow formation can be accomplished without pretreatment. However, undercover sowing of grasses is universally excluded. These recommended methods have demonstrated both efficacy and cost-effectiveness in improving degraded steppe pastures, making phytomeliorative work a feasible proposition. The initial investment typically yields returns within a period of 3 to 5 years [22].

In Kazakhstan, the irrational use of land resources and increased anthropogenic loads have altered the ecological scenario [23, 24], accelerating the degradation of hayfields and pastures on low-fertile lands, intensifying desertification, and increasing the prevalence of diseases and pests [25-27]. Given these circumstances, the development of resource-saving techniques for improving degraded pastures on low-fertile (fallow) lands, meadows, and solonetz complexes in Northern Kazakhstan's conditions is highly pertinent.

The present research aimed to compare various tillage methods' efficacy in improving degraded pastures in the steppe zone of Northern Kazakhstan. Surface (disk tillage, rotary tillage) and root (moldboard plowing and sweep plowing) approaches, in conjunction with the sowing of alfalfa (*Medicago* L.) and brome (*Bromus* L) grass mixtures, were evaluated.

2. MATERIALS AND METHODS

2.1 Description of the study sites

The study was carried out in 2020-2022 at the Kokshetau University named after Shokan Ualikhanov on the initiative of the Ministry of Agriculture of the Republic of Kazakhstan to evaluate the methods for restoring degraded pastures in the steppe zone of Northern Kazakhstan. The pasture lands at the Zhaysan farm of the Zerendinsky district of the Akmola region are degraded and are subject to restoration. Therefore, the pastures of this farm with leached chernozem soils were chosen as the object of the study where we evaluated the techniques for restoring degraded pastures (Figure 1).

The experiment design is shown in Table 1. The study included a comparison of surface (disk tillage, rotary tillage) and root (moldboard plowing and sweep plowing) approaches to improving pastures with the sowing of alfalfa (*Medicago* L.) and brome (*Bromus* L) grass mixtures.

Figure 1. Location of the study objects, coordinates: N52°93.316[1]; E69°29.940[1]

Tabe 1. Design of the field experiment to study the effect of natural pasture improvement techniques on their productivity

Factor A Surface Improvement Methods	Factor B Root Improvement Methods		Grass Mixture During Meadow Formation
	Sweep Plowing	Moldboard Plowing	
Control (without tillage)	-	-	Alfalfa and brome
Disk tillage at 10-12 cm (centimeters)	+	+	
Rotary tillage at 10-12 cm	+	+	
Double disk tillage at 10-12 and 14-16 cm	+	+	
Double rotary tillage at 10-12 and 14-16 cm	+	+	

The experiment is two-factor, where factor A is a surface improvement method and factor B is a root improvement method. The area of the experimental site of the first level (factor A, where methods of surface improvement of pastures are studied) is 5,000 m^2 (square meters), and the surface of the second level site (factor B, where methods of root improvement of pastures are studied) equals 700.0 m^2. Area of the experimental plot – 787 m^2. The repetition of the experiment was threefold, the placement of sites had been randomized.

2.2 Soil sampling

The soil of the experimental site was leached chernozem, with medium humus of reduced capacity. The content of humus was 4.7% and easily hydrolyzable nitrogen content was 41.0 mg/kg. The mobile phosphorus content was 15.0 and the exchangeable potassium content was 350 mg/kg of soil, pH-

7.3.

2.3 Physical and chemical soil analyses

Determination of soil moisture reserves: sampling was carried out at four points of the site, by drilling up to 1 m through 10 cm with AM 26 soil drills (Prompribor, Yekaterinburg, Russia) by the thermal gravimetric method according to the seasons of the year (spring, summer, and autumn) in threefold repetition.

Determination of soil density was performed by the cylinder's method developed by N.A. Kachinsky. To determine the density of the soil in the field, samples from soil horizons 0-10, 10-20, 20-30, and 30-40 cm were taken with a drill cylinder with a volume of about 500 cm^3. Soil samples were collected in weighing cups to determine humidity. At the laboratory stage, the soil was dried at 105°C to a constant weight. After obtaining the mass of a dried-soil weighing cup and the mass of an empty weighing cup (BAG-18, YEVROTEST, St. Petersburg, Russia), the mass of air-dry soil was found. Then, by dividing the mass of dry soil by its volume (the volume of the ring), the density of the soil was established [28].

Mobile phosphorus compounds were determined by the photometric method developed by I. Machigin, which is based on the extraction of mobile phosphorus compounds from the soil with a solution of ammonium carbonate $(NH_4)_2CO_3$ with a concentration of 10 g/dm^3 with a ratio of soil to the solution equaling 1:20 and subsequent determination of phosphorus in the form of a blue phosphorus-molybdenum complex on a photoelectrocolorimeter AE-30F (ERMAINC, Japan) [28].

The determination of nitrate nitrogen was carried out using a photocolorimetric method, which is based on the formation of a salt of picric acid (sodium picrate) in the presence of disulfophenolic acid and NaOH, which turns the solution yellow [28].

2.4 Agricultural technology

Root improvement was carried out according to the type of bare fallow. To level the surface and destroy the formed soil crust and the weeds, small loosening tilling treatments were carried out.

On the experimental variants, against the background of sweep plowing and moldboard plowing, disk tillage at 10-12 cm, rotary tillage at 10-12 cm, double disk tillage at 10-12 and 14-16 cm, and double rotary tillage at 10-12 and 14-16 cm were studied.

Sweep plowing is a method of boardless plowing, which provides crumbling, loosening of the soil, and cutting of underground plant organs to a depth of 25-30 cm with deep-drilling plank cutters PGN-3 (manufactured by Uralenergo, Yekaterinburg, Russia), with up to 90% stubble (crop residues) remaining on the soil surface.

Moldboard plowing with a PN-8-35 plow (produced by Minsk Tractor Plant, Belarus) to a depth of 20-22 cm. This is the main method of introducing fallow (solonetz) lands into arable land during the development of virgin and fallow lands. At that time, the most fertile supra-solonetz horizon and the illuvial horizon determining the solonetz properties were mixed. There were no conditions for the replacement of exchangeable sodium since soil calcium salts in the form of carbonates and gypsum were not involved in the treated layer.

After the surface and root improvement of the site, the surface was leveled and the lumps were further crushed with a BDT-7 harrow (manufactured by Rosagromash, Rostov-on-Don, Russia) to a depth of 10-12 cm. The determination of the tillage depth was carried out using a metal rod (produced by Chelyabinsk Valve Plant, Russia).

2.5 Data analysis

The indicators were statistically processed by the method of single-factor analysis of variance [29].

3. RESULTS

3.1 Water regime

Layer-by-layer determination of productive moisture reserves in the early spring period of 2022 showed that in the arable 0-30 cm soil layer, the moisture content against the background of moldboard plowing varied from 37.7% (0-10 cm) to 63.8% (20-30 cm), and against the background of sweep plowing from 33.5% (0-10 cm) to 60.7% (20-30 cm), from soil moisture tension (SMT) (Table 2).

For both tillage backgrounds, the greatest amount of moisture was concentrated at a depth of 60-80 cm, which amounted to 71.9-75.8% of the SMT for moldboard plowing, and 65.5-64.0% for sweep plowing. The determination of moisture reserves before harvesting showed that the dynamics of the use of moisture for the formation of yield was in the same position in layers, i.e., there was no pronounced loss of moisture in the soil layers, only with a difference in the coefficient of water consumption depending on the background of tillage.

Table 2. Effect of root improvement of degraded pastures on soil moisture content in spring

Layer Depth of the Soil, cm	Productive Moisture Content, %	
	Moldboard Plowing at 25-27 cm	Sweep Plowing at 25-27 cm
0-10	37.7	33.5
10-20	62.5	58.3
20-30	63.8	60.7
30-40	68.0	65.0
40-50	64.3	61.3
50-60	67.5	63.2
60-70	71.9	65.5
70-80	75.8	64.0
80-90	55.4	50.7
90-100	44.5	40.3

During the growing season of alfalfa and brome mixture, productive moisture is consumed from the entire meter layer of soil, regardless of the methods of root or surface improvement of the soil. Thus, under the crops of the grass mixture of the third year of life, the coefficient of water consumption during moldboard plowing at 25-27 cm compared to sweep plowing at 25-27 cm decreased from 610-750 to 450-620 m^3, which is due to the improvement of water/air and nutrient regimes of the soil.

In general, the moisture reserves and the provision of plants with it during the growing season were in satisfactory condition.

3.2 Nutrient status

Our observations have shown that the content of nitrate nitrogen against the background of sweep plowing was 1.0-1.26 times inferior to moldboard plowing, especially in the upper 0-40 cm soil layer (Table 3), regardless of surface improvement.

However, the dynamics of the layered nitrogen supply of the soil, regardless of the methods of root and surface improvement, occurred evenly, where the higher nitrate content for the treatment backgrounds was in the soil layer 0-40 cm, and in the layer 40-100 cm there was a sharp decrease.

The studied tillage variants did not significantly affect the content of mobile phosphorus P_2O_5 and exchangeable potassium K_2O, where their content in the arable soil layer was, respectively, 2.0-2.2 mg and 47.0-52.0 mg per 100 g of soil. The main reason for the large accumulation of K_2O near the soil surface is the movement of plant residues, which contain only a small amount of phosphorus, from deeper soil layers.

Table 3. The effect of methods of root and surface improvement of pastures on the content of nitrate nitrogen in the soil, mg/100 g of soil

Layer Depth, cm	Moldboard Plowing at 25-27 cm	Sweep Plowing at 25-27 cm
0-10	2.75	2.22
10-20	2.63	2.19
20-30	2.11	2.09
30-40	1.07	1.03
40-50	1.04	0.82
50-60	1.03	0.85
60-70	0.96	0.89
70-80	0.90	0.83
80-90	0.87	0.77
90-100	0.83	0.75

3.3 Volume mass of the soil

In our studies, against the background of moldboard plowing, the volume mass of the soil varied in the range of 0.95-1.00 g/cm^3, where the upper horizons of 0-10 and 0-20 cm were in looser states (Table 4).

Table 4. Volume weight of the soil depending on the methods of tillage, g/cm^3

Layer Depth, cm	Moldboard Plowing at 25-27 cm	Sweep Plowing at 25-27 cm
0-10	0.96	1.10
10-20	0.95	1.11
20-30	1.00	1.23
30-40	0.99	1.22

With an increase in the depth of the soil horizon, some compaction occurred on average by 0.03-0.01 g/cm^3. However, these changes were not so significant, and in general, against this background, the arable horizon was in a loose state.

Against the background of sweep plowing, the soil density along the horizons was 1.10-1.23 g/cm^3, where, as with moldboard plowing, the looser state was in the upper horizons at 0-10 and 0-20 cm. In the lower 20-30 and 30-40 cm horizons, the soil was denser, 1.23 and 1.22 g/cm^3.

3.4 Productivity of alfalfa and brome pastures

The yield of the seeded herbage was formed in different ways. Thus, in the third year of the life of grasses, the greatest collection of dry mass was provided by two-fold disk tillage and two-fold rotary tillage against the background of moldboard plowing. The difference compared to the control variant was 16.2-18.7 c/ha (Table 5).

The results of the study on the botanical composition showed that the proportion of alfalfa in the grass mixture in the third year of its life in the phytocenosis was 31.0%, and the proportion of brome was 69.0%, while in the total dry matter yield the proportion of legumes was higher.

The highest yield was observed after combined tillage, such as two-fold disk tillage and two-fold rotary tillage on the background of moldboard plowing, in 2022 amounting to 29.9-32.4 c/ha.

Table 5. The effect of the methods of root and surface improvement on the yield of alfalfa and brome mixture, c/ha of dry weight

Tillage Method	c/ha
Control without tillage	13.7
Moldboard plowing	
Disk tillage at 10-12 cm	19.7
Rotary tillage at 10-12 cm	26.0
Double disk tillage at 10-12 and 14-16 cm	29.9
Double rotary tillage at 10-12 and 14-16 cm	32.4
Sweep plowing	
Disk tillage at 10-12 cm	18.6
Rotary tillage at 10-12 cm	22.4
Double disk tillage at 10-12 and 14-16 cm	25.0
Double rotary tillage at 10-12 and 14-16 cm	29.6
*$LSD_{0.5}$	2.80

*LSD_{05} is the least significant difference for a 5% significance level.

When determining the nutritional value of the feed, it was found that the yield of feed units per ha was 15.2-27.6 c (Table 6). The largest number of feed units was obtained with two-fold disk tillage after moldboard plowing (27.6 c/ha), as well as two-fold rotary tillage after sweep plowing (26.0 c/ha). The increase compared to the control variant was 16.2 and 14.6 c/ha, respectively. The lowest collection of feed units among the tillage variants was the variant with one-track disk tillage (15.2-17.9 c/ha).

In terms of the amount of digestible protein obtained from 1 ha, the largest yield was with two-fold disk tillage at different depths after moldboard plowing, where, according to the experimental variants, it was (7.2-8.3 c/ha). With sweep plowing, the digestible protein was higher in the rotary tillage variant and amounted to 6.2-7.4 c/ha.

The determination of the metabolizable energy showed that its greatest yield per ha was obtained with two-fold disk tillage and two-fold rotary tillage after both plowing methods (25.9-22.4 GJ/ha).

The results of the statistical analysis showed significant differences between the studied tillage options in terms of yield, collection of feed units, and digestible protein, as well as in the output of metabolizable energy at a significance level of 95%.

Based on fodder units, the difference in pasture productivity with double rotary tillage by 10-12 and 14-16 cm between the options for root improvement (moldboard and non-moldboard) was 1.2 c/ha, or 4.84% (p-level<0.05).

In the variant of moldboard tillage, the highest amounts of primary protein (8.3 dt/ha) and metabolizable energy (25.9 GJ/ha) were obtained with double disking at 10-12 and 14-16 cm (p-level<0.05).

The highest and most reliable indicators of primary protein (7.4 c/ha) and metabolizable energy (22.4 GJ/ha) were obtained with non-moldboard tillage (p-level<0.05).

Table 6. Pasture productivity depending on improvement techniques

Tillage Method	Feed Units, c/ha	Digestible Protein, c/ha	Metabolizable Energy, GJ/ha
Control without tillage	11.4	4.4	9.6
Moldboard plowing			
Disk tillage at 10-12 cm	15.2	7.2	12.1
Rotary tillage at 10-12 cm	24.4	6.0	22.3
Double disk tillage at 10-12 and 14-16 cm	27.6	8.3	25.9
Double rotary tillage at 10-12 and 14-16 cm	24.8	6.4	22.8
Sweep plowing			
Disk tillage at 10-12 cm	17.9	5.9	13.2
Rotary tillage at 10-12 cm	20.0	6.2	16.8
Double disk tillage at 10-12 and 14-16 cm	21.9	6.9	18.7
Double rotary tillage at 10-12 and 14-16 cm	26.0	7.4	22.4
*$LSD_{0.5}$	2.55	2.90	3.10

*LSD_{05} is the least significant difference for a 5 % significance level.

4. DISCUSSION

4.1 The effect of tillage on soil moisture content

A study conducted by Abdallah et al. [30] indicated a strong influence of agricultural techniques on the water-retaining capacity of the soil. The most significant ability to accumulate moisture during moldboard plowing, which decreased along with a decrease in the depth of tillage, was found by Cherenkov et al. [31]. The decrease in moisture reserves in the spring in the soil layer of 0-150 cm with direct sowing compared to intensive loosening was 8-21 mm [32]. In our study, during moldboard plowing at 25-27 cm against the background of double disk tillage and double rotary tillage at 10-12 and 14-16 cm, the largest reserves of productive soil moisture were accumulated in the 0-100 cm soil layer at the beginning of spring fieldwork. With sweep plowing to 25-27 cm, the reserves of productive moisture significantly decreased (by 4.89%).

4.2 The effect of tillage on the mineral elements in the soil

The content of nitrates in the soil is an objective indicator of the nitrogen supply of plants, which is one of the main indicators of soil fertility. Studies have noted a higher content of nitrates in the soil layer of 40-100 cm. Similar data on nitrate changes in soil layers are presented in the studies of Kravchenko et al. [33]. According to our results, higher levels of nitrate nitrogen in leached chernozem soil (2.11-2.75 mg/100 g of soil), especially in the upper layers of 0-30 cm, were found in the case of moldboard plowing at 25-27 cm against the background of double disk tillage and double rotary tillage at 10-12 and 14-16 cm.

Being an integral part of the crop production process, tillage has a direct effect on seasonal fluctuations of mineral nutrients depending on their location in the soil matrix [34, 35]. In studies by Deubel et al. [36], similar to our results, despite the higher availability of P_2O_5 and especially K_2O, the removal during harvesting was equal or even tended to be less.

4.3 The influence of tillage techniques on the physical properties of the soil

The tillage techniques affect the physical properties of the soil in different ways, which depend on the soil and climatic conditions of the area of interest [37, 38]. In our study, with sweep plowing at 25-27 cm in the 0-40 cm soil layer, the density was 1.17 g/cm^3, and moldboard plowing of 25-27 cm reduced the soil density by 0.19 g/cm^3 or by 19.39%.

The results of our study did show slight differences in density between tillage systems, which is confirmed by data from Ordoñez-Morales et al. [39], where the value of soil density varied between 1.21 to 1.39 g/cm^3.

4.4 Productivity of improved herbage

In studies, the highest productivity of grass stands was noted when using moldboard plowing. Similar results were obtained at the Karabalyk experimental station, where moldboard plowing was more productive (29 c/ha) than surface sweep plowing (15.4 c/ha of hay) [40].

According to our results, an increase in the intensity of tillage (from sweep plowing to moldboard plowing) against the background of two-time disk tillage and two-time rotary tillage at 10-12 and 14-16 cm increased the yield of the dry mass of alfalfa and brome mixture to 29.9-32.4 kg/ha, which is 118.3-136.5% more compared to the control variant (without tillage).

Moldboard plowing at 25-27 cm against the background of double disk tillage and double rotary tillage at 10-12 and 14-16 cm provided a higher feed and energy-protein value of alfalfa and brome pasture lands. The proposed method of improvement provides the yield of 24.8-27.6 c/ha of feed units, 6.4-8.3 c/ha of digestible protein, and 22.8-25.9 GJ/ha of metabolizable energy.

In our study, surface plowing approaches were limited to disk tillage and rotary tillage, and root plowing approaches were limited to moldboard and sweep plowing. Further research should be aimed at comparing other approaches of surface and root plowing.

5. CONCLUSION

Based on our results, we can recommend using combined treatments to improve the pastures of in the North of Kazakhstan: two-fold rotary tillage against the background of moldboard processing.

The research results can also be used for pasture improvement in countries and areas with similar climate and pasture resource use.

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