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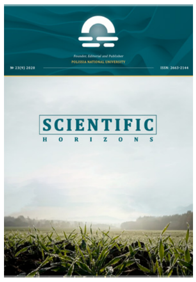

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Nutrient regime and balance of nutrients in soil under forage crops under application of different types of fertilizers (on the example of Kyzylorda region)

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Abstract. Modern agriculture is facing a number of challenges, among which the efficient use of fertilisers to provide plants with the necessary nutrients is of particular importance. In particular, the growing focus on sustainable agriculture and the need to preserve soil resources underline the relevance of research into optimising fertiliser use. The purpose of the study was to identify effective methods of fertiliser

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use to provide plants with nutrients. To achieve this goal, the effectiveness of green manure, organic (manure) and mineral fertilisers under *Sorghum* and perennial grasses (*Medicago sativa*, *Elytrigia*, *Agropyron*) on saline soil was investigated. The study founded that organic fertilisers, such as manure and green manure, contribute to a more even supply of nutrients to plants compared to mineral fertilisers. This is particularly important in the context of nitrogen and phosphorus balance, where *Medicago sativa* has a positive nitrogen balance due to its ability to symbiotically fix nitrogen. Other crops studied, such as *Elytrigia*, *Agropyron* and *Sorghum*, showed a negative nitrogen balance on the control variant, but the application of $N_{100}P_{50}K_{110}$ mineral fertiliser resulted in a positive nitrogen balance. The replacement of mineral fertilisers with organic fertilisers such as manure and green manure increased nitrogen inputs but also increased nitrogen removal from the soil due to the increase in phytomass yields. The results of the study confirmed the importance of transitioning to a more sustainable and environmentally friendly way of production in agriculture, which will ensure the development of the industry and increase its competitiveness in the international market. The practical significance of the study is to provide farmers with the opportunity to increase the yield of their crops and at the same time preserve soil fertility through the optimal use of nutrients contained in fertilisers

Keywords: exchangeable potassium; phosphorus; nitrogen; humus; *Sorghum*; *Medicago sativa*

INTRODUCTION

Agriculture is a key component of the economy of many regions, including Kazakhstan, where the development of this sector often depends on soil fertility and efficient use of fertilisers. Over the past decades, much attention has been paid to studying the impact of different types of fertilisers on the soil nutrient regime and nutrient balance in the fodder crops growing system (Carr *et al.*, 2020; Asaye *et al.*, 2022). The Kyzylorda region, located in the southern part of Kazakhstan, is an important agricultural centre where a variety of fodder crops are grown for animal feeding. However, due to the region's specific conditions, such as dry climate and saline soils, the issue of soil fertility and balanced crop nutrition becomes extremely important. One of the main methods of maintaining soil fertility is the use of different types of fertilisers (Allam *et al.*, 2022).

The World Meteorological Organization calls the drying up of the Aral Sea one of the largest anthropogenic ecological crises of the 20th century. The disappearance of the sea has had a systemic negative effect on the flora, fauna, landscape, and climate of the Aral Sea region. The drying up of the Aral Sea has led to the sharp desertification of the Aral Sea region and provoked the salinization of its lands. Due to lack of moisture, former hydromorphic soils turn into salt marsh in 3-5 years (Ismayilzada *et al.*, 2023). According to the latest data, the area of saline irrigated lands in Kyzylorda region is about 225.9 thousand ha, of which slightly saline – 87.6 thousand ha, moderately saline – 73.3 thousand ha, strongly and very strongly saline – 65.1 thousand ha. Therefore, this article presents the increase in adaptive potential of crops by optimizing nutrient regime, and dynamics of ingredients content in the soil layer under fodder crops depending on the types of fertilizers. In recent years, against the background of increasing rates of soil degradation, the biological cycle of substances in agriculture has been disturbed, and a sharply negative balance of substances has been formed. According to scientists' data, soil organic matter is lost mainly as a result of water-erosion and deflation processes – 1 t/ha or more of organic matter is alienated from the biological cycle together with fine-grained soils (Palchikov *et al.*, 2018; Tanchyk *et al.*, 2021). The results of research for the reproduction of soil fertility, compensation of unproductive erosion, and other losses in them according to the calculations of the same author require annual application of 6-7 t/ha of organic fertilizers in terms of litter manure. But the actual need for organic fertilizers is satisfied only by 10%. According to his data, the main reserve for replenishment of organic matter reserves in the soil is the phytomass of agrocenoses, and the share of side dressing in the future should account for 27-30% of fertilized arable land, which will amount to 15 kg nitrogen, phosphorus, and potassium (NPK) per 1 ha on a national scale (Rosemarin *et al.*, 2020; Pahalvi *et al.*, 2021).

In this regard, firstly, to maintain and restore soil fertility, it was necessary to eliminate or minimize soil erosion and deflation, and secondly, for the sustainable functioning of agroecosystems, it was necessary to ensure a balanced cycle of biophilic elements and the reproduction of the humus state of soils by applying organic fertilizers, which led to the purpose of the current study.

MATERIALS AND METHODS

The research was conducted in three districts of the Kyzylorda region, i.e., on weakly and strongly saline agricultural lands of the Shiyeli, Zhanakorgan, and Kazaly districts. In general, about 150 thousand ha out of 225.9 thousand ha of lands belonging to Kyzylorda region were covered (Fig. 1).

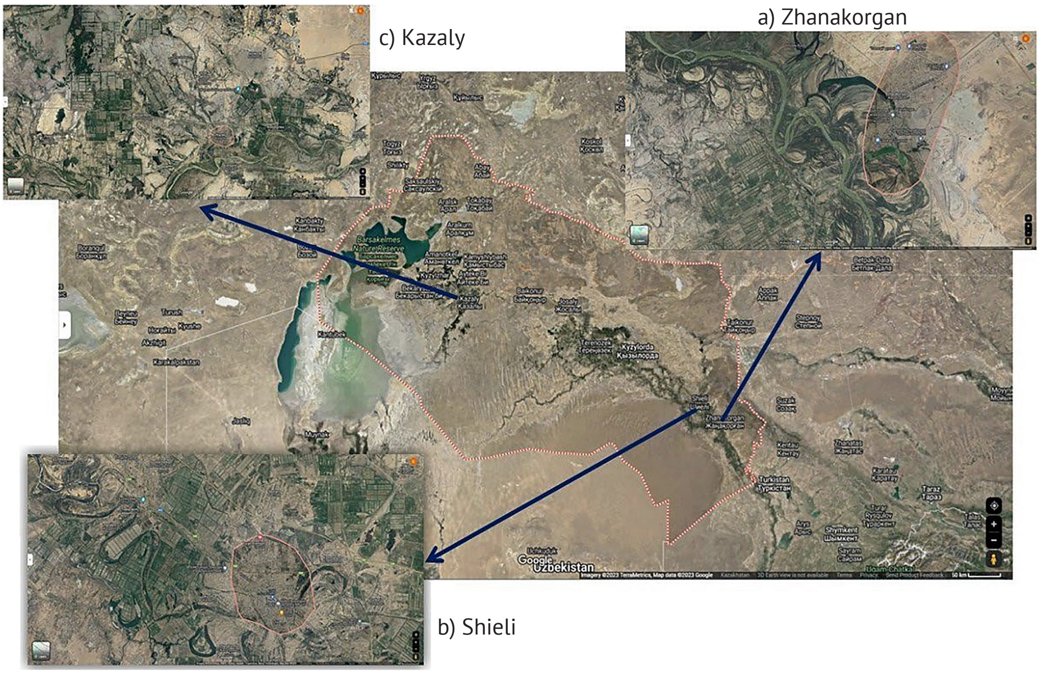

***Figure 1**. Study area of Kyzylorda region*

***Source:** compiled by the authors*

A study of crop productivity potential (phytomeliorants) under different methods of enrichment of saline soils with nutrient elements was carried out on medium and highly saline soils. The efficiency of separate and joint application of manure and different doses and types of mineral fertilizers for fodder agrocenoses was studied on slightly saline soil:

1. Without fertilizer (control).
2. Manure 40 t/ha.
3. Manure 40 t/ha+P60 (basic fertilizer).
4. Basic fertilizer+N120 P120.
5. Basic fertilizer+N180P120.
6. Basic fertilizer+N240P120.
7. Basic fertilizer+N120P90.
8. Basic fertilizer+N120P120 + N120 in top dressing.

The efficiency of sideral, organic (manure), and mineral fertilizers for *Sorghum* and perennial grasses (*Medicago sativa, Elytrigia, Agropyron*) was studied on strongly saline soil. A green mass of barley and *Medicago sativa* was used as a green manure crop, manure was applied at the rate of 20 t/ha. The dose of mineral fertilizers corresponded to the nutrient elements contained in the specified amount of manure (N100P50K110). In case of a discrepancy of elements entering the soil with barley and *Medicago sativa* biomass to this amount, the missing part was replenished with mineral fertilizers.

Studies on the optimization of plant water availability conditions were carried out under all three soil salinity degrees. On slightly saline soil irrigation of the studied crops – *Medicago sativa* and *Sorghum* – was carried out at the lower moisture threshold of 70-75% field moisture capacity (FMC). Only the depth of soil moistening and alternation of irrigation differed:

1. Soil moistening depth of 0.4 m.
2. Soil moistening depth of 0.6 m.
3. Soil moistening depth of 0.8 (0.9) m – control.
4. Alternating irrigation with soil moistening to 0.4 m and 0.8-0.9 m.

On medium saline soil, studies were carried out on three variants of *Sorghum* irrigation: no irrigation, control; irrigation at the lower threshold of soil moisture 80% of the FMC; irrigation at the lower threshold of soil moisture 70% FMC before flush, 80% in the subsequent vegetation period. Variants with two thresholds of pre-watering soil moisture – 70-75% and 80-85% of FMC (factor A), three depths of moistening – 0.4 m, 0.6 m, and 1.0 m (factor B) of four crops – *Sorghum*, *Medicago sativa*, *Elytrigia* and *Agropyron* (factor C) – were tested on strongly saline soil. Experiments were laid out using the organized repetition method. Within the repetitions, plots were placed randomly.

Root mass accumulation by plants was determined according to the method of N.Z. Stankov. Monolith was taken in layers 0-0.2; 0.2-0.4 and 0.4-0.6 m, with dimensions 0.331×0.302 m for perennial grasses, 0.24-0.70 m for row crops. To determine the volumetric mass, a soil sample with an undisturbed structure was taken with a cutting cylinder, 200 cm in volume; the density of the solid phase was determined by picnometric method; the lowest water capacity – by the method of flooded sites (2×2 m), structural aggregate composition –

by N.I. Savvinov method; water permeability – by Nesterov device; productive moisture reserves in soil – by calculation method.

Soil nutrient regime was determined in experiments by fertilizer, tillage practices, and irrigation regime. Soil samples for analysis were taken before the main tillage, at sowing, in the phases: tillering, flush, and at *Sorghum* harvesting; at harvesting of each cutting of perennial grasses on layers 0-0.2 m and 0.2-0.4 m in each variant of experiment I and III repetitions. The chemical composition of aboveground mass and root residues was determined according to the methods of biochemical study of plants: total nitrogen – by Kjeldahl, phosphorus – by Levitsky, potassium – on a flame photometer, fat – by Soxhlet, fiber – by Gennesberg and Stamman. All photographs in the manuscript were taken by the lead author. The majority of the identifiable images feature doctoral students from Kazakh National Agrarian Research University. Before taking these photographs, all doctoral students were informed of their intended use and gave their consent to exposing these photos. Any remaining identifiable individuals in the photographs are co-authors of this manuscript and have also given their consent for publication. The authors followed the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS

Organic fertilizers used in the authors' study – manure and green mass of barley and *Medicago sativa* – contribute to a more uniform provision of plants with nutrients than when mineral fertilizers are applied to the soil. Thus, the content of hydrolyzable nitrogen in the arable layer of soil in the first year of use of perennial grasses in the variant where fertilizers were not applied, the highest was at the first date of determination – 15 May – on average under blue grass and *Sorghum* – 34.9 mg, under *Medicago sativa* – 43.0 mg/kg. It was also high enough when determined a month later – 33.7 and 37.5 mg/kg, respectively (Fig. 2). Further, the specified form of nitrogen in soil continues to decrease and at the harvesting of the second cutting of blue grasses (15 September) compared to the determination in the middle of August either did not change (*Elytrigia*) or slightly (by 0.2-0.4 mg/kg) increased (*Sorghum, Agropyron*). A slight increase (by 3.9 mg/kg) was also noted under *Medicago sativa*.

Average nitrogen content (on 5 determinations) in the soil under *Medicago sativa* from 33.3 mg on control increases up to 47.0 mg at the application of mineral fertilizers, up to 54.7 mg – at manure application, up to 63.3 mg – at sideration. The nitrogen regime of soil under *Elytrigia* and *Agropyron* under these types of fertilizers remains practically the same. Nitrogen content in the soil under them on mineral fertilizer background increases by 25.2 and 22.0%, on manure – by 45.0-43.6%, and on sidedress – by 49.1 and 46.2%. The content of hydrolyzable nitrogen under *Sorghum* at the application of manure and mineral fertilizers increases in comparison with the control by the same value (by 36.1-36.5%), but at sideration its index was higher – 72.8%.

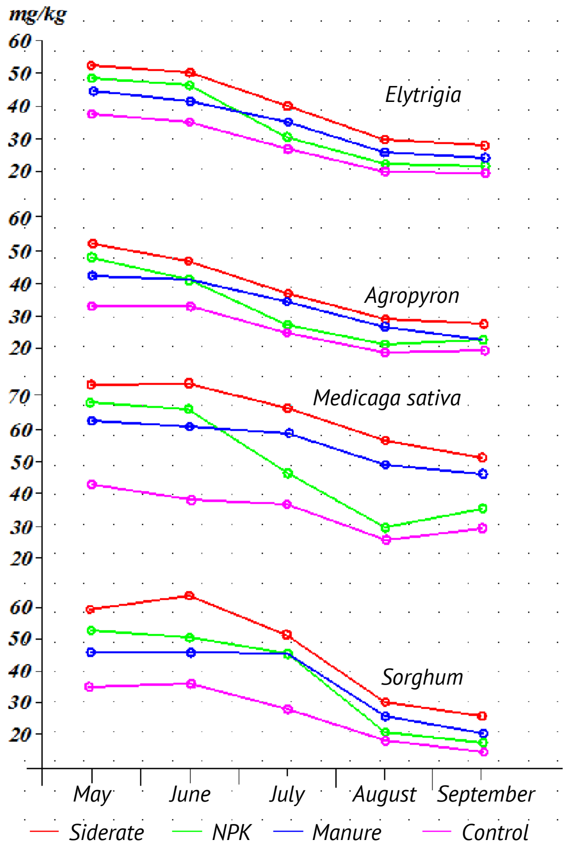

***Figure 2**. Dynamics of hydrolysable nitrogen content in arable soil layer under forage crops depending on types of fertilizers*
***Source:** compiled by the authors*

It is known that in irrigated conditions the main form of assimilated nitrogen is nitrate. In irrigated conditions of Kyzylorda region nitrogen, even from fertilizers applied in ammonia form, very quickly passes to nitrate form and during the whole vegetation period, it is represented by very mobile nitrate form. The most favorable environment for nitrification is soil moisture between 60-80% and a temperature of 20-30°C. Such conditions in the authors' study were formed exactly in the first two terms of determination of hydrolyzable nitrogen in the soil – in May and the first half of June. The maximum amount of nitrogen in the soil under forage crops falls on this period.

In the subsequent period, due to soil compaction after irrigation, leaching by irrigation water, as well as denitrification by water stagnation during irrigation, the content of assimilable nitrogen in the soil decreases, especially in the mineral fertilizer background. This is also caused by its consumption by plants for crop formation, which is confirmed by the results of studies. The significant increase of hydrolyzable nitrogen in the soil in comparison with this variant when manure is applied to forage crops is explained by the fact that this not only adds nutrients to the soil but also creates conditions for the formation and development of microorganisms that contribute to the transition of nutrient elements into mobile compounds. In this case, nitrogen losses for leaching and denitrification are minimal, as nitrogen release from organic matter is gradual rather than simultaneous, as in the case of mineral fertilizer application.

Tilling the soil with a green mass of plants, especially legumes, increases the biological activity of the soil and increases the content of nutrients, including nitrogen. It acts as a kind of "biological fire starter" for the decomposition of not only fresh green mass but also other organic residues in the soil. However, when plowed in the first half of summer, the green mass of siderates decomposes 1.5-2.0 times faster than straw, crop, and root residues of grain crops. In the beginning, there is a rapid release of carbon dioxide, simultaneously the formation of a significant amount of ammonia, then its accumulation is weakened and in aerobic conditions nitrate formation processes intensify.

For these processes, microorganisms need additional energy material in the form of nitrogen and other elements, in connection with which there is even a slight decrease in the yield of subsequent crops. In autumn sidedressing into the soil siderates creates different conditions for supplying plants with nitrogen. Between the fallow pea green mass and active consumption of nitrogen by forage crops, a relatively long time passes, and the phenomenon of biological nitrogen fixation in this case is no longer observed. For these reasons, the nitrogen content in the soil under *Medicago sativa* after sideration increases by 90.1%, *Sorghum* – by 72.8%, *Agropyron*, and *Elytrigia* – by 46.2 and 49.1%, respectively, which indicates the most favorable effect of green mass *Medicago sativa* on the nutrient regime of the soil compared to other fertilizer options. The dynamics of phosphate content in soil are essentially similar to the dynamics of hydrolyzable nitrogen, except for the autumn increase of P_2O_5 (Fig. 3). But their total content in the soil is much lower. In the control, it decreases from 22.5-24.3 mg/kg at the first determination in mid-May to 15.6-17.8 mg/kg at the last one in mid-September, which is a consequence of increasing plant consumption.

The amount of phosphorus available for plants depends to a greater extent on soil fertilization than on seasonality because, during the whole vegetation period on fertilized variants, its content is significantly higher than on unfertilized ones. Thus, the application of mineral fertilizers N100P50 contributes to the increase of phosphate in the arable layer on average for five terms of determination for the growing season of fodder crops by 38.7% (from 20.4 to 28.3 mg/kg). Organic fertilizers contribute to the increase of P_2O_5 content in the soil: manure by 41.7%, siderate – by 59.6%, compared to the control. As in the case of hydrolyzable nitrogen, a more uniform supply of assimilable phosphorus as a result of the decomposition of manure and siderate in the soil contributes to its greater accumulation in the soil than in the case of mineral fertilizers. This fact is related to the fact that on highly saline soil single application of the whole dose of phosphorus fertilizer (except for 10 kg/ha, which was given at sowing) leads to the precipitation of part of assimilable phosphorus (PO_4) into sediment.

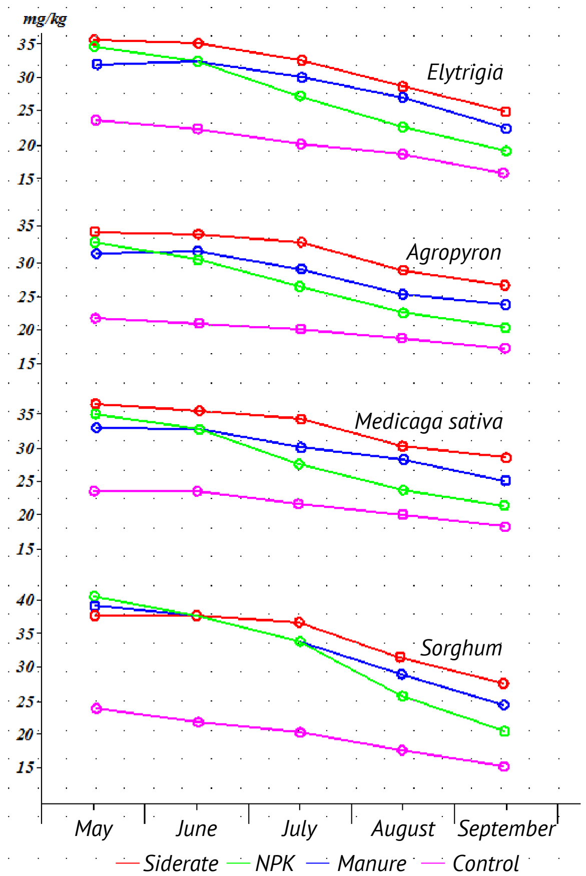

***Figure 3**. Dynamics of P_{205} content*
in an arable layer of soil under forage crops depending on types of fertilizers
***Source:** compiled by the authors*

Among the studied crops, the highest phosphate content in soil was under sugar *Sorghum*, which is apparently due to the higher nitrogen demand of this crop and inadequate (disproportionate) consumption. Soils of the considered region are characterized by sufficient content of assimilable potassium. The arable layer of soil contains 420-470 kg/ha of exchangeable potassium, and with 10 t/ha of perennial grasses only 150-200 kg/ha is taken out. Apparently, for this reason, little change in potassium content was observed under the tested crops in the study (Fig. 4). The average amount of K_2O on the control variant ranged from 351.6 to 352.0 mg/kg for crops, in the setting of mineral from 353.7 to 355.2 mg, in the setting of manure from 353.8 to 355.7 mg and from 355.9 to 356.9 mg/kg on average for all terms of determination. It follows from the same data that the types of fertilizers do not have a noticeable effect on the content of exchangeable potassium in the soil. Its increase in the arable layer of the soil was observed at the application of mineral fertilizers only by 0.5-1.1%, manure by 0.5-1.2% and soil sideration by 1.1-1.5%.

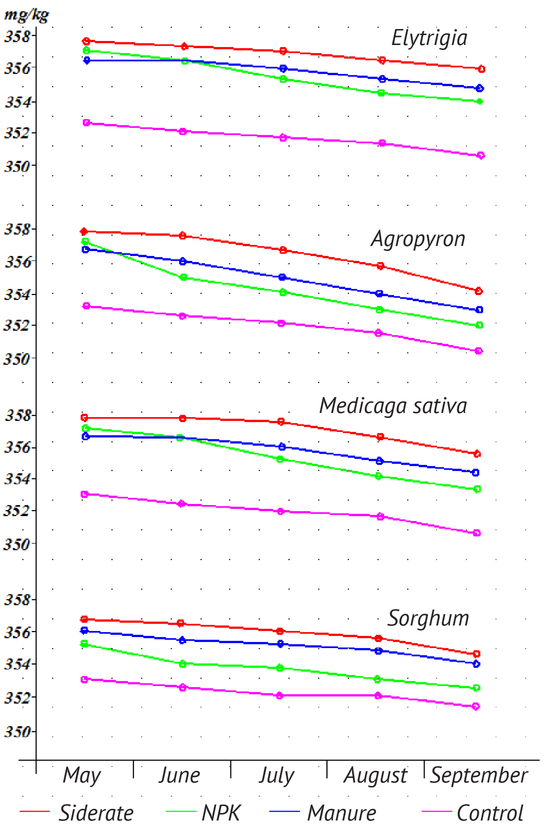

***Figure 4**. Dynamics of K_2O content in the topsoil layer under forage crops depending on types of fertilizers*
***Source:** compiled by the authors*

An insignificant change of mobile potassium content during the vegetation period on meadow-chestnut soils is explained by the fact that it is rich in potassium and its exchangeable form is always maintained at a constant level due to the transition of a part of its total amount to the exchangeable state, instead of extracted by plant roots for the formation of yield. How the nutrient regime of the soil is formed and what measures should be taken to improve it can be judged by the balance of nutrients in the soil.

Its incoming part includes nutrient inputs from fertilizers, seeds, plant residues, precipitation, and symbiotic and non-symbiotic fixation of atmospheric nitrogen. The expenditure part takes into account the removal with economic yield, gaseous losses of nitrogen as a result of denitrification, as well as leaching into deep layers during irrigation, heavy precipitation, and losses from soil erosion (deflation). Looking ahead, it should be noted (since the issue of crop yields about the applied fertilizers has not yet been considered) that in the study with the economic yield of fodder crops *Medicago sativa* takes out from the soil from 62.5 to 132.2 kg/ha of nitrogen, from 15.5 to 30.1 kg of phosphorus and from 39.3 to 72 kg/ha of potassium depending in the setting of fertilizers (Table 1).

Bluegrasses are somewhat less tolerant of nitrogen and phosphorus, but much more potassium 51.6-127.7 kg/ha. The harvested *Sorghum* crop contains 1.72 times more nitrogen than *Medicago sativa*, 2.13 times more nitrogen than *Agropyron*, and 1.78 times more nitrogen than *Elytrigia*. It also takes more phosphorus – 3.2; 3.3 and 3.6 times and potassium – 2.47; 1.50 and 1.78 times. This is not due to its high percentage content in *Sorghum* phytomass but to the higher yield of this crop compared to others. A significant amount of nutrients is accumulated in the soil and with stubble (crop residues) – root residues (SRR). The average nitrogen content in such mass of *Medicago sativa* is 26.4 kg/ha, in *Elytrigia* – 24.4; in *Agropyron* – 21.7 and least of all – 7.5 kg/ha – in *Sorghum* SRR. P_2O_5 is most accumulated in the considered mass of *Medicago sativa* – 8.1 kg/ha against 6.8; 6.4 and 3.4 kg/ha of other crops, respectively (Table 2).

***Table 1**. Content of main nutrients in above-ground phytomass of fodder crops depending on types of fertilizers for 2021-2022*

Types of fertilizer	Feeding elements	In 1 kg air-dry weight, %				In phytomass yield, kg/ha			
		Medicago sativa	*Elytrigia*	*Agropyron*	*Sorghum*	*Medicago sativa*	*Elytrigia*	*Agropyron*	*Sorghum*
Without fertilizer, control	N	2.10	2.1	2.00	2.40	62.5	57.7	50.5	95.4
	P_2O_5	0.52	0.48	0.55	0.80	15.5	13.2	13.9	31.8
	K_2O	1.32	2.18	2.04	1.95	39.3	59.9	51.6	77.5
NPK	N	2.42	2.2	2.0	2.39	95.4	96.8	76.0	172.1
	P_2O_5	0.56	0.50	0.54	1.00	22.2	22.0	20.5	72.0
	K_2O	1.33	2.20	2.10	2.00	52.9	96.8	79.8	144.0

Table 1. Continued

Types of fertilizer	Feeding elements	In 1 kg air-dry weight, %				In phytomass yield, kg/ha			
		Medicago sativa	*Elytrigia*	*Agropyron*	*Sorghum*	*Medicago sativa*	*Elytrigia*	*Agropyron*	*Sorghum*
Manure	N	2.46	2.2	2.1	2.41	11.75	110.5	94.0	201.8
	P_2O_5	0.56	0.52	0.55	1.10	26.7	26.1	24.6	92.1
	K_2O	1.33	2.26	2.15	2.11	63.5	113.6	96.2	176.7
Siderate	N	2.46	2.2	2.1	2.42	132.2	124.3	105.5	225.7
	P_2O_5	0.56	0.53	0.55	1.13	30.1	30.0	27.6	105.4
	K_2O	1.34	2.26	2.17	2.15	72.0	127.7	109.0	200.5

Source: *compiled by the authors*

Table 2. *Content of main nutrition elements in stubble (crop residues) – root residues for 2021-2022*

Types of fertilizer	Nutritional elements	In 1 kg air-dry weight, %				In total mass, kg/ha			
		Medicago sativa	*Elytrigia*	*Agropyron*	*Sorghum*	*Medicago sativa*	*Elytrigia*	*Agropyron*	*Sorghum*
Without fertilizer, control	N	1.60	1.12	1.05	0.85	17.8	15.7	13.2	4.7
	P_2O_5	0.46	0.30	0.32	0.39	5.1	3.9	4.0	2.0
	K_2O	0.94	1.04	1.00	1.30	10.4	13.6	12.6	7.2
NPK	N	1.64	1.13	1.05	0.81	24.5	23.7	21.3	6.9
	P_2O_5	0.49	0.32	0.31	0.38	7.3	6.7	6.0	3.2
	K_2O	0.96	1.05	1.02	1.29	14.3	22.0	19.7	11.0
Manure	N	1.66	1.15	1.05	0.86	29.9	27.6	24.0	8.8
	P_2O_5	0.51	0.33	0.32	0.38	9.2	7.9	7.3	3.9
	K_2O	1.04	1.06	1.02	1.30	18.8	25.4	23.3	13.3
Siderate	N	1.67	1.14	1.06	0.85	33.4	30.8	27.3	9.6
	P_2O_5	0.55	0.32	0.31	0.38	11.0	8.6	8.2	4.3
	K_2O	1.11	1.04	1.02	1.29	22.2	28.1	26.3	14.6

Source: *compiled by the authors*

In terms of potassium content in SRR on average for all fertilizer variants, *Elytrigia* and *Agropyron* surpassed *Medicago sativa*, they accumulated 2.3 and 18.2 kg/ha, respectively, against 16.4 kg/ha for *Medicago sativa*, and the minimum amount was observed in *Sorghum* residues – 11.5 kg/ha. The data on nutrient removal by plants and their accumulation in SRR the authors obtained were used in the preparation of the balance of nutrients in the soil under forage agrocenoses in connection with the applied fertilizers. Other balance items are given based on available literature sources, taking into account the natural conditions in which the authors' research was conducted. Taking into account the insufficient amount of precipitation during the years of research and the absence of large industrial facilities in the areas of the experiments, it took the average for the main agricultural areas of nutrients in the soil with precipitation: 5 kg/ha of nitrogen and 0.1 kg/ha of phosphorus.

The most important item of nitrogen input into the soil is its fixation from the air by leguminous crops, in the authors' case *Medicago sativa*. Many scientists have calculated that this crop, with a yield of 100 kg of hay annually accumulates 100 kg of nitrogen in the roots and 200 kg of nitrogen per hectare in the above-ground part. The same ratio between yield and nitrogen accumulation is given by other researchers (Tomaz *et al.*, 2021). In the current study, it was assumed that free-living microorganisms fix 2.0 kg/ha of nitrogen, taking into account the available humus stock and 10 kg/ha of fresh organic matter entering the soil, for a total of 12 kg/ha (Sapkota *et al.*, 2020).

A certain amount of nutrients is leached from the soil each year. According to the study of 1 ha annually leached nutrients available or applied with fertilizers: in England on clay soil 18-27 kg of nitrogen and 1.9-3.9 kg of potassium; in the USA – respectively 31-104 and 0.9-2.4 kg; in Germany – 10-20 and 20-60 kg; in Sweden – 0.8-24 and 16-37 kg. From the given data it is clear that the intensity of nitrogen and potassium leaching from the soil is influenced by many factors and they have been arranged in the following order of importance: rainfall and irrigation intensity, the granulometric composition of the soil, doses, forms, timing, and methods of fertilizer application, etc.

Under conditions of the Kyzylorda region, studies on accounting for nutrient leaching in soil have not been conducted. There is only data that at irrigation rates of 17.8-19.9 thousand meters of water per 1 ha 10.5-20.5 kg/ha of nitrogen is lost. Based on these data, taking into account also the irrigation norm adopted for field crops in the zone (3.5-4.0 thousand m/ha) and the difference in the amount of precipitation (100 mm), nitrogen losses due to leaching in the area under study are equated to 6 kg/ha. Phosphorus leaching in the size of practical importance was not observed by the research. A certain part of nitrogen applied to the soil with fertilizers is lost (carried away from the soil in the form of volatile compounds – nitrogen oxides, elemental nitrogen, and ammonia). Depending on the type and dose of fertilizer, soil type and land use 10-20% (Slaton *et al.*, 2022) and sometimes up to 30-41.8% of nitrogen is lost for this reason (Klimczyk *et al.*, 2021). Other reports indicate that between 8 and 21.1 kg/ha of applied N are lost from the soil or between 0% on heavy soils and 7% on sandy soils (Xie *et al.*, 2021; Tadesse *et al.*, 2022).

In Kyzylorda region, where the authors' research was conducted, there is no need for potassium fertilizers, because the reserves of its assimilable form significantly exceed the removal with economic yield. Therefore, the authors have carried out balance calculations only for two main elements of plant nutrition – nitrogen and phosphorus, the content of which in the soils of the region under consideration is minimal. According to the authors calculations, in the incoming part of the nitrogen balance of *Medicago sativa* in the control variant, where fertilizers were not applied, the share of symbiotically fixed nitrogen is 46.2 kg/ha (57.0%), the share of nitrogen supplied with plant residues is about 23.0%, and the rest of it is non-symbiotically fixed and supplied with atmospheric precipitation. Despite a rather large removal with harvest (62.5%), mainly due to nitrogen fixation from the atmosphere, a positive balance of nitrogen was formed here (Table 3).

Table 3*. Nitrogen and phosphorus balance in arable layers of soil under forage crops under different types of fertilizers for 2021-2022 (kg/ha)*

Types of fertilizer	Balance sheet items	*Medicago sativa*	*Elytrigia*	*Agropyron*	*Sorghum*
		Nitrogen			
No fertilizer, control	Parish	81.0	32.7	30.2	21.7
	Expenditure	68.5	63.7	56.5	101.4
	Balance	+12.5	-31.0	-26.3	-79.7
Npk	Parish	214.1	142.7	140.3	125.9
	Expenditure	116.7	108.1	97.3	193.4
	Balance	+97.4	+34.6	+43.0	-67.5
Manure	Parish	235.8	146.6	143.0	127.8
	Expenditure	123.5	116.5	100.0	207.8
	Balance	+112.3	+30.1	+43.0	-80.0
Siderate	Parish	250.4	149.8	146.3	128.6
	Expenditure	138.2	130.3	111.5	231.7
	Balance	+114.2	+19.5	+34.8	-103.1
		Phosphorus			
Without fertilizer, control	Parish	5.1	3.9	4.0	2.0
	Expenditure	15.5	13.2	13.9	31.8
	Balance	-10.4	-9.3	-9.1	-29.8
Npk	Parish	57.3	56.7	56.0	53.2
	Expenditure	22.2	22.0	20.5	72.0
	Balance	35.0	34.7	35.5	-18.8
Manure	Parish	59.2	57.9	57.3	53.9
	Expenditure	26.7	26.1	24.6	92.1
	Balance	32.5	31.8	32.7	-38.2
Siderate	Parish	61.0	58.6	58.2	54.3
	Expenditure	30.1	30.0	27.6	105.4
	Balance	30.9	28.6	30.6	-51.1

Source: *compiled by the authors*

For other tested crops, due to the absence of this main item of the incoming part, a negative balance of humus was formed on the control, which was: *Elytrigia* – 31.0; *Agropyron* – 26.3; *Sorghum* – 79.7 kg of nitrogen per 1 ha. Application of N100P50K110 to the soil allowed a positive balance of nitrogen for all three perennial grasses, but even in this case, its index for *Medicago sativa* was higher than for bluegrass by 6.2-5.0 times for the same reason mentioned above. Application of manure and siderate to *Medicago sativa* instead of mineral fertilizers allows for an increase in the input part of the balance due to the increase of symbiotically fixed part of nitrogen, as well as the input due to plant residues by 21.7 and 36.3 kg/ha, respectively. This led to an increase in nitrogen balance by 14.9 and 16.8 kg/ha, although at the same time, its removal from the soil with higher phytomass yield increased by 22.1 and 49.7 kg/ha.

And under bluegrasses similar growth of balance index is not observed due to the increase of phytomass yield at organic fertilizer application and corresponding increase of its removal from the soil. Under sugar *Sorghum*, there is a negative balance of nitrogen not only on the control but also on all variants (types of fertilizers). The reason for this is one – failure to replenish nitrogen removal from the soil by the fertilizer doses the authors made. The same regularity is observed for phosphorus balance – a positive balance under perennial grasses under all types of applied fertilizers and a negative balance under control. Under sugar *Sorghum*, it was negative at the application of all types of fertilizers, even though there was a decrease of the balance indicator at the application of organic fertilizers in comparison with the application of mineral fertilizers, due to an increase of its removal with higher yields of phytomass.

DISCUSSION

Ensuring high quality and stable yields of fodder crops depends on the rational use of fertilisers and optimisation of the soil's nutrient regime. In modern agricultural practice, much attention is paid to the selection and application of different types of fertilisers aimed at improving soil fertility and providing a fodder base for livestock. In recent years, research in the field of agronomy and soil science has revealed a significant impact of different types of fertilisers on soil nutrition and growth parameters of forage crops. In particular, the use of various fertilisers, such as mineral, organic or combined fertilisers, can play a key role in providing the necessary nutrients for plant growth and development (Lynch *et al.*, 2021; Kong *et al.*, 2022).

The authors' research shows that different types of fertiliser can affect the concentration of nitrogen, phosphorus, potassium and other nutrients in the soil. For example, mineral fertilisers that dissolve quickly in water can provide plants with the necessary nutrients immediately after application (Panfilova *et al.*, 2019). This is especially important when you need to quickly improve crop growth or increase yields. Organic fertilisers, on the other hand, such as compost or manure, can gradually release nutrients over a long period of time. This can be useful when it is desirable to maintain a steady, long-term plant nutrition or to facilitate the control of soil nutrient levels over a longer period. Scientific studies presented by scientists such as M. Stepaniuk and A. Głowacka (2022) showed that different types of fertilisers can play an important role in changing the chemical composition of animal feed. In particular, the addition of fertilisers containing certain elements such as potassium, phosphorus or nitrogen can significantly affect the content of these elements in feed. For example, fertilisers rich in potassium can increase the concentration of potassium in feed, which in turn is important for providing animals with the necessary nutrients. Such studies point to the importance of the correct selection and application of different types of fertilisers to improve feed quality and ensure optimal conditions for the development of livestock farming.

Research also indicates that different types of fertilisers can have different effects on the adaptive potential of plants to environmental changes. In particular, some organic fertilisers, such as compost or crop residues, can improve soil structure and increase organic matter content, which helps to retain moisture and nutrients in the soil during periods of drought. On the other hand, micronutrients added to mineral fertilisers can increase plant resistance to certain diseases or stressful conditions, for example, boron can help plants better tolerate periods of high temperature or drought (Ostapenko, 2024). Such fertilisation strategies help crops to adapt to adverse conditions, which ensures more stable and productive cultivation in the face of climate change (Cai *et al.*, 2020).

Scientists emphasise the need to consider the environmental and biodiversity impact of different types of fertiliser. Some types of fertiliser may have less negative environmental impact than others. For example, the use of organic fertilisers such as manure, composts or biodegradable materials can help to conserve biodiversity and reduce soil and water pollution (Shahini *et al.*, 2024). On the other hand, some mineral fertilisers can have potentially harmful effects on the environment, such as pollution of soil and aquatic ecosystems with chemicals. Therefore, it is important to choose fertilisers based on their impact on environmental sustainability and conservation of natural resources (Zhang *et al.*, 2021).

The studies by M. Chilundo *et al.* (2018) emphasise the importance of taking into account the specific agro-climatic conditions of the region when choosing the type of fertiliser and its dosage. Thus, according to the authors, in the severely arid conditions typical for Kyzylorda region, the use of organic fertilisers can be important for ensuring the moisture retention properties of the soil and improving its structure. However, at the same time, mineral fertilisers may be necessary to provide plants with nutrients, which is also reflected in the study. In support of this view, the authors' research demonstrates the benefits of mineral fertilisers in increasing the yield and quality of fodder crops, emphasising their rapid availability to plants and high concentration of nutrients. In contrast, other studies focus on the use of organic fertilisers, which help to improve soil structure, preserve its water-air regime and provide a long-term fertilisation effect.

However, X. Chen *et al.* (2022) note that combined fertilisation approaches that use both mineral and organic components are extremely important to achieve an optimal balance of nutrients in the soil and maintain sustainable crop growth. This combination allows to determine the optimal fertilisation strategies to ensure a balanced soil nutrient regime and increase the yield and quality of fodder crops in different agroclimatic conditions. S.J. Yan *et al*. (2021) focus on analysing the impact of different types of fertilisers on soil biological activity and microbiological processes that can affect the nutrient regime and health of the soil system. They also emphasise the cost-effectiveness of using different types of fertilisers, taking into account their cost and potential income from increased crop yields and quality, as economic profitability is of great importance in agriculture today.

S. Huang *et al*. (2021) note that successful fertiliser use involves not only choosing the right types of fertiliser, but also considering the optimal sequence and doses to achieve the best results in plant nutrition and soil fertility. It is important to take into account the individual characteristics of each field, such as its structure and physicochemical properties, as well as the specific needs and requirements of different crop types, as demonstrated in the study. Thus, the authors' research and this study confirm that, given the potentially negative impact of mineral fertilisers on the ecological state of soil and water resources, it is important to actively promote the use of organic fertilisers. Organic fertilisers, such as composts, vermicompost or natural plant-based fertilisers, have a lower environmental impact and contribute to the conservation of biodiversity. Their use helps maintain soil fertility and reduce erosion and water pollution. In order to support the transition to organic farming, it is important to take into account the diversity of conditions and needs of each field, as these may affect the effectiveness of different types of fertilisers (Tonkha *et al*., 2024). An individual approach to the selection and application of fertilisers allows us to maximise crop yields while maintaining the environmental sustainability of soil and aquatic ecosystems.

It is also important to systematically monitor soil conditions and nutrient levels to ensure sustainable production. This allows you to identify problems in time and take the necessary measures to resolve them. Adaptability in the use of fertilisers and crop cultivation technologies is key to successful agricultural production in a changing climate and resource environment (Ivanova *et al*., 2022). Thus, the results of research on the impact of different types of fertilisers on soil nutrient status and growth parameters of fodder crops emphasise the importance of rational and balanced fertiliser use to ensure sustainable and productive agriculture. Overall, the study of soil nutrient balance and optimisation of fodder crop nutrition in Kyzylorda oblast has great potential to improve the sustainability and productivity of the agricultural sector, as well as to provide food for the local population.

CONCLUSIONS

The agricultural sector is constantly facing challenges related to the lack of nutrients in the soil and their insufficient supply for various crops, including fodder. An important aspect of ensuring balanced plant nutrition is to study the impact of different types of fertilisers on the soil's nutrient regime and nutrient balance. The study found that organic fertilisers, such as manure and green manure, contribute to a more even supply of nutrients to plants than when using mineral fertilisers. The study reveals profound patterns in the nitrogen and phosphorus balance of different crops, particularly highlighting the distinctive behaviour of *Medicago sativa*. In the control variant without fertilisation, *Medicago sativa* showed a positive nitrogen balance: 46.2 kg/ha, 57.0% of which was attributed to symbiotic fixation and approximately 23.0% to plant residues. Despite a significant level of removal (62.5%) at harvest, mainly due to atmospheric nitrogen fixation, the crop maintained a positive nitrogen balance.

Other crops studied without the benefit of symbiotic nitrogen fixation showed a negative nitrogen balance. Thus, *Elytrigia*, *Agropyron* and *Sorghum* suffered from nitrogen deficiency on the control variant, respectively: 31.0 kg/ha, 26.3 kg/ha and 79.7 kg/ha. However, the application of N100P50K110 resulted in a positive nitrogen balance for all three perennial grasses, although *Medicago sativa* showed significantly higher results due to its excellent symbiotic nitrogen fixation ability. In addition, the replacement of mineral fertilisers with manure and green manure for *Medicago sativa* resulted in an increase in N application of 21.7 kg/ha and 36.3 kg/ha, respectively. However, the simultaneous increase in phytomass yields required higher nitrogen removal rates, mitigating the overall increase in nitrogen balance. Similar trends were observed in the phosphorus balance, with perennial grasses showing a positive balance for all fertiliser types, while *Sorghum* consistently showed a negative balance for all options. It was also found that organic fertilisers contribute to increased soil biological activity and nutrient accumulation, while mineral fertilisers can cause greater mobilisation of substances and increased losses. Thus, the efficient use of organic fertilisers can be key to maintaining a sustainable agro-ecosystem and ensuring high yields.

Thus, the use of different types of fertiliser can affect the nutrient balance in the soil under forage crops, which is important for planning flexible and efficient fertilisation strategies. Taking these results into account can help to optimise fertiliser use and ensure sustainable growth and development of forage crops without undue stress on the environment.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Поживний режим і баланс поживних речовин у ґрунті під кормовими культурами при застосуванні різних видів добрив (на прикладі Кизилординської області)

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Анотація. Сучасне сільське господарство стикається з низкою викликів, серед яких особливе значення має ефективне використання добрив для забезпечення рослин необхідними поживними речовинами. Зокрема, зростаюча увага до сталого сільського господарства та необхідність збереження ґрунтових ресурсів підкреслюють актуальність досліджень з оптимізації використання добрив. Метою дослідження було визначення ефективних методів використання добрив для забезпечення рослин поживними речовинами. Для досягнення поставленої мети досліджували ефективність сидератів, органічних (гній) та мінеральних добрив під сорго та багаторічні трави (*Medicago sativa*, *Elytrigia*, *Agropyron*) на засоленому ґрунті. Дослідження показало, що органічні добрива, такі як гній та сидерати, сприяють більш рівномірному забезпеченню рослин поживними речовинами порівняно з мінеральними добривами. Це особливо важливо в контексті балансу азоту та фосфору, де *Medicago sativa* має позитивний баланс азоту завдяки своїй здатності до симбіотичної фіксації азоту. Інші досліджувані культури, такі як *Elytrigia*, *Agropyron* і *Sorghum*, показали негативний баланс азоту на контрольному варіанті, але внесення мінеральних добрив $N_{100}P_{50}K_{110}$ призвело до позитивного балансу азоту. Заміна мінеральних добрив органічними добривами, такими як гній та сидерати, збільшила внесення азоту, але також збільшила винос азоту з ґрунту завдяки збільшенню врожайності фітомаси. Результати дослідження підтверджують важливість переходу до більш сталого та екологічно безпечного способу виробництва в сільському господарстві, що забезпечить розвиток галузі та підвищить її конкурентоспроможність на міжнародному ринку. Практичне значення дослідження полягає у наданні аграріям можливості підвищити врожайність вирощуваних ними культур і водночас зберегти родючість ґрунту за рахунок оптимального використання поживних речовин, що містяться в добривах

Ключові слова: обмінний калій; фосфор; азот; гумус; *Sorghum*; *Medicago sativa*