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STATE AND PROSPECTS OF MINERAL FERTILIZERS USE IN AGRICULTURE OF KAZAKHSTAN

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SUMMARY

The article is a dedicated analysis of the production and use of mineral fertilizers globally, focusing on the agriculture of Kazakhstan**.** From 1950 to 2020, the fertilizer use ranged between 3.6–29.0 kg of NPK per hectare in arable agricultural land of Kazakhstan. The maximum benefit of fertilizers happened in 1986 in Kazakhstan, with 1,039 t of mineral fertilizers (active substances) applied at an area of 47% of the total arable land, while in 1965, the fertilized area was only 6.6% of the entire sown field. In Kazakhstan, the annual recommended need for mineral fertilizers is one million tons (active ingredient). The paper also discussed the influence of the long-term application of fertilizers on the leading indicators of soil fertility and crop productivity. Employing regression analysis also explored a high degree of probability of a positive relationship among the four viable factors, i.e., fertilizer use intensity, agrochemical indicators of the soil, crop plants yields, and their quality.

Keywords: Mineral fertilizers, humus, nutrition elements, agrochemical indicators of the soil, fertilizers' efficiency, crop productivity

Key findings: In the agriculture of Kazakhstan, the fertilizer analysis indicates a low level of use. The annual need for mineral fertilizers for the entire sown area of the Republic was 2.5 million t in physical weight (including 1.2, 1.3, and 0.03 million t of nitrogen, phosphorus, and potassium, respectively).

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INTRODUCTION

In Kazakhstan, the total area of the land fund is 272.5 million hectares.. Of these, agricultural land - 222.6 million hectares (82%), of which 26.6 million hectares (15%) are arable, including irrigated (1.4 million hectares, 0.63%), hayfields (5 million hectares, 2.5%), pastures (184 million hectares, 68%), and perennial plantations (121.8 thousand hectares, 0.05%) (Klebanovich *et al*., 2016). The soil cover of Kazakhstan has a pronounced zonal and altitudinal zoning. In general, the country is characteristically latitudinal zonality of soils, i.e., chernozems in the North, while chestnut, brown semi-desert, takyrs, and desert sands soils in the South. Kazakhstan ranks ninth

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position globally based on soil cover area characterized by low resistance to anthropogenic loads, subjected to degradation and desertification processes. The solonetzic and saline regions of the Republic are more than 93 million ha.

A significant part of arable lands is illustrative of low content of humus and mobile forms of nitrogen, with more than half of the area insufficiently provided with mobile forms of phosphorus (Klebanovich *et al*., 2016; Bastaubayeva *et al*., 2023; Sabra *et al*., 2023). In Kazakhstan, the prolonged illogical land use in agriculture leads to annual losses of humus (0.5–1.4 t ha^{-1}), causing dehumidification and soil fertility loss (25%–30%) of the original, and it reflected a decrease in productivity of arable land and boost the wind and water erosion processes. In the grain areas north of the Republic, about 17.8 million ha got threatened by deflation, and 2.6 million ha suffered from severe wind erosion (Kenenbayev *et al*., 2017; Kenenbayev and Jorgansky, 2018).

In Kazakhstan, the areas of crops have changed slightly over the past decade; however, the shifts are still noticeable. Agricultural production’s diversification and departure from monoculture still progress in the Republic. Thus, the share of area under grain and leguminous crops in the total sowing wedge decreased to 66.0% versus 77.5% before (Table 1). However, wheat still occupies more than half of the sown area in Kazakhstan. During this period, the oilseed crop area increased significantly from 1.7 to 3.1 million ha, and the fodder crops from 2.5 to 4.0 million ha (Kenenbayev *et al*., 2016). The purpose of the research is to analyze the use of mineral fertilizers in Kazakhstan for a long (more than 50 years) period of time. Establishing the relationship between the levels of soil availability with elements of effective soil fertility, the intensity and duration of fertilizer use, and the productivity of cultivated crops.

MATERIALS AND METHODS

The presented findings resulted in the analysis and processing of the statistical data for the last 50 years based on applied mineral fertilizers for the entire sown area and the proportion of fertilized areas. A summary of the data and the scientific results of agriculture-related research institutions on the effective use of fertilizers in various crops follows.

Table 1. Main crops grown during 2010–2021 in the Republic of Kazakhstan.

Years	Cereals and legumes	Oilseeds	Potato	Vegetables	Melon crops	Forage crops	Total
2010	16619.1	1748.1	179.5	120.3	63.3	2555.6	21438.7
2011	16219.4	1816.2	184.4	128.7	67.7	2484.3	21083.0
2012	16256.7	1853.9	190.2	128.7	81.8	2517.4	21190.7
2013	15877.6	1980.9	184.8	133.1	82.3	2866.8	21271.0
2014	15291.5	2299.5	186.8	137.7	89.8	3109.9	21244.6
2015	15320.4	2108.8	189.8	139.0	94.4	3260.2	21450.0
2016	15400.7	2037.5	186.9	146.2	93.6	3671.3	21660.1
2017	15062.2	2095.5	186.7	144.5	93.2	4118.9	21826.1
2018	15135.3	2838.2	193.1	152.0	96.1	3443.1	22011.2
2019	14888.9	2719.6	207.3	158.5	97.6	4097.2	22301.9
2020	14809.1	3029.3	193.7	163.9	107.0	4012.6	22315.6
2021	15969.1	3093.2	195.8	168.6	110.0	3103.5	22903.0

RESULTS AND DISCUSSION

Increased crop production is one of the priority goals of agriculture. However, that aim is linked inextricably with improving and preserving soil fertility, rational use of land and crop resources, and effective use of advanced agricultural technologies. An essential function in solving this problem is fertilizer use, which is a reliable factor directly affecting soil fertility and, eventually, crop productivity.

Mineral fertilizers revolutionized agriculture, and their global demand will enhance with time. According to the International Association of Fertilizer Producers, in 2017–2018, the global requirements for fertilizers amounted to 188 million t, while in 2021–2022, it rose to 200 million t. Internationally, the main consumers of fertilizers are the densely populated China and India. Assuming a third of the total demand and the real determiners of global prices are the USA, Europe, and Brazil (Yakovleva, 2017).

In the present era, global fertilizer consumption has significantly increased by 1.6% over the past two to three years. The increase in fertilizers use refers to an upsurge in demand due to the beneficial rainy season in India and the consumption recovery in the United States. In South Asia and North America, fertilizer utilization amounted to about 6.0% (2.0 and 1.4 million t, respectively) (World Market of Mineral Fertilizers, 2021). During this period, in the regions of Eastern Europe and Central Asian states, fertilizer requirements increased by more than 10% (0.9 million t), mainly due to the growth in the Russian Federation. Fertilizer usage in Latin America and the Middle East increased by 0.5 million t (2% and 10%, respectively). However, in Europe and Oceania, the consumed volumes remained stable (Table 2).

In African countries, there was a decrease in demand for fertilizers by 2.4% (about 0.2 million t). During this period in East Asian countries, a record decrease in fertilizers consumption by 3.5% (2.3 million t) transpired, mainly because fertilizer demand in China, Indonesia, and Malaysia decreased due to bad weather (drought) conditions and unfavorable situations in the palm oil market (Mineev and Bychkova, 2000; Tleubaev *et al*., 2021).

The mineral fertilizers applied per hectare to arable lands worldwide in 2019 ranged from 6.9 to 586.6 kg ha^{-1}. In that year, the users of the highest dose of fertilizer included Kuwait (586.6 kg ha^{-1}), China (350.5 kg ha^{-1}), Belarus (151.6 kg ha^{-1}), Canada (105 kg ha^{-1}), Ukraine (63.4 kg ha^{-1}), and Russia (22.3 kg ha^{-1}) (Mineral fertilizers, 2021). However, using the lowest dose of mineral fertilizers was in Kazakhstan (6.9 kg ha^{-1}). Comparing the average wheat yields of Canada and Kazakhstan, which also has similar environmental conditions for grain production, the wheat yields were 3.1 and 1.2 tons ha^{-1}, respectively.

Russia plays a principal role in the world market of mineral fertilizers, listed in the top three producing countries and the top 10 countries consuming mineral fertilizers. Russia is the largest exporter of mineral fertilizers, with nitrogen fertilizers also mainly produced there. In 2020, its production was 45% of worldwide manufacturing (Kiryushin, 2015). However, Russia is one of the world's 10 biggest consumers of mineral fertilizers, ranking nine after China, India, Brazil, the USA, Pakistan, France, Canada, and Germany. Russia trails behind the level of developed countries in the total consumption of mineral fertilizers, possibly due to constraints in financing the industry (Kiryushin, 2015).

Table 2. World consumption of fertilizers (million tons a.s.).

Fertilizers	2019/2020	2020/2021	Change 2019/2020 (%)	Change 2020/2021 (%)
Nitrogen (N)	106.7	108.4	2.8%	1.6%
Phosphoric (P2O5)	47.1	48.6	2.6%	3.2%
Potash (K2O)	36.1	36.6	(2.7%)	1.4%
Total	189.9	193.6	2.7%	1.9%

In Kazakhstan, nitrogen and phosphorus fertilizers represent the production of mineral fertilizers. Despite their effective contribution to the development of crops, minimum potash fertilizers are available in the market. Nitrogen and phosphorus fertilizers have a better impact on improving soil conditions and increasing yields than other fertilizers. For the last 10 years, Kazakhstan has observed moderate but steady development in the agro-industrial sector and the production of mineral fertilizers. The said growth refers to an enhancement in the domestic companies engaged in producing and supplying mineral fertilizers; the presence of a large amount of natural raw materials; and an increase in suppliers acting as operators of state subsidies for farms (Production of Mineral Fertilizers in Kazakhstan, 2020).

In Kazakhstan during 2020, the volume of nitrogen fertilizer production amounted to 378,000 t, more than doubled compared with 160,000 t in 2010, revealing a positive trend. For this period, the phosphorus fertilizers production amounted to 196,000 t, almost five times more than 41,000 t in 2010. Notably, in Kazakhstan, the annual need for mineral fertilizers for the entire sown area is 2.5 million t in physical weight comprising nitrogen, phosphorus, and potash, with values of 1.2, 1.3, and 0.03 million t, respectively. Kazakh local fertilizer producers can provide 40% of domestic needs. A significant part of the produced mineral fertilizers also serves as exports to Ukraine, Kyrgyzstan, the Russian Federation, and Uzbekistan (Kazakhstan Producers of Mineral Fertilizers, 2021). The volumes and the dynamics of mineral fertilizers application and the share of the fertilized arable area as a whole in the Republic appear in Figures 1 and 2.

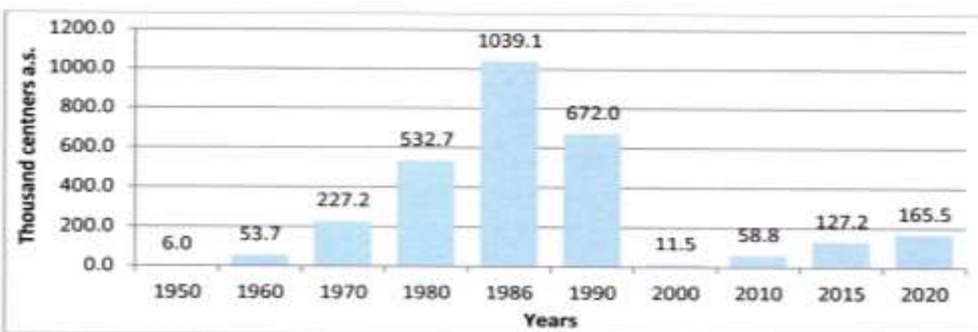

Figure 1. Dynamics of the volume of application of mineral fertilizers in agriculture of the Republic of Kazakhstan during 1950–2020.

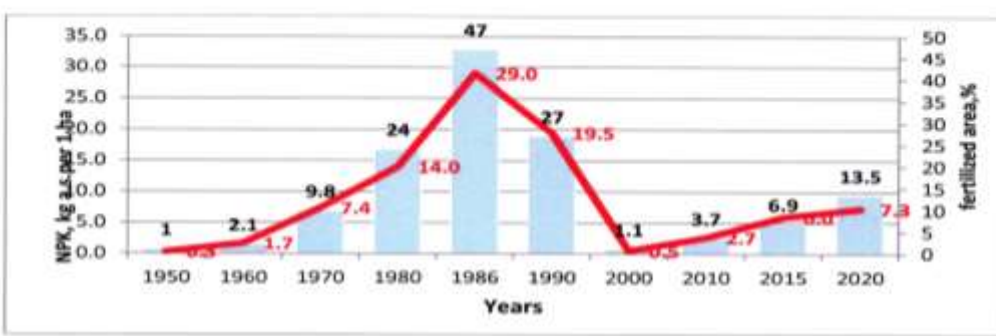

Figure 2. Dynamics of mineral fertilizers application (kg/ha a.s.) and the share of arable land area applied with mineral fertilizers in Kazakhstan during 1950–2020.

The peak of chemicalization in Kazakhstan occurred in the mid-80s of the last century. In arable land, the per hectare fertilizers utilization increased from 3.6 to 29.0 kg of NPK (8.1 times more), and the fertilized area amounted to 47% of the whole planting ground, with the same area was 6.6% in 1965, thus increasing by 7.1 times. Since 1987, a sharp and steady decline in fertilizers used in agricultural production began in the Republic in 2000. However, recent years showed a constant, increasing trend of fertilizers usage in Kazakhstan. From 1990 to 2000, the areas applied with mineral fertilizers sharply decreased (108 times), but since 2001 there has been a growing trend.

The first agrochemical survey of arable land ensued in 1983–1987 in the Republic's 31.6 million ha (90% of arable land) for humus content in the soil. The related data analysis revealed that 71.6% of the surveyed lands were of low humus content (2.0%–4.0%), 23.9% (4.1%–6.0%) moderate humus, and 4.5% elevated with very high humus content (6.1%–10.0%). According to the agrochemical survey of 2007–2016, the soil proportion with low humus content has not changed at 71.4% (Report of Agrochemical Soil Surveys, 2007-2016). There are more soils with an average humus content of 26.6%, possibly due to the long-term use of arable land without sufficient organic fertilizers' application, which is the prime source of humus replenishment. Scientific institutions of the Republic also advised the need to make 7–10 t ha^{-1} of manure annually to preserve and increase the soil's humus content (Eleshev, 2015).

According to an agrochemical survey conducted in 1965–1972, 72.3% of the total arable soil area has low-mobile phosphorus, 24.5% as a medium, and only 3.2% with a high content of mobile phosphorus (Report of Agrochemical Soil Surveys, 2007-2016)**.** In the repeated survey conducted in 1975, the proportion of soils with low content of mobile phosphorus significantly decreased, while the proportion of medium- and high-phosphorus soils increased. In the same survey conducted in 1987, the proportion of soil areas with low availability of mobile phosphorus decreased to 44.5%, respectively, while the proportion of soil areas with medium and high phosphorus availability increased (Table 3). The provision of soils with exchangeable potassium has not changed significantly, which might be due to the element's higher content in the lands of Kazakhstan.

During the chemicalization period, the increased use of fertilizers in agriculture contributed to a significant improvement in the phosphate regime of the Republic's soils, positively impacting crop yields. Agricultural research conducted by various institutions and the practice of agricultural production has convincingly proved fertilizers' effectiveness in all of Kazakhstan's soil and climatic zones. The results indicated a close interdependence among the level of fertilizer application, the provision of soil with nutrients, and crop yields. These researches also established that judicious use of fertilizers contributes to preserving and improving the leading indicators of soil fertility, providing an increase in yield and enhancing the quality of crop production (Fertilizer Indicator, 2000; Milashchenko *et al.*, 2015; Agro-industrial Complex of Russia, 2016; Kenenbayev, 2018).

The total volume of mineral fertilizers used in 2001–2005, 2006–2010, 2010–2015, and 2016–2020 gradually increased to 30,200, 49,300, 110,000, and 165,500 t, respectively. The share of the area that received mineral fertilizers by 2020 increased by 12.3 times compared with 2000. On average, in Kazakhstan, the amount of mineral fertilizers applied per hectare to arable land also enhanced to 7.3 kg ha^{-1} a.s. (Figures 1 and 2), positively influencing increased crop yields (Table 4). Fertilizers are one of the chief factors affecting soil fertility and crop productivity. Past studies conducted by the Kazakh Research Institute of Agriculture and Plant Growing on irrigated light chestnut soils of the Southeast revealed that long-term crop cultivation without using mineral fertilizers leads to depletion, deterioration of soil, and less available nutrients to plants (Yang *et al*., 2020).

Table 3. Distribution of arable land by the content of mobile forms of nutrients (in % of the surveyed area).

Arable land was surveyed (thousand hectares)	Content level	Mobile phosphorus				Exchange potassium			
		1972	1975	1987	2016*	1972	1975	1987	2016*
35505.3	Low	72.3	68.8	44.5	43.9	2.2	4.1	1.9	0.9
	Average	24.5	26.4	40.5	40.3	7.3	8.8	6.4	4.4
	High	3.2	4.8	15.0	15.8	90.7	87.1	91.7	94.7

Note: *Arable land was surveyed in 2016 - 24196.0 thousand hectares

Table 4. Dynamics of the major crops yield in Kazakhstan (t ha^{-1}) (according to the Bureau of National Statistics of the Republic of Kazakhstan).

Crops	Years								
	1961-1965	1986-1990	1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	2021
Wheat	0.61	0.92	0.76	0.84	1.02	1.05	1.16	1.17	0.93
Corn grain	2.08	3.88	2.46	2.46	4.16	4.63	5.21	5.72	5.99
Rice	1.91	4.51	3.28	2.93	3.17	3.50	3.92	4.98	5.21
Sugar beet	23.58	28.80	11.50	13.80	19.92	21.02	21.94	28.89	27.55
Cotton	1.79	2.58	2.01	1.74	2.18	2.00	2.59	2.33	2.64
Sunflower	-	0.99	0.36	0.36	0.62	0.52	0.64	2.00	1.10
Potato	7.50	10.62	9.50	9.26	13.90	15.12	17.69	20.25	20.74
Vegetables	6.61	16.46	10.90	11.96	17.94	20.91	23.69	25.98	26.80

Humus plays a vital role in managing soil fertility and increasing the sustainability of the agriculture sector. The soil's physical, chemical, and biological properties largely depend on the humus content since humus is a source of plant nutrition. Soil humus, its content, and composition are subject to significant fluctuations depending on the characteristics of cultivated crops, tillage, humidity, aeration regime, and the levels of agricultural technology (Torshina and Basibekov, 1979; Ramazanova *et al*., 2001). The preservation and multiplication of soil organic matter are the most favorable conditions for cultivating the ground with various crops, optimizing fertility, and preventing degradation.

The study revealed that with prolonged crop rotation without fertilizers, the humus content decreased in the arable layer by 0.37%, while in the sub-arable layer by 0.34% compared with the control (Table 5). With the complete application of mineral fertilizers to the eight-field beet crop rotation, the humus content by the end of the fifth rotation decreased by only 0.10% in the upper soil layer and 0.15% in the lower soil layer compared with the initial level (2.50%). Using the recommended dose of mineral fertilizers with organic manure (60 t ha^{-1}) during the eight-full crop rotation increased the humus content by 0.09% (amounting to 2.69%) in the upper soil layer. In the 20–40 cm soil layer, the humus content also decreased over the same period, but to a lesser extent than the soil without mineral fertilizers (Table 5).

Humus reserves in the soil in varied forms without fertilizers decreased by 6.9 and 1.7 t ha^{-1} in the upper and lower soil layers by the end of the fifth rotation, respectively. By applying an entire dose of mineral fertilizer at the end of the fifth rotation, the reserves stabilized again at the level of the initial values, with the humus increased by 3.1 t ha^{-1} in the lower soil layer. The combined application of mineral fertilizers and manure helped expand the humus reproduction in the soil; reserves increased against the initial values by 4.8 and 5.7 t ha^{-1} in the upper and lower soil layers, respectively.

Table 5. Changes in the content of humus and mobile nutrients in irrigated light chestnut soil over 40 years.

Variants	Humus (%)		Mobile P_2O_5 (mg kg^{-1})		Exchange K_2O (mg kg^{-1})	
	Soil layer (cm)					
	0-20	20-40	0-20	20-40	0-20	20-40
Without fertilizers	2.23	2.16	16.9	14.0	119	418
NPK	2.50	2.35	39.7	28.9	601	524
Manure (60 t/ha) + NPK	2.69	2.45	52.3	45.4	765	717
Original (1961)	2.60	2.50	24.0	19.5	525	470

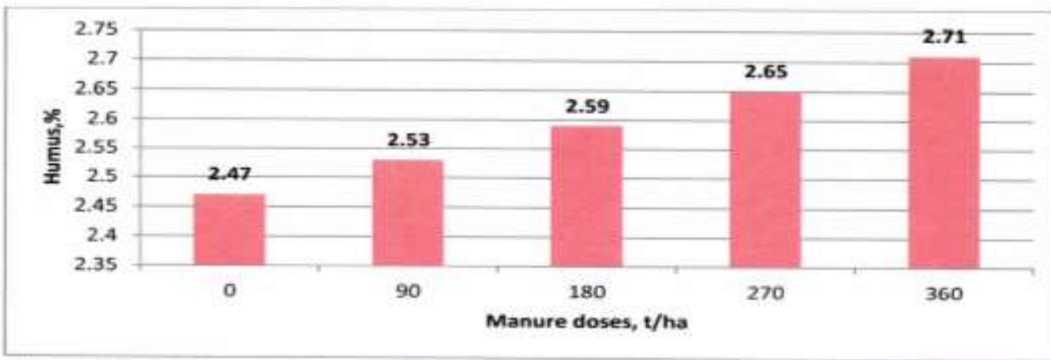

Figure 3. The effect of periodic manure application on the humus content in a 0–30 cm layer of light chestnut soil over 25 years (1991–2016).

The multifactorial studies allowed the formulation of the dependence of the humus content with systematic application of mineral fertilizers for 25 years in irrigated light chestnut soil. Further observations revealed that the humus content increases with a gradual increase in the manure rate, as described with a sufficient degree of probability by the regression equation ($Y = 2.47 + 0.06N$ at $R = 0.594$). The introduction of increasing manure rates for three rotations of an eight-field crop increased the humus content by 0.06%–0.24% (Figure 3).

Phosphorus is the most crucial element of plant nutrition, and its lack in the soil negatively affects growth, development, and crop production. The low-level mobile phosphorus in the grounds of the Southeast generally limits the increase in productivity of field crops in Kazakhstan. Long-term studies conducted in the Southeast of the Republic have established the formation of soil phosphate in that region, the optimal level and availability of mobile phosphorus for the main field crops, the values of its removal, and calculated coefficients of the use of soil phosphorus and fertilizers, and the development of complete recommendations for the effective use of phosphorus fertilizers (Ramazanova *et al*., 2017).

In long-term studies, the initial content of mobile phosphorus was at the level of 24.0 mg kg^{-1} in the upper soil layer. Crop cultivation of eight-field crop rotation during five rotations without fertilizers showed mobile phosphorus content decreased by 7.1 and 5.5 mg kg^{-1} in the upper and lower layers of the soil, respectively, against the initial values (Table 5). Multifactorial studies established a direct relationship among the three factors, i.e., the rate of fertilizers applied, the duration of their use, and the availability of mobile phosphorus in the soil (Eleshev, 1984). Based on the results, a developed regression model helped describe the highest effects of phosphorus fertilizers and manure on mobile phosphorus content in the soil (Y = 24.7 + 9.1P + 15.7PH at R = 0.930) (Figure 4).

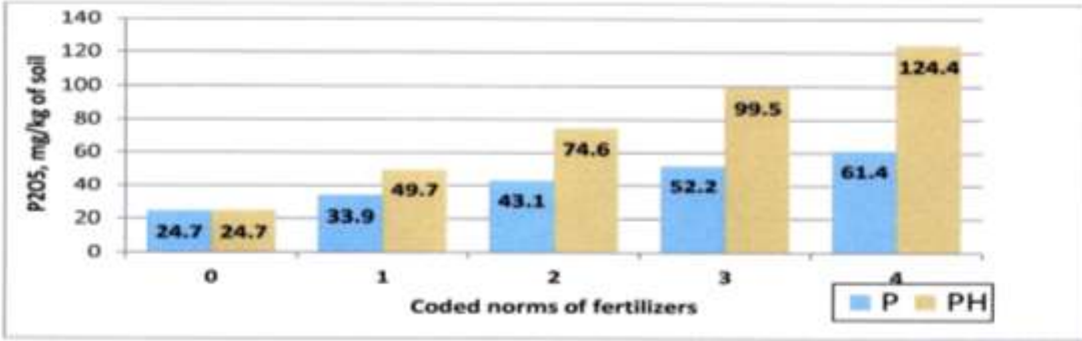

Figure 4. The effect of long-term use of fertilizers on the content of mobile phosphorus in a 0–30 cm layer of irrigated light chestnut soil (1991–2016).

Table 6. Effect of long-term recommended application of fertilizers on the yield and quality of beet crop rotation crops in the fifth rotation.

Variants	Sugar beet		Winter wheat		Corn	Alfalfa
	Yield (t/ha)	Sugar content (%)	Yield (t/ha)	Protein (%)	Yield (t/ha)	Yield (t/ha)
Without fertilizers	15.2	13.1	2.4	12.2	7.0	11.1
NPK	45.9	15.9	4.9	14.0	9.9	15.2
Manure (60 t/ha) + NPK	43.1	15.8	4.8	14.5	10.2	15.8

Individual application of manure leads to a non-significant increase in the mobile phosphorus content in the soil, whereas the joint application of manure and phosphorus fertilizers gave a fivefold surge. Fertilizers positively affect the nutrient regime of the irrigated light chestnut soils and increase the productivity of beet crop rotation crops (Table 6). As noted above, with prolonged crop cultivation without fertilizers, deterioration occurred in the agrochemical indicators of the irrigated light chestnut soil, eventually causing a sharp decrease in the crop yield and its quality. Thus, with fertilizer use, the sugar beet yield increased more than twice compared with the control variant, winter wheat grains (more than three times), corn of medium-ripened hybrids (1.4 times), and alfalfa hay (almost 1.5 times). Similarly, significant improvement in the product quality also manifested – the sugar content of root crops has increased by 2.7%–2.8%, the content of crude protein in wheat grain has increased by 1.8%–2.3%, and by 1.8% in corn grain. Higher yields with good quality resulted with the recommended combined use of mineral and organic fertilizers.

CONCLUSIONS

Overall, previous reports indicated low fertilizer use in agriculture in Kazakhstan. However, the maximum use of mineral fertilizers occurred in 1986, with 1,039 t consumed (in terms of active substances). The fertilized area accounted for 47% of the total arable land area, while in 2020, with 165,500 t, the fertilized area was 13.5%. In Kazakhstan, the annual requirement of mineral fertilizers for the entire sown area is 2.5 million t in physical weight (with 1.2, 1.3, and 0.03 million t of nitrogen, phosphorus, and potassium, respectively). Combined recommended application of mineral and organic fertilizers enhanced the sugar beet yield more than twice compared with the control, winter wheat grain (more than three times), corn hybrids (1.4 times), and alfalfa hay (1.5 times). Likewise, the quality of the resulting crop production has also significantly improved. Regression analysis revealed a close relationship among the fertilizer application levels, agrochemical properties of the soil, and yield and quality.

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