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# Biological Resources to reproduce Arable Soils Fertility in the Old-cultivated Regions of Kazakhstan

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**Abstract.** The article examines the preconditions for the use of local biological resources in farming agriculture of the North Kazakhstan Region. Wild land reclamation in the central and southern regions has resulted in enhanced extensive nature of farming agriculture in the region which is due to the low agronomic standards and difficult soil and climatic conditions. An increased share of soil-depleting crops in the post-Soviet period aggravated both arable soils dehumification and excessive nutrients removal. Using the statistics provided by the Department of Agriculture and Land Relations, statistical analysis method and generally accepted procedures we have determined the annual volumes of bedding manure, poultry droppings and straw. In addition, we have analyzed the reserves of local agronomic ore, i.e. sapropel, which is the most valuable multicomponent organic raw material with long-term effect. It has been established that the volume of generated biological resources to be used as fertilizers exceeds 17 million tons which can potentially replenish the annual removal of 15% of humus, 39% of nitrogen, 53% of phosphorus, and 57% of potassium taken from fields with harvested crops and erosion products.

## 1. Introduction

As a result of the implementation of the Soviet macro-project – the development of wild and fallow lands – Kazakhstan, along with the RSFSR and Ukraine, became the leading producer of food grain in the USSR (a record-breaking harvest of 28.3 million tons was harvested in 1986). However, this was achieved only through the introduction of areas being huge even by Soviet Union standards (18 million hectares) into economic circulation. After the wild land campaign which eventually turned into working by spurts, a northern (wheat) belt of dry-land farming was formed in Kazakhstan with its south border reaching the latitude of Karaganda (more precisely, the southern limits of the Nura district of the Karaganda Region). At present this border has significantly shifted to the north and passes approximately along the 300 mm isohyetal line whereas the belt itself covers most of the Kostanay and Akmola Regions as well as the entire North Kazakhstan Region, excluding the Pavlodar Region in the post-Soviet period (due to active deflationary processes it has become environmentally unstable and economically inappropriate to have farming agriculture in this region). The mainstream of extensive steppe agriculture development emerged from the very beginning and subsequently intensified in the concerned agricultural space. During the period of agricultural land use (1954–2015) in the wild land regions of Kazakhstan, more than 1.2 billion tons (28.3%) out of 4.3 billion tons of humus reserves in the arable layer (0–25 cm) were irrevocably lost with the removal of crops and erosion products (due to organic matter mineralization) [1]. However, it is typical for the North Kazakhstan Region (hereinafter referred to as the “Region”) to have maximum losses of humus and



nutrients in the arable soils: the inter-cluster spaces of its territory began to be agriculturally developed immediately after the establishment of the Novoishimskaya fortification line and the foundation of St. Peter Fortress (1752). The development of farming agriculture in this most old-cultivated region of Kazakhstan has long since been connected with the agro-ecological features of agricultural landscapes: arable land share, exceptional soil complexity (the share of black alkali soils varies from 10% in the northern part of the forest-steppe area to 70% in the southern part of the dry-steppe zone), the ratio of environment stabilizing and destabilizing lands, etc. Spatial heterogeneity of soil fertility and its temporal variability in terms of cultivated crops variability have predetermined a contrast pattern and polarization of the agricultural space productivity of Northern Kazakhstan, the leading natural and agricultural region of the country: the long-term average annual yield capacity of the southern forest-steppe agricultural landscapes is 2.5–3 times higher than the dry steppe analogs.

## 2. Problem Definition

In new state-run farms of the Region the long-term average annual wheat yield (1954–1991) varied within 11 dt/ha (from 11.9 dt/ha in the forest-steppe area to 10.2 dt/ha in the steppe one) in the post-virgin period, which was about 3 times lower than in Ukraine. This was due both to low agronomic standards prevailing at that time, in particular on newly developed lands, and the complexity of soil and climatic conditions and agroecological factors for farming agriculture (“zone of risky farming” still remains a favorite argument of some farmers complaining about agro-climatic risks). The situation was significantly aggravated by crop production diversification policy which was adopted by the Region in the 2010s and led to an increased share of oilseeds: in 2020, 1 million hectares were allocated for rape and crown flax (for comparison: in 2020 rape occupied 1.6 million hectares of cultivated areas throughout Russia). Unfortunately, despite the fact that the governmental subsidies for unreasonably high-priced mineral fertilizers provided to agricultural companies specializing in oilseeds have increased up to 75% since 2020, the maximum number of fertilizers applied does not exceed 65 kg of active agent per ha, which fails to replenish the deficit-free (zero) balance of humus and nutrients even by  $\frac{3}{4}$ . However, the chemical and technogenic intensification prioritized in the Soviet period proved to be unworkable when state-run and collective farms actually had unlimited possibilities to apply mineral fertilizers. So, in 1990, 949 kg of mineral fertilizers were on average applied per 1 ha of arable land in the Kazakh Soviet Socialist Republic (in the Region this indicator exceeded one ton). However, due to the traditional (uniform) fertilization procedure, the average grain yield was less than 11 dt/ha in the Region in the late Soviet period. All the above initiated the search for alternative ways of conservation and increase of arable soils fertility.

In view of the exhaustion of currently pre-existing natural and man-made resources (opportunities) for the reproduction of soil fertility (natural and artificial fertility respectively) which led to arable soils dehumification, agricultural yield decrease, and economic fertility fall of agricultural and arable lands in particular, the only economically acceptable mechanism for the development of the Region’s farming agriculture is its biologization.

## 3. Materials and Methods

Although biologization refers to a lot of definitions most researchers understand it as intensification of biological methods and resources for conservation and increase of arable soils fertility in order to realize fully the productive potential of cultivated crops with due account for the ecological principles of land use. It is the local renewable natural resources that are able to replenish the ever-increasing negative balance of humus and biophilic elements.

In addition to conservation of arable soils fertility (due to biocatalytic transformation of organic matters and activation of in-soil biological processes) the biologization of farming agriculture is also one of the determinants of agroecological deterioration curbing and agrosphere rehabilitation. First of all, this concerns an alternative to the use of mineral fertilizers which have significantly aggravated the soil-ecological problems of agricultural landscapes in the heat of post-virgin chemical and technogenic intensification of farming agriculture. These problems include soil pollution with heavy metals, soil

structure deterioration, activity suppression, and subsequent depletion of useful entomofauna and microorganisms, which have sharply reduced arable soil suppressiveness.

The use of biological methods for conservation of arable soils fertility amid an intensification of the Region's farming agriculture depends on a number of factors which include soil and climatic conditions of specific agricultural landscapes and specialization of agricultural formations in cultivation of a certain line of agricultural crops.

Let's make a reservation right away: the use of organic and organomineral fertilizers neither implies a rejection of traditional mineral fertilizers nor diminishes their importance. On the contrary, it is only possible to have an adaptive intensification of the Region's farming agriculture with a new line of soil-depleting crops when there is an expanded reproduction of fertility which can only be achieved due to synergistic effect of traditional mineral and organic fertilizers compensating doses complementarity. This is confirmed by numerous literature data [2, 3, 4]. However, in our case, it is organic fertilizers that play a decisive role for soil fertility reproduction in the strategy of arable land productivity with due account for the significant volumes of local resources.

The latest studies conducted by local scientists clearly indicate progressive dehumification and biogenic load on the arable soils against an increased share of soil-depleting industrial crops: during the post-virgin period the main forest-steppe soils – meadow chernozems and ordinary chernozems – have lost over 40% of humus reserves [5, 6]. So, in the 1990s, as a result of the crisis developments and decrease in the application of all types of fertilizers down to zero, the negative humus balance for specialized grain crop rotations was 1.58–1.65 t/ha [7].

Due to the ongoing intensification of farming agriculture and prioritization of both most profitable (in the given soil and climatic conditions) and most soil-depleting crops (crown flax is returned to its former field no earlier than in 6 to 8 years), it has become urgent to transfer to the renewable local natural resources which can replenish the ever-increasing critically short balance of humus and biophilic elements, stop a sharp fall in potential and effective fertility of the arable soils in the Region. In 2020 the oilseeds yield turned out to be 22% lower as compared to the previous year for the first time from the beginning of their cultivation in the Region, which had been previously predicted in the published papers [8].

Although the Region has numerous types of renewable biological resources, the previous period was used to accumulate experience in the application of only one type of organic fertilizer, i.e. bedding manure. However, this experience was interrupted in the post-Soviet period due to an unprecedented cattle reduction.

The volumes of organic fertilizers and removal of nutrients together with harvested crops were calculated by cultivated area structure, gross yield of major agricultural crops and livestock inventory with the use of the statistical data provided by the Akimat Department of Agriculture and Land Resources of the North Kazakhstan Region [9]. We used the generally accepted methods and recommendations to account the balance of cattle bedding manure, poultry droppings, straw resources for fertilization, to determine isohumus coefficients (humification ratios) of organic fertilizers and to calculate the average rates of conversion of various types of organic fertilizers into cattle bedding manure [10, 11].

#### **4. Results and Discussion**

It is possible to have an economically balanced development of the Region's farming agriculture only subject to the implementation of the provisions of the Kazakhstan Strategy for Green Economy Transfer where the transition to organic fertilizers makes one of the imperatives for ecological paradigm of farming agriculture and arable soils fertility conservation [12]. The local biological resources which are suitable for use as organic fertilizers, inter alia include straw, bedding manure, poultry droppings, and sapropel.

Straw is the cheapest local biological resource with maximum utilization capacity for the reproduction of arable soils fertility in the presence of soil-depleting farming agriculture. Annually the Region accumulates millions of tons of straw which is partially chopped during

harvesting and remains as mulch on the fields of some farms. However, much larger volume is seized for the needs of animal husbandry (for forage and bedding). An increased share of industrial (oilseed) crops has resulted in higher volumes of crown flax and rape straw which is massively used as fuel by local boiler houses due to its complicated processing for the use as a fertilizer. The calculation of straw balance has shown that grain crops (wheat and barley) straw has the greatest practical value for the use as a fertilizer. Due to some changes in the cultivation technology used for basic and new agricultural crops, farming agriculture intensification and yield capacity, the grain (seeds):straw ratio can vary significantly, therefore we will provide an average ratio: it is 1:1.3 for spring wheat and 1:1.2 for barley. In addition, when making calculations it is important to take into account the chaff which makes ~20% of the straw yield. With one ton of straw the soil receives on average 819 kg of organic matter, 5–14 kg of nitrogen, 1–2.5 kg of phosphorus, 10–17 kg of potassium, 3–12 kg of calcium, 1–3 kg of magnesium as well as sulfur and trace elements. The isohumus coefficient of straw is 0.2–0.25, that of chaff is 0.17. In addition, the organic matter produced enriches the soil with carbon dioxide which is very important for plant growth.

The use of straw as a valuable organic fertilizer is limited by its extremely low rate of in-soil decomposition, which is due to increased nitrogen immobilization in the soil because of wide C:N ratio prevailed in lignin and cellulose straw. To improve both nitrogenous nutrition conditions for plants and accelerated decomposition it is essential to maintain biocatalization, i.e. treatment with humic preparations, which significantly increases soil enzymatic activity and accelerates straw mineralization and humification.

It is worth noting individually the role of by-products (non-marketable crop) in stabilization of humus condition of arable soils; this role is reflected in the empirical studies by Russian scientists [13, 14]. During numerous production experiments conducted in the Region's farms and on the fields of the North-Kazakhstan agricultural experimental station [7] it has been proved that it is poorly efficient to plow down root and crop residues in order to save at least zero humus balance: when you have an average wheat yield (13–15 dt/ha), about 2.5 tons of humus are removed away from 1 ha while during bio-conversion of organic matter maximum 0.8 tons of humus is formed from root and crop residues. Even when straw and chaff were fully ploughed into similar arable soils in the Trans-Ural region, the negative humus balance was 1.2–1.3 t/ha [15].

Despite the mass transition of agricultural formations to expensive industrial crops (crown flax and rape), the Region remains one of the leaders in the country in terms of grain area – about 3 million hectares with a gross harvest of 4.5 million tons by the end of 2020. Spring wheat and barley straw is the most valuable raw material as an organic fertilizer, its humification and mineralization enrich the soil with mobile forms of macro- and microbiogens which are essential for plants.

As mentioned above, bedding manure was the only biological resource which was actively used during the Soviet period of the Region's agricultural development. In the 1990s state-run and collective farms of the Region applied more manure on fields than others in the Kazakh Soviet Socialist Republic – 1300 kg/ha. However, after the collapse of the USSR, due to a fivefold reduction of livestock in agricultural formations, this figure fell down to 3.8 kg/ha by 2004 and 17 kg/ha in 2009 but it increased to 48 kg/ha in 2015 [16].

As of February 01, 2021 there were 415,600 heads of cattle in the Region, including 204,400 cows. The percentage ratio of animals in agricultural formations and households is as follows: the total number of animals is 39:61, the number of cows is 36:64 whereas in the late 1980s the state-run and collective farms had up to 80% of the total number of cattle. Across all the districts the number of cattle is higher only in the agricultural formations of 2 forest-steppe districts than in the households, that is, Kyzylzharsky and Akkaiynsky districts – 56:44 and 54:46, respectively. This fact can be explained by massive government support provided to form a food belt around the regional center, and by the construction of large dairy units. In terms of the number of cattle and cows the private farms have the highest share in Akzharsky (66.7% and 68%) and M. Jumabaev (67.4% and 72%) districts. Such clarifications are extremely important to get an idea of the feasibility of bedding manure application into arable soils given the concentration of livestock in the agricultural formations. The

fertilizing value of manure and the chemical composition of biogens depend on both animal species and feed consumed.

The production experiments conducted by the North-Kazakhstan agricultural experimental station and the Region's farms have shown that 1 ton of bedding manure (which is equal to 50 kg of humus) incorporated into 1 ha of arable land used for grain fallow rotation can provide 0.4 to 0.6 dt of grain units increase to the yield (with due account for after-effect).

Among all biological resources available in the Region, poultry droppings stand out for their maximum value both in terms of its nutrient content and its availability for cultivated crops. Unfortunately, due to the bird flu epidemic in September 2020, the poultry population has decreased by more than half on the Region's poultry farms. The Region's poultry farms annually accumulate about 187,000 tons of poultry droppings. Poultry droppings contain 30 to 80% of organic matter, depending on fraction sizes. Given that over 92% of poultry are kept under industrial conditions in the suburban Kyzylzharsky Region, this makes the given type of fertilizer especially relevant and valuable since this particular region stands out for its maximum share of oilseeds in the arable land structure.

Table 1 shows the calculations for annual production of straw, bedding manure and poultry droppings in the Region's agricultural formations and for potential yield of organic matter and nutrients.

**Table 1.** Biological Resources for Fertilizers in the North Kazakhstan Region (t/year).

Type of fertilizer	Quantity	In recalculation of cattle straw-based manure	The potential release of nutrients			
			Organic substance	Nitrogen	Phosphorus	Potassium
Cattle straw-based manure	2,450,000	2,450,000	490,000	11,025	5,635	12,250
Bird manure	187,000	561,000	112,200	2,805	1,403	3,366
Straw+ chaff	7,130,000	14,260,000	5,846,600	71,300	35,650	85,560
Total	9,767,000	17,271,000	6,448,200	85,130	42,688	101,176

Among the local natural agronomic ores sapropel has the greatest potential for use. Sapropel is commonly regarded as lake (most commonly) bottom silt; in terms of organic matter content, sapropel deposits vary from 30% (organic) to 85% (mineralized), and according to some data, this range is even wider: 15 to 95% [17]. The value of sapropel is determined by 3 complementary components: mineral, organic, and biologically active ones.

Slow-moving forms of nutrients prevail in sapropel. The feasibility is also proved by the fact that being a renewable natural resource sapropel is a unique multi-component organic raw material with enormous bio-energy potential (from 3 to 7). 1 ton of sapropel applied as a fertilizer makes it possible to obtain additional 200–250 kg of grain crop units, mainly grains and industrial crops [18].

The Region's lakes are characterized by intensive processes of agro-genic eutrophication (which gained momentum in the post-virgin period) leading to a significant growth of organomineral masses and gradual water-logging. Thus, sapropel extraction prevents weediness of lakes, contributes to improved geo-ecological situation (normalization of general sanitary and organoleptic water quality indicators) and, in addition to the extraction of valuable agrochemical raw materials, creates favorable conditions for the development of commercial fish farming. The latter fact is of decisive importance because since 2005 all Region's promising fishery reservoirs have been leased on a long-term basis for lake pasture fish breeding – to raise crucian carp, pelyad, pike and carp – and they need regular reclamation.

Nevertheless, the Region's area is characterized by a very poor level of knowledge about lake sapropel reserves despite the studies initiated by some environmental scientists (unfortunately, not by agrarians). Detailed sapropel exploration (category A reserve estimation) has been carried out only for

19 lakes located in the northern (forest-steppe) part of the Region, their sapropel reserves are estimated at 12 million tons; greenfields exploration (category C2 reserve estimation) have also been conducted for two dozen of water reservoirs.

It is sapropel fertilizers (among all types of organic fertilizers used in the Region's farms) that have shown the greatest efficiency in radical improvement of arable soils, their humification and sanitation, with a yield increase up to 40% for vegetable crops [19].

The Region has currently been performing an experimental extraction of sapropel only on the Safonkovo Lake, table 2 shows the content of main macro- and micro-components.

**Table 2.** Content of Sapropel and Rafting Components in the Safonkovo Lake (according to the Data provided by N. P. Beletskaya).

Analysis data	Sapropel, 20 m from the bank, mg/kg	Sapropel, 120 m from the bank, mg/kg	Sapropel, 300 m from the bank, mg/kg	Floating bog, mg/kg
Hydrolyzed nitrogen	125.4	240.1		6,100
Labile phosphorus	21.2	24.8	6.7	1,000
K			5.0	10,000
Gross phosphorus			960	450
Gross potassium			10,500	11,800
Cu	2.84	0.7	73	21.32
Zn	5.23	1.33	65	40.24
Pb	3.04	2.53		90
Cd	0.18	0.17	0.5	0.22
Mn	77.76	10.79	520	117.47
Co	1.32	0,0	11	5.24
Na			4,700	6,800
Ca			7,800	7,800
Fe			28,000	23,000
Se			1.8	0.0004
B			900	400
Zonal distribution,%			54.3	85

One of the main constraints for commercial sapropel extraction is small layer thickness – it is maximum 2 meters whereas in Russia it is up to 18 meters (in the Moscow Region) and 30 to 40 meters in Belarus.

## 5. Conclusion

Thus, we can state that the full use of all biological sources for mineral nutrition of plants can stabilize arable soils fertility, increase the bioenergetic potential of soil humus, compensate the critically short balance of nutrients in the regional agriculture, increase the productivity of field crops, and improve the ecological situation in agrocenoses. Farming agriculture biologization will make it possible to fertilize annually the Region's arable soil with a total of 17.3 million tons of biological substances (in terms of bedding manure), which is equivalent to 863,550 tons of humus, 228,994 tons of nitrogen, phosphorus and potassium, thus allowing to replenish 15% of humus, 39%, 53%, and 57% of these nutrients respectively which are removed with harvested crops and erosion products. In addition, the

main positive difference between organic and mineral fertilizers is the long-lasting effect of the organic ones on yields and product quality – up to 4 years or more.

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