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Agro-ecological assessment of the condition of arable soils of the CCR

A V Surinov*

Belgorod State National Research University, Belgorod, Russian Federation

* E-mail: surinoff.2012@yandex.ru

Abstract. The data sources for the study were the results of a continuous agrochemical (for 3 cycles) and soil erosion survey of soils, as well as official statistical data. The study period was characterized by an increase in the content of organic matter in the soil by 0.35%, alkaline hydrolyzable nitrogen by 20 mg/kg, an increase in pH acidity degree by 0.15 pH units, a reduction in the amount of medium acidic soils by 16.4%. It was found that on poorly eroded soils, the content of organic matter decreases by 0.4%, on medium eroded soils – by 1.7%. Doses of organic fertilizers increased by 3.0%, mineral fertilizers – by 7.8%. The winter wheat yield increased by 13.3%, spring barley – by 20.7, grain maize – by 4.7, sunflower – by 13.6, sugar beet – by 12.6, and soybeans – by 18.4%.

1. Introduction

Belgorod region is traditionally one of the leaders of the agricultural sector in Russia. The richest soils – chernozems, the most important resource of production, contributed to successful farming [1]. Anthropogenic impact on virgin ecosystems provokes the manifestation of factors of soil cover degradation, the preservation of which is the main task for all mankind. The end of the last century had a negative impact on the soil fertility state. The unfavorable economic situation in the country affected many areas of activity, including the agricultural sector. The volume of investments in agriculture has decreased, which has led to such problems as: violation of tillage technologies, stopping liming of acidic soils, reducing the use of organic and mineral fertilizers. As a result, the content of plant nutrients in the soil decreased, the problems of preserving soil organic matter worsened against the background of increased erosion processes and dehumidification [2-6]. Since the beginning of the 2000s, the situation began to change for the better. The economy has stabilized, targeted programs have been approved aimed at preserving and restoring soil fertility of agricultural lands, reducing anthropogenic load on the soil. In parallel, the goal was pursued to increase the return on invested funds. At the same time, an integral part of intensive agriculture is the control of the agro-ecological state of arable soil fertility.

2. Materials and methods of research

The study is based on the results of the last three cycles of a continuous agrochemical soil survey of the Gubkinsky district of the Belgorod region for the period from 2012 to 2021 and the results of a soil erosion survey.

The study area is located in the north of the Belgorod region in the forest-steppe zone. During the growing season, 270-295 mm of precipitation falls on this territory, while the sum of the average daily temperatures is 2450-2600 °C. The average long-term value of the hydrothermal coefficient (HTC) according to Selyaninov corresponds to the range of 1.0-1.2 [1].

The soil cover of arable soils of the Gubkinsky district is mostly represented by subtypes of typical (57.7%) and leached (32.3%) chernozem. The territory with a slope steepness of more than 3° occupies more than 35% of the district area. Eroded soils occupy 42.1% of arable land, of which 7.9% are medium-washed and 3.0% are heavily washed soils [2].

Soil sampling was carried out according to established methods. Laboratory studies were carried out in the testing laboratory of the FSBI Belgorodskiy Agrochemical Service Center in accordance with generally accepted methods: mass fraction of mobile phosphorus and potassium compounds according to the Chirikov method (GOST 26204-91), pH of salt extract according to GOST 26483-85, hydrolytic acidity (Ng) according to Kappen (GOST 26212-91), organic matter according to the Tyurin method (GOST 26213-91), mass fraction of alkaline hydrolyzable nitrogen according to the guidelines for determining alkaline hydrolyzable nitrogen in soil by the Cornfield method, mass fraction of mobile sulfur according to GOST 26490-85, mass fraction of mobile forms of zinc according to GOST R 50686-94, copper and cobalt according to GOST R 50683-94, manganese according to GOST R 50685-94, molybdenum according to GOST R 50689-94, extracted acetate-ammonium buffer solution with a pH of 4.8.

The published statistical data of the Belgorodstat for 2012-2021 are used in the work.

3. Results and Discussion

3.1. Application of fertilizers

In Gubkinsky district for the first 5 years of the study (2012-2016), the dose of organic fertilizers was twice lower than the average dose in the Belgorod region and amounted to 3.3 t/ha. In 2017-2021, the application dose remained almost at the same level - 3.4 t/ha, while the average dose in the region increased by 38.8% and reached 9.3 t/ha. The production volume of organic fertilizers depends on the degree of the livestock industry development. In 2020, 1753.2 thousand tons of livestock and poultry meat were slaughtered in live weight in the Belgorod region, 23.7 thousand tons - in the Gubkinsky district. This is not the highest indicator among other districts of the region, but more than, for example, the entire Kostroma region produces (19.8 thousand tons) [7]. A positive balance of organic matter in arable chernozem soils implies the introduction of at least 6-8 tons of manure per 1 ha of crop rotation area [8]. The dynamics of organic fertilizer application in the study area is shown in Fig. 1.

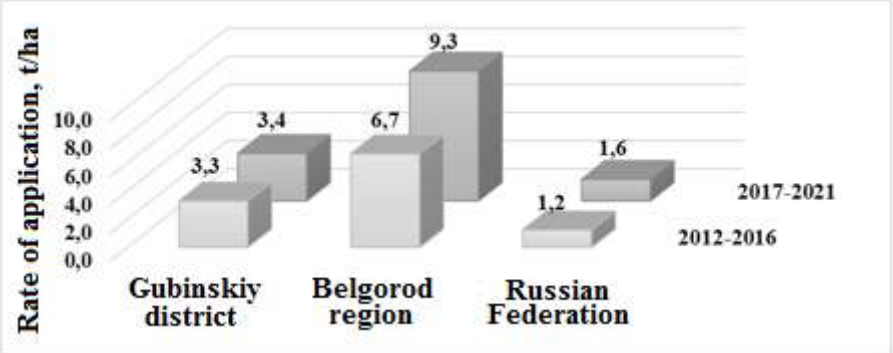


Figure 1. Dynamics of organic fertilizer application, t/ha

Analysis of data on the use of mineral fertilizers shows that the average doses both in the Gubkinsky district and in the Belgorod region as a whole were at the same level. In the study area for 2012-2016, the average dose of application was 98.6 kg /ha of r.a., for 2017-2021 – 106.3 kg /ha, the increase was 7.8%. In the Belgorod region, over the same period, the dose increased by 18.1% and reached the level of 111.6 kg /ha r.a. (Fig. 2).

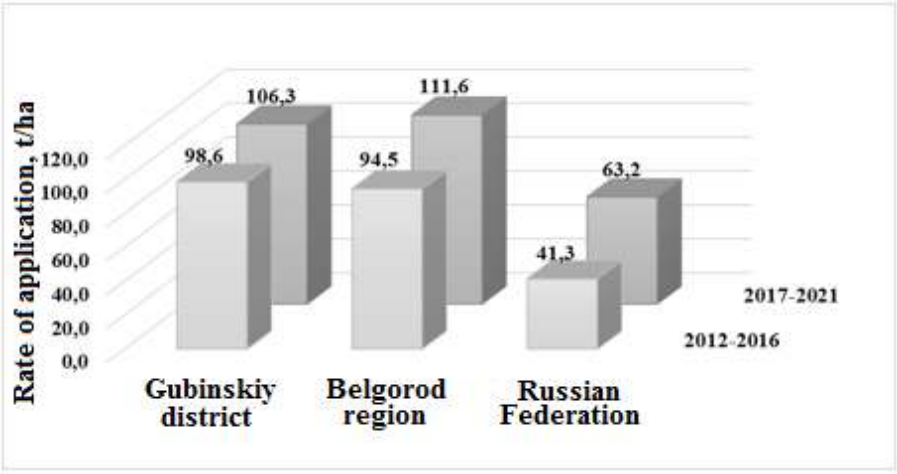
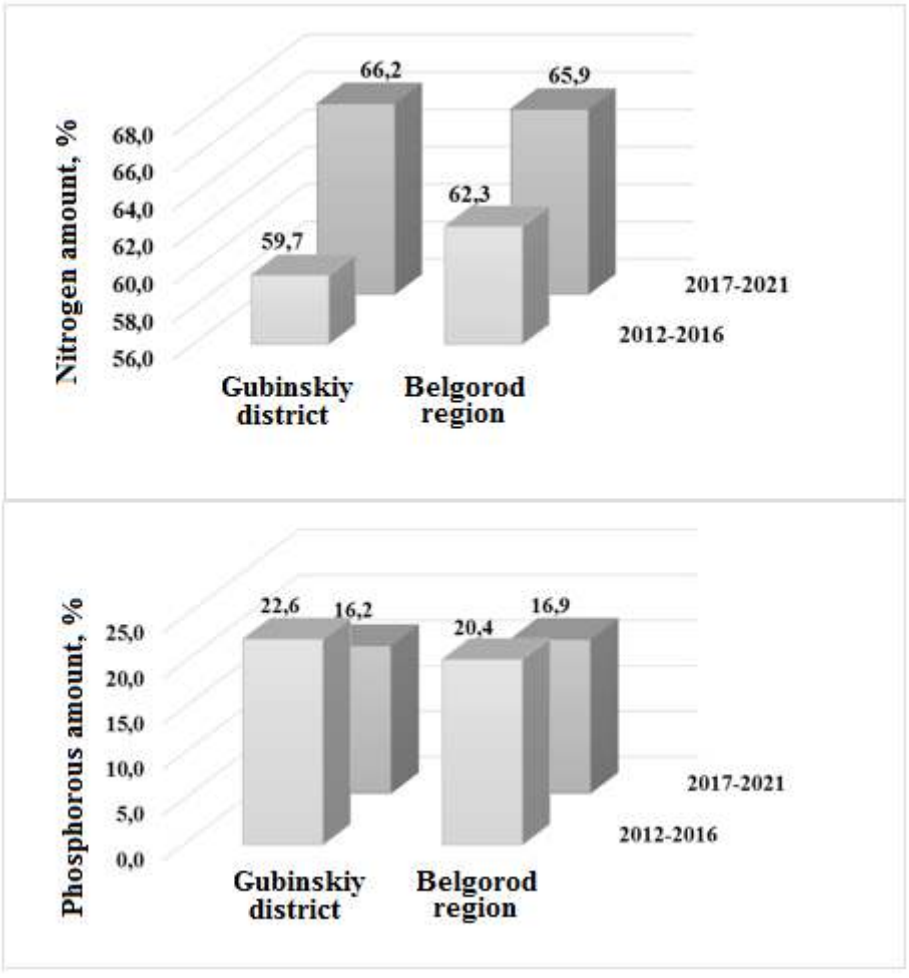


Figure 2. Dynamics of mineral fertilizers application, kg/ha

One of the characteristics of domestic agriculture in recent years is the tendency to increase the proportion of nitrogen in the structure of the use of mineral fertilizers. In Gubkinsky district, the share of nitrogen in 2017-2021 increased by 6.5%, in the Belgorod region - by 3.6%. The share of phosphorus in the Gubkinsky district decreased by 6.4%, in the Belgorod region - by 3.5%. The proportion of potassium decreased both in the Gubkinsky district and in the Belgorod region by 0.1% (Fig.3).



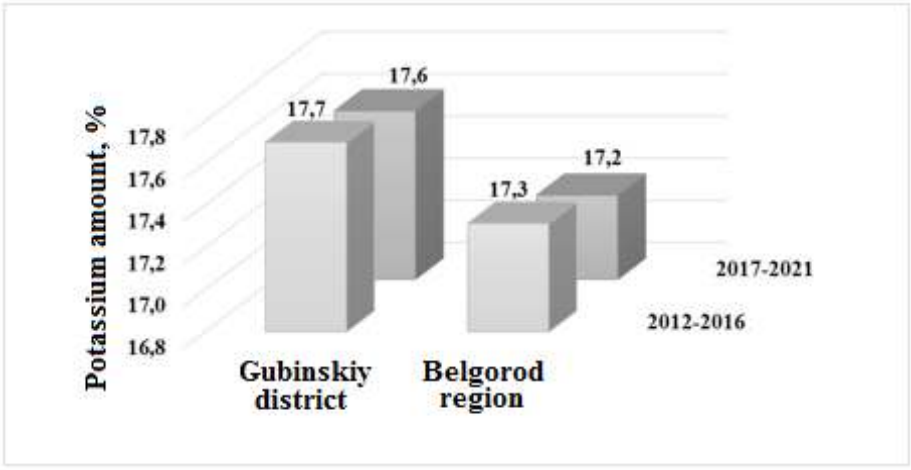


Figure. 3. The share of nutrition elements in the structure of the use of mineral fertilizers, % of the total volume

3.2. Changes in agro-ecological properties of the soil

Based on the data of the agrochemical survey in the Gubkinsky district at the beginning of the study (2012), 59.3% of acidic soils from the total area of the surveyed arable land were recorded, of which strongly and moderately acidic - 25.3%. At the end of the study (2021), the area of acidic soils was 48.9%, of which strongly and moderately acidic - 8.9% (Fig. 4). Over the same period in the Belgorod region, the total area of acidic soils decreased by 16.3%, of which strongly and moderately acidic by 9.5% and amounted to 29.6 and 3.3%, respectively. For 10 years, methods of reclamation of acidic soils in the region were carried out on an area of 609.7 thousand hectares, in the Gubkinsky district - on an area of 23.9 thousand hectares.

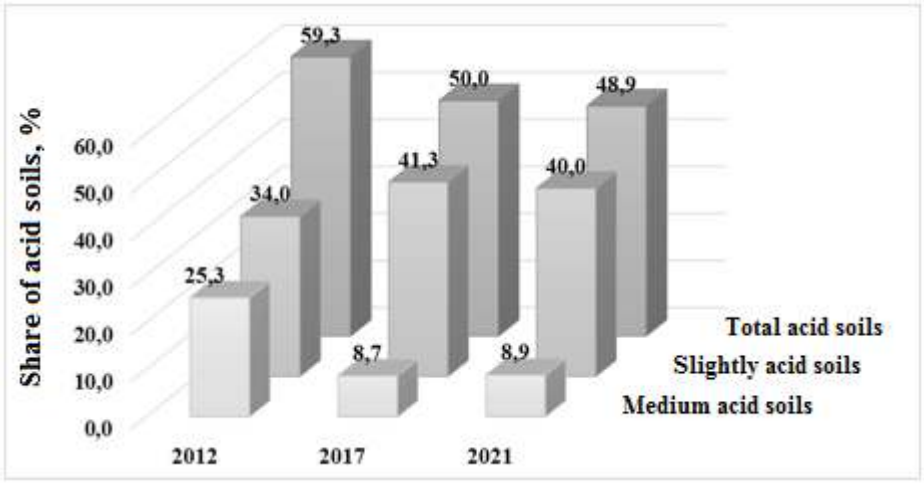


Figure 4. Dynamics of the share of acidic soils, % of the surveyed area

Changes in the indicators of the agrochemical state of arable soils of the Gubkin district are presented in Table 1.

Table 1. Dynamics of agrochemical indicators

Indicator		9 cycle 2012	10 cycle 2017	11 cycle 2021	Deviation of the 11th cycle from the 9th, units
Mass fraction of organic matter, %		5.60	5.96	5.95	0.35
pHKCl, pH unit		5.50	5.63	5.65	0.15
Hydrolytic acidity Ng, mmol/100 g of soil		4.00	3.57	3.57	-0.43
Content of alkaline hydrolyzable nitrogen, mgN/kg		177	185	197	20
Mass fraction, mg/kg	mobile phosphorus	141	124	119	-22
	mobile potassium	153	151	151	-2
	mobile sulfur	2.6	2.8	3.2	0.6
	mobile copper	0.137	0.131	0.142	0.005
	mobile manganese	10.14	11.12	10.90	0.76
	mobile zinc	0.45	0.46	0.51	0.06
	mobile cobalt	0.125	0.112	0.084	-0.041

During the observation period, the content of organic matter in the soil increased by 0.35%, while 48.9% of the surveyed arable land according to this indicator belongs to the group with an average (4-6%) and 48.1% - to the group with an increased (6-8%) content. The content of alkaline hydrolyzable nitrogen increased by 20 mg/kg of soil, while 48.5% of the surveyed arable land belongs to the group with an average (150-200 mg/kg) and 47.7% - to the group with an increased (>200 mg/kg) content. The pHkcl soil acidity index increased by 0.15 pH units, the hydrolytic acidity of Ng decreased by 0.43 mmol/100 g of soil. The content of mobile phosphorus decreased by 22 mg/kg of soil, while 43.5% of the surveyed arable land was located in the group with an average (50-100 mg/kg), 28.9% - in the group with an increased (100-150 mg/kg), 13.1% - in the group with a high (150-200 mg/kg) and 9.0% - in the group with a very high (>200 mg/kg) content. The content of mobile potassium decreased by 2 mg/kg of soil, while 33% of the surveyed soils were located in the group with an increased (80-120 mg/kg), 46.8% - in the group with a high (120-180 mg/kg) and 15.5% - in the group with a very high (>180 mg/kg) content. The dynamics of meso- and microelements in the soil is insignificant. The content of sulfur mobile forms increased by 0.6 mg/kg of soil, copper - by 0.005, manganese – by 0.76, zinc – by 0.06, cobalt decreased by 0.041 mg/kg of soil. Almost 100% of the surveyed arable land was located in the group with a low content of meso- and trace elements in the soil, with the exception of manganese, according to which 44.2% of the surveyed arable land belongs to the group with low (<10 mg/kg), 55.1% - with medium (10-20 mg/kg), and 0.70% - with high (>20 mg/kg) provision. A similar pattern of dynamics of agrochemical indicators is typical for the entire Belgorod region [9].

Agrochemical indicators, as well as soil fertility in general, are directly influenced not only by the anthropogenic factor, but also by the natural one, namely the terrain [10]. Studies have proved the effect of terrain on soil fertility, the intensity of water erosion [11]. The upper and lower sections of the slope can affect not only fertility indicators, crop yields, but also the effectiveness of fertilizers used [12].

The main indicator of soil fertility is organic matter (humus). In this article, the regularity of organic matter distribution along the soil profile and along the slope length, depending on the erosion degree, is analyzed. Digging points were laid in the study area as part of the soil erosion survey of arable soils. The regularity of the organic matter distribution along the soil profile horizons is shown in Fig. 5.

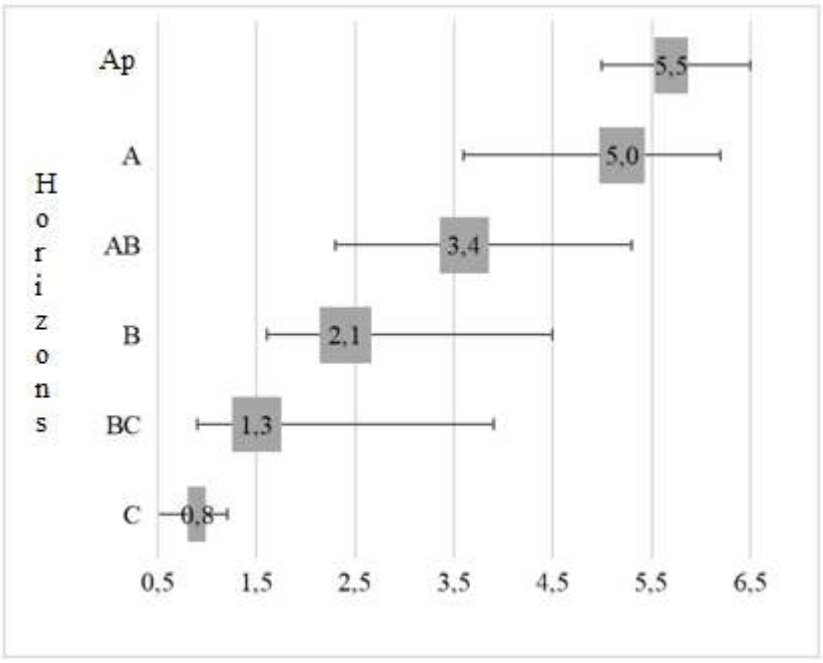


Figure 5. The content of organic matter in the profile of typical chernozem, %

Some scientists consider the content of organic matter in the arable chernozem soils of the CCR to be 5-7% optimal, others – 6-7% [8, 13-14]. The highest content of organic matter in the studied area was noted in the upper horizon of the Ap – 5.5%. With depth, there is a gradual decrease in this parameter to 0.8% in the C horizon. For comparison, an example of the organic matter content in virgin chernozem of a typical site "Yamskaya Steppe" of the Belogorye Reserve of the Gubkinsky district is given (Table 2).

Table 2. The content of organic matter in virgin chernozem typical thick rich

Genetic horizons	Sampling depth, cm	Content, %
A1	10-20	10.1
A2	30-40	5.8
AB	55-65	4.7
B	80-90	3.3
BC	105-115	2.8
C	150-160	1.1

From the data in Fig. 5 and Table. 2, it follows that the content of organic matter in the upper horizon of arable soils in the process of long-term use has almost halved from 10.1 to 5.5%, the same decrease is observed in other horizons. In the monograph of V. V. Dokuchaev "Russian chernozem" indicated that, a little more than a hundred years ago, soils with an organic matter content of >10% were much more common than today [15].

According to Kiryushin V.I., the probability of restoring the organic matter content in arable chernozem soils to the level of virgin indicators is extremely unlikely, the reason for this is the difference in the amount of organic matter entering the soil [6]. Akulov P.G. argues that a sharp decrease in the content of organic matter of the soil due to plowing is not catastrophic [8].

The distribution of the organic matter content along the slope, depending on the erosion degree, is as follows: on non-eroded soils in the Ap horizon – 5.5%, on slightly eroded in the Ap horizon – 5.1% (decrease by 0.4%), on average eroded in the Ap horizon - 3.8% (decrease by 1.7%).

Based on the data obtained, the obvious effect of erosion processes clearly demonstrates its negative impact on the capacity of the fertile horizon and the fertility of the soil. The irreversibility of this process pushes agricultural producers to increase the doses of fertilizers used, mainly mineral.

The gross content of toxic elements such as cadmium, arsenic, mercury, and lead in the arable soil of the Gubkinsky district does not exceed the approximate permissible concentrations (APC) for a long-term period of research [16].

3.3. The yield of the main agricultural crops

The current level of fertility in combination with agrotechnical methods of cultivation of agricultural crops allows farmers to achieve very good yield indicators (Table 3).

Table 3. Dynamics of crop yields, t/ha

Crop name	Gubkinsky district				Belgorod region			
	2012-2016	2017-2021	Deviation		2012-2016	2017-2021	Deviation	
			t/ha	%			t/ha	%
Winter wheat	4.12	4.67	0.55	13.3	4.11	4.89	0.78	19.0
Spring barley	3.05	3.68	0.63	20.7	3.13	3.68	0.55	17.6
Grain maize	6.33	6.63	0.30	4.7	6.05	6.78	0.73	12.1
Sugar beet	45.3	51.0	5.70	12.6	43.2	42.8	-0.40	-0.90
Grain sunflower	2.42	2.75	0.33	13.6	2.38	2.79	0.41	17.2
Soybean	1.58	1.87	0.29	18.4	1.79	2.00	0.21	11.7

At the current level of application of organic fertilizers in the Gubkinsky district, there is a positive dynamics of yield among the main cultivated crops. Thus, during the study period, winter wheat gave an increase of 13.3%, spring barley – 20.7, grain maize – 4.7, sugar beet - 12.6, grain sunflower – 13.6, and soybean – 18.4%.

4. Conclusion

In the course of the study, it was found that on slightly eroded soils, the content of organic matter decreased by 0.4%, and on medium eroded soils – by 1.7% of the content on non-eroded soils. According to the results of a continuous agrochemical survey, a change in the following agrochemical indicators of soil fertility was found: the content of organic matter increased by 0.35%, alkaline hydrolyzable nitrogen – by 20 mg/kg, mobile forms of sulfur – by 0.6 mg/kg, copper – by 0.005, manganese – 0.76 and zinc – by 0.06 mg/kg, the degree of acidity pHkcl increased by 0.15 units, the hydrolytic acidity Ng decreased by 0.43 mmol/100g of soil. Negative dynamics was found in the following indicators: the content of mobile phosphorus by 22, potassium by 2 mg/kg, cobalt – by 0.041 mg/kg. Reclamation techniques managed to reduce the amount of medium acidic soils by 16.4%, the total amount of acidic soils decreased by 10.4%. The dose of organic fertilizers increased by 3.0%, mineral fertilizers – by 7.8%. The yield of winter wheat increased by 13.3%, spring barley – by 20.7, grain maize – by 4.7, sugar beet – by 12.6, grain sunflower – by 13.6, soybean – by 18.4%.

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