# Monitoring of the agrochemical state of agricultural chernozems of the forest-steppe zone of the central chernozem region of Russia

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**Abstract.** The Borisovsky district of the Belgorod region, located in the south-west of the forest-steppe zone of the Central Forest Region, was chosen for the study. The study covered an 11-year period, during which 3 cycles of agrochemical soil survey were conducted in the district - in 2010, 2016 and 2020. Analyzing the use of mineral and organic fertilizers, an increase in crop yield indicators was noted. Thus, an increase in the dose of organic fertilizers (up to 1.96 t/ha) and mineral fertilizers (up to 127.2 kg/ha) made it possible to obtain 5.13 t/ha of winter wheat, 4.19 t/ha of spring barley, 7.9 t/ha of corn for grain and 3.29 t/ha of sunflower seeds. In addition, the content of macro and microelements in the soil has changed. The active fight against soil acidity affected the content of available forms of phosphorus and zinc, the indicators of which decreased slightly.

## 1 Introduction

The food security of any country depends on the soil fertility, as well as the degree of development and implementation of measures to preserve, maintain and increase its fertility. In the Central Chernozem Region (CCR), the main wealth is highly fertile chernozem soils. But human agricultural activity often leads to a deterioration of the soil condition. The low level of application of organic and mineral fertilizers leads to a negative balance of humus and a decrease in the content of mobile forms of nutrients in the soil. Failure to carry out measures for chemical reclamation of acidic soils leads to their even more significant acidification. As a result, the yield decreases and the quality of agricultural crops worsens [1-4].

## 2 Materials and Methods

The research was conducted in the Borisovsky district, located in the west of the Belgorod region. In the soil cover of arable land, typical chernozems occupy 51.8% of the area, leached chernozems - 33.1%. The share of eroded arable land is 26.5%. The average long-term value of the hydrothermal coefficient (HTC) according to Selyaninov is 1.1. The average sown area in 2010-2015 was 35.10 thousand hectares, in 2016-2020 – 35.45.

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The results of the agrochemical soil survey conducted by the FSBI "CAC "Belgorodsky" were used as the studied material. The determination of indicators in soil samples was carried out in accordance with the accepted methodology:

- the mass fraction of mobile forms of phosphorus and potassium was determined by the Chirikov method;
- $pH_{KCl}$ was determined according to GOST 26483-85;
- hydrolytic acidity was determined according to Kappen (GOST 26212-91);
- the mass fraction of organic matter - according to the Tyurin method;
- the mass fraction of alkaline hydrolyzed nitrogen - according to the Kornfield method;
- the mass fraction of mobile sulfur was determined according to GOST 26490-85;
- the mass fractions of copper, manganese, zinc, molybdenum, cobalt were determined according to the method of Krupsky and Alexandrova, an acetate-ammonium buffer solution with a pH of 4.8 was used for extraction.

Also, the official information of the Belgorodstat on the application of fertilizers, crop yields and their sown areas was used in the work.

## 3 Results and Discussion

The most important condition for increasing crop yields and increasing soil fertility is the use of fertilizers. Borisovsky district has low indicators of animal husbandry development in comparison with other districts of the Belgorod region, which affects the volumes of organic fertilizers applied. Nevertheless, using effectively the available resources for the use of organic and mineral fertilizers, the district has achieved an increase in soil fertility and crop yield. For the period from 2010 to 2015, an average of 0.75 was introduced, and from 2016 to 2020 – 1.96 t/ha of organic matter. Over the same periods in the Russian Federation, the volume of organic use increased from 1.15 to 1.52 t/ha, and in the Belgorod region - from 5.28 to 8.85 t/ha, respectively (Fig. 1). It is scientifically proven that it is necessary to adhere to the dose of organic fertilizers from 6 to 8 t/ha of the crop rotation area to stabilize the content of organic matter in arable chernozems used for grain-tillage crop rotations [3].

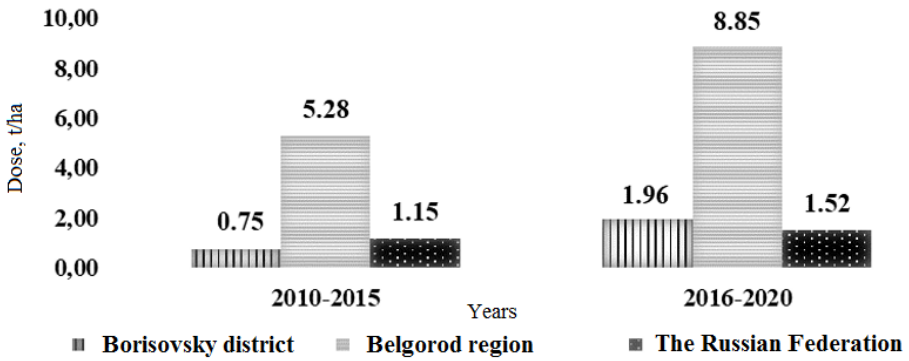


**Fig. 1.** Dynamics of organic fertilizer application, t/ha.

The average dose of mineral fertilizers in the study area is higher than in the Belgorod region. During the periods similar to the periods of applying organic fertilizers, the dose of mineral fertilizers in the Borisovsky district increased by 14.3%, in the Belgorod region - by 12.1%, in the Russian Federation - by 48.2% (Fig. 2). Recently, there has been a tendency in domestic agriculture to increase the share of nitrogen in the structure of the use of mineral

fertilizers. The Borisovsky district and the Belgorod region as a whole are not exceptions. Thus, in 2010-2015, the share of nitrogen in the Borisovsky district was 60.6%, phosphorus - 19.7%, potassium - 19.7%. In 2016-2020, the ratio of elements changed and amounted to: nitrogen - 71.2%, phosphorus - 14.6% and potassium - 14.2%. In the Belgorod region for the same periods, the trend is also traced and is as follows: nitrogen - 60.4%, phosphorus - 20.8%, potassium - 18.8% for 2010-2015 and 66.4%, 17.4%, 16.2% for 2016-2020, respectively (Fig. 3).

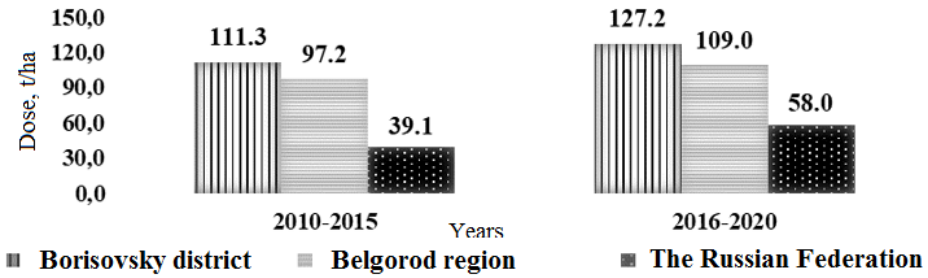


**Fig. 2.** Dynamics of application of mineral fertilizers.

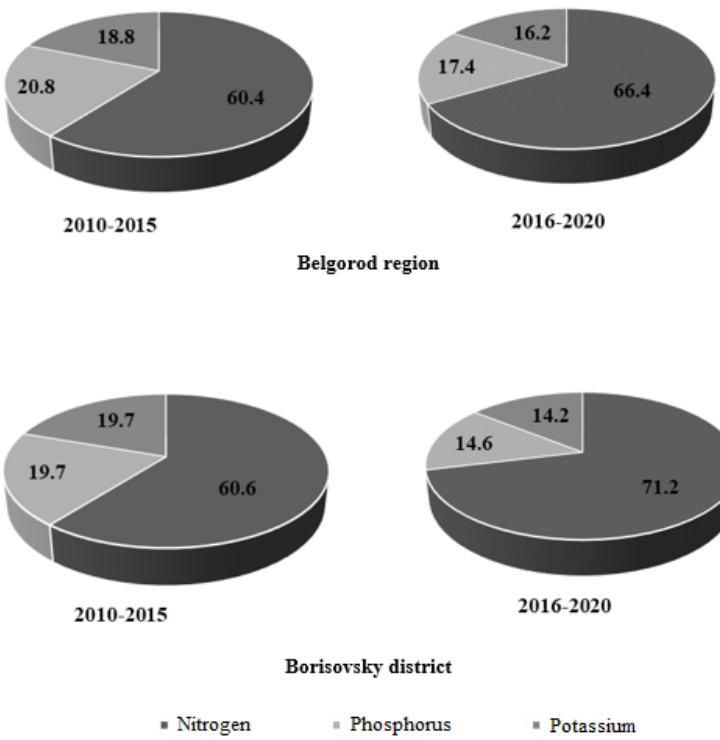


**Fig. 3.** The share of fertilizer elements in the structure of the use of mineral fertilizers.

The organic matter of the soil contains a lot of nutrients necessary for plants, so it is important to maintain it at a high level. In addition, organic matter determines the water-physical properties of the soil. The content of organic matter in a layer of 10-20 cm of typical chernozem, not affected by agricultural activity, is 10.1%. A significant increase in the use

of organic fertilizers together with postharvest residues contributed to the accumulation of organic matter in the soils of the Borisovsky district by 0.33% from 2010 to 2020. The main increase occurred in the group with an average (4-6%) content of organic matter. According to the results of the 2020 survey, the group with an average content includes 71.33%, with an increased content – 0.25% of the surveyed soils, and the weighted average content of organic matter was 4.53%. The accumulation of organic matter in the soil was followed by an increase in the weighted average content of alkaline hydrolyzable nitrogen by 4% to 155 mg/kg (Table 1).

Macronutrients - phosphorus and potassium - are also important indicators of soil fertility [5, 6, 7]. Virgin analogues of arable chernozems of the Belgorod region contain 24-28 mg/kg of mobile forms of phosphorus and 101-105 mg/kg of mobile forms of potassium in the upper part of the humus-accumulative horizon [4]. The old-arable chernozems of the Central Chernozem District in the middle of the last century were characterized by a rather low supply of mobile phosphorus [4]. In the process of increasing the volume of fertilizer use, which took place at the end of the last century, the content of mobile forms of phosphorus in arable soils of the CCR increased, but at the beginning of this century there was a tendency to decrease this parameter associated with a reduction in the use of fertilizers [6, 8]. In the Borisovsky district, from 2010 to 2020, there is a decrease in the content of mobile forms of phosphorus in arable land, which is caused by chemical reclamation of arable soils, as a result of which the mobility of phosphates decreases. From 2010 to 2020, the decrease was 20 mg/kg. According to the 11 cycle of agrochemical survey, 42.2% phosphorus belongs to the group of middle-class - (51-100 mg/kg) of soil, 36.48% - increased-class (101-150 mg/kg), 10.62% – higher-class (151-200 mg/kg) and a group with a very high coverage (more than 200 mg/kg) is 8.39% of the surveyed soils.

**Table 1.** Dynamics of agrochemical indicators of the soil.

| **Indicator** | | **Survey cycles and years** | | |
|---|---|---|---|---|
| | | **9/2010** | **10/2016** | **11/2020** |
| Mass fraction of organic matter, % | | 4.20 | 4.32 | 4.53 |
| pHKCl, pH unit | | 5.20 | 5.39 | 5.60 |
| Hydrolytic acidity, mmol/100 g of soil | | 4.51 | 4.02 | 3.10 |
| Share of acidic soils, % of the surveyed area | total | 83.44 | 73.05 | 43.01 |
| | including medium and strong acidic | 40.62 | 18.90 | 3.81 |
| Mass fraction, mg/kg | alkaline hydrolyzable nitrogen | 149 | 149 | 155 |
| | mobile phosphorus | 139 | 133 | 119 |
| | mobile potassium | 170 | 173 | 170 |
| | mobile sulfur | 2.9 | 3.0 | 4.2 |
| | mobile copper | 0.085 | 0.090 | 0.105 |
| | mobile manganese | 9.06 | 15.08 | 12.25 |
| | mobile zinc | 0.77 | 0.72 | 0.58 |
| | mobile cobalt | 0.080 | 0.074 | 0.076 |

As for potassium, it is worth noting that chernozems have significant reserves of its gross content, and in virgin soils, the background content of mobile forms of potassium is usually always higher than phosphorus. Organic fertilizers are also one of the sources of potassium replenishment in the soil. If to compare it with phosphorus, the potassium content does not change throughout the entire period of our study. According to the data of the 11th cycle of the agrochemical survey, 18.66% of the surveyed arable land is located in the group with an increased content (81-120 mg/kg), 42.75% - with a high content (121-180 mg/kg), 37.56% – in the group with a very high (more than 180 mg/kg) provision.

In the district, much attention is paid to liming of acidic soils. Thanks to this method, the farms of the district managed to recover some of the calcium lost due to its migration to the sub-arable layers. If in the 9th cycle of the agrochemical survey the share of acidic soils was 83.4% (including medium-acidic - 39.28%, strongly acidic - 1.34%), then in the 11th cycle the share of acidic soils decreased to 43.01% (including medium-acidic - up to 3.81%). Over the same years, the value of the weighted average pHKCl increased from 5.2 to 5.6, and the value of hydrolytic acidity decreased from 4.51 to 3.10 mmol/100 g of soil. From 2014 to 2020, 44.6 thousand hectares of acidic soils were cultivated in the district, 145.7 thousand tons of meliorant were introduced.

The size and quality of the crop are largely determined by the balanced microelement nutrition of plants. Trace elements activate enzymes, take an important part in the physiological processes occurring in plants [8-12]. The low content of mobile forms of trace elements is characteristic not only for chernozems of the forest-steppe zone of the CCR, but even for virgin chernozems.

During the time period between the 9th and 11th cycles of the agrochemical survey, an increase in the weighted average content of mobile forms of manganese (by 3.19 mg/kg), copper (by 0.02 mg/kg), sulfur (by 1.3 mg/kg) was noted. The content of mobile forms of cobalt and zinc decreased. The main source of trace elements in the soil is organic fertilizers. According to the data of the 11th cycle of the agrochemical survey, 99.34%, cobalt (less than 0.15 mg/kg) – 98.10%, copper (less than 0.2 mg/kg) – 97.80% of arable soils belong to the category of low-provided mobile forms of zinc (less than 2 mg/kg). The proportion of soils with low provision of mobile forms of manganese (less than 10 mg/kg) was 34.15%, and sulfur (less than 6 mg/kg) – 81.85%. On such soils, it is recommended to use sulfur fertilizers and fertilizers containing trace elements. There has never been an excess of the approximate permissible concentrations (APC) of the gross content of such toxic elements as arsenic, cadmium, lead and mercury in arable soils of the Belgorod region [13, 14].

During the study period, the growth in the volume of organic and mineral fertilizers applied in the Borisovsky district, along with high agricultural technology, led to a significant increase in the yield of winter wheat by 28.9, barley – by 42.5, corn for grain – by 31.4, sunflower – by 33.2, soy – by 27.5%. (Table 2).

**Table 2.** Dynamics of crop yield in the Borisovsky district, t/ha.

| Crop | Years | | Deviation 2016-2020 to 2010-2015 |
|---|---|---|---|
| | 2010-2015 | 2016-2020 | |
| Winter wheat | 3.98 | 5.13 | 1.15 |
| Spring barley | 2.94 | 4.19 | 1.25 |
| Corn for grain | 6.01 | 7.9 | 1.89 |
| Sunflower | 2.47 | 3.29 | 0.82 |
| Soybean | 1.82 | 2.32 | 0.5 |

## 4 Conclusions

In the conditions of the Borisovsky district, many agricultural crops responded well to the increase in the doses of organic (from 0.75 to 1.96 t/ha) and mineral (from 111.27 to 127.22 mg/kg) fertilizers used. Thus, the harvest of winter wheat increased from 3.98 to 5.13, spring barley - from 2.94 to 4.19, corn for grain - from 6.01 to 7.90, soybean - from 1.82 to 2.32 and sunflower - from 2.47 to 3.29 t/ha. Along with the increase in yield, the weighted average content of various plant nutrients increased, such as mobile forms of sulfur - from 2.9 to 4.2, copper - from 0.085 to 0.105, manganese – from 9.06 to 12.25 mg/kg of soil. The content of organic matter in the soil also increased from 4.20 to 4.53%, as well as alkaline hydrolyzable nitrogen from 149 to 155 mg/kg of soil. The potassium content was not changed and

amounted to 170 mg/kg of soil. The active growth of activities related to liming of acidic soils affected the content of available forms of phosphorus and zinc in the soil, as a result of which their decrease was noted from 139 to 119 and from 0.77 to 0.58 mg/kg, respectively. At the same time, the share of acidic soils significantly decreased from 83.40 to 43.01 % of the total sown area of the district. During the period from 2014 to 2020, 44.6 thousand hectares of acidic soils were cultivated, 145.7 thousand tons of meliorant were introduced.

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