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# Fertility dynamics of the forest-steppe zone's arable soils in the central chernozem region (on the example of the Prokhorovsky district of the Belgorod region)

A V Surinov <sup>1,2,\*</sup>

<sup>1</sup> Belgorod State National Research University, Belgorod, Russian Federation

<sup>2</sup> Center of Agrochemical Service "Belgorodsky", Belgorod, Russian Federation

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

**Abstract.** The work is based on the results of a continuous arable soils' agrochemical survey of the Prokhorovsky district of the Belgorod region conducted by the center of the agrochemical service "Belgorod" from 2012 to 2020. During this time, 3 research cycles were performed. The study period was divided into 2 parts: from 2012 to 2016 and from 2017 to 2020. In the course of the study, it was found that chemical reclamation techniques allowed to reduce the area of acidic soils by 25.15%, including medium and strongly acidic by 21.84%; the weighted average value of hydrolytic acidity decreased by 0.70 mmol /100 g of soil. The complex of chemical and agrotechnical measures contributed to the accumulation of soil organic matter by 0.52%, alkaline hydrolyzable nitrogen - by 29 mgN/kg, mobile forms of potassium - by 16, sulfur - by 3.2, manganese - by 3.08, copper - by 0.002 mg/kg, as well as an increase in the yield of winter wheat by 27.0%, spring barley - by 26.2%, soy - by 16.8%, grain sunflower - by 14.8%, grain maize - by 6.2%.

## 1. Introduction

The main task of the agricultural sector is the food base development to provide the population with the necessary food and the development of the country's economic sphere. The effective functioning of the agro-industrial complex allows to solve the set tasks in a timely manner. With this, prolonged anthropogenic impact on natural biocenoses leads to the depletion of their natural potential. Against the data background from the International Food Organization on the loss of land resources due to degradation processes (6.7 million hectares annually), the importance of ensuring the soil cover preservation does not require special evidence [1]. In this regard, measures to combat such negative phenomena in agriculture as erosion processes, salinization, soil acidification should be no less effective. All these circumstances affect the quantitative and qualitative indicators of yield [2-4].

## 2. Materials and methods of research

The studied time interval included 3 cycles of arable soils' agrochemical survey of the Prokhorovsky district, the results of which were summarized and analyzed. The area of the surface element in the sampling process was 15-20 hectares, the sampling depth was 0-25 cm, the sampling points were fixed using navigators in the satellite coordinate system. Analyses of soil samples were carried out in an accredited laboratory of the center of agrochemical service "Belgorod" in accordance with generally accepted methods:



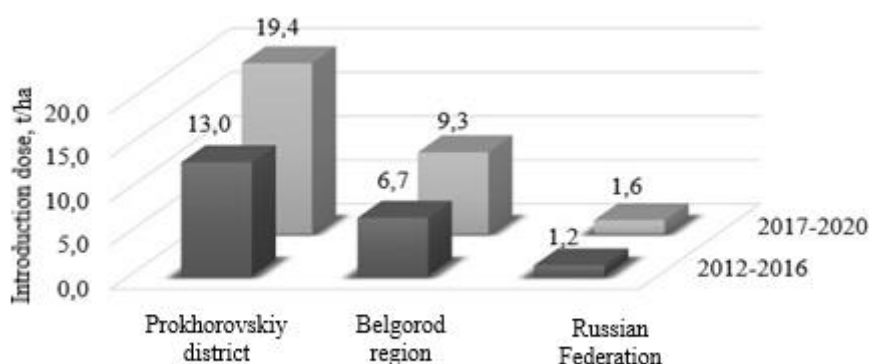
1. Organic matter as per the Tyurin method (GOST 26213-91)
2. Mass fraction of alkaline hydrolyzable nitrogen (IR for determining alkaline hydrolyzable nitrogen in the soil by the Cornfield method)
3. Mass fraction of mobile phosphorus and potassium compounds according to the Chirikov method (GOST 26204-91)
4. pH of salt extract (GOST 26483-85)
5. Hydrolytic acidity (Ng) according to Kappen (GOST 26212-91)
6. Mass fraction of mobile sulfur (GOST 26490-85)
7. Mass fractions of mobile forms of zinc (GOST R 50686-94), copper and cobalt (GOST R 50683-94), manganese (GOST R 50685-94), molybdenum (GOST R 50689-94) extracted by an ammonium acetate buffer solution with 4.8 pH.

The Prokhorovsky district is located in the northwestern part of the forest-steppe zone of the Belgorod region. The average annual value of the hydrothermal coefficient (GTC) according to Selyaninov is in the range of 1.1-1.2. The sum of annual precipitation is 600 mm, the sum of active temperatures is 2650 °C. Typical chernozems are the prevailing subtype of arable soils (56.8%) in the district, the second place is occupied by the subtype of leached chernozems (39.4%) [3]. Only 3 districts in the region have soil bonitet equal to 80; the Prokhorovsky district is among them. Total eroded arable soils in the region - 35.1%, of which slightly washed - 30.0%, medium washed - 3.5%, strongly washed - 1.4% [6]. During research years 2012 to 2020, the sown area varied in the range of 80.3 – 87.1 thousand hectares.

The published statistical data of Belgorodstat for 2012-2020 were used in the work.

### 3. Results and discussion

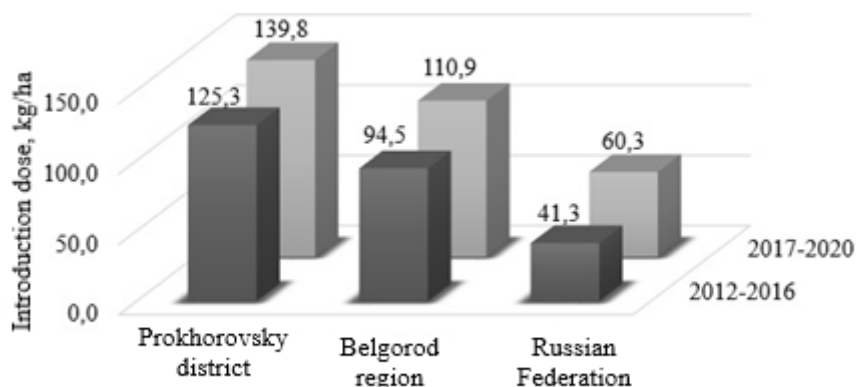
From 2012 to 2016, the dose of organic fertilizers' introduction in the Prokhorovsky district averaged to 13.0 t/ha. Commissioning of new livestock farms contributed to an increase in the organic fertilizers' production and an increase in the dose of their soil application. For the period from 2017 to 2020, the increase amounted to 49.2%; the application dose reached a value of 19.4 t/ha. For a positive balance of organic matter in arable chernozem soils, it is required to introduce at least 6-8 tons of manure per 1 ha of crop rotation area [2]. The doses of fertilizers' application in the Prokhorovsky district, the Belgorod region and the Russian Federation are given below (Figure 1).



**Figure 1.** Dynamics of organic fertilizers' introduction, t/ha

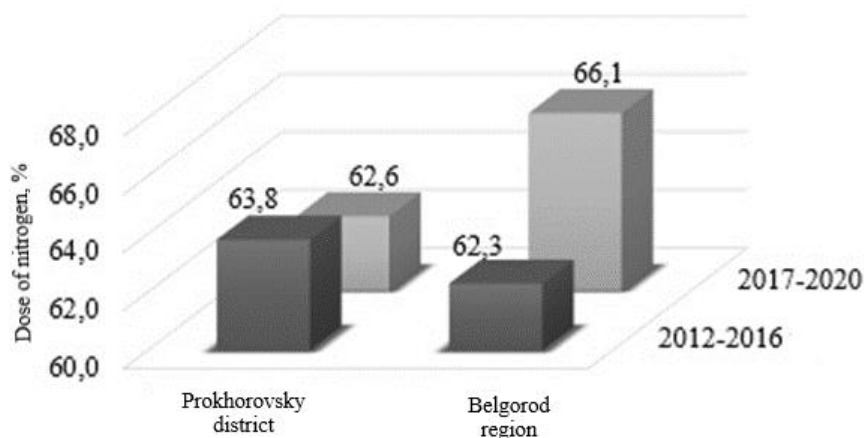
Against the background of the Russian Federation and the Belgorod region, the Prokhorovsky district is a clear leader in the mineral fertilizers' use. For the period 2012-2016, the average dose of application was 125.3 kg/ha a.s., for 2017-2020 - 139.8 kg/ha, which was 11.6% higher. During this time in the

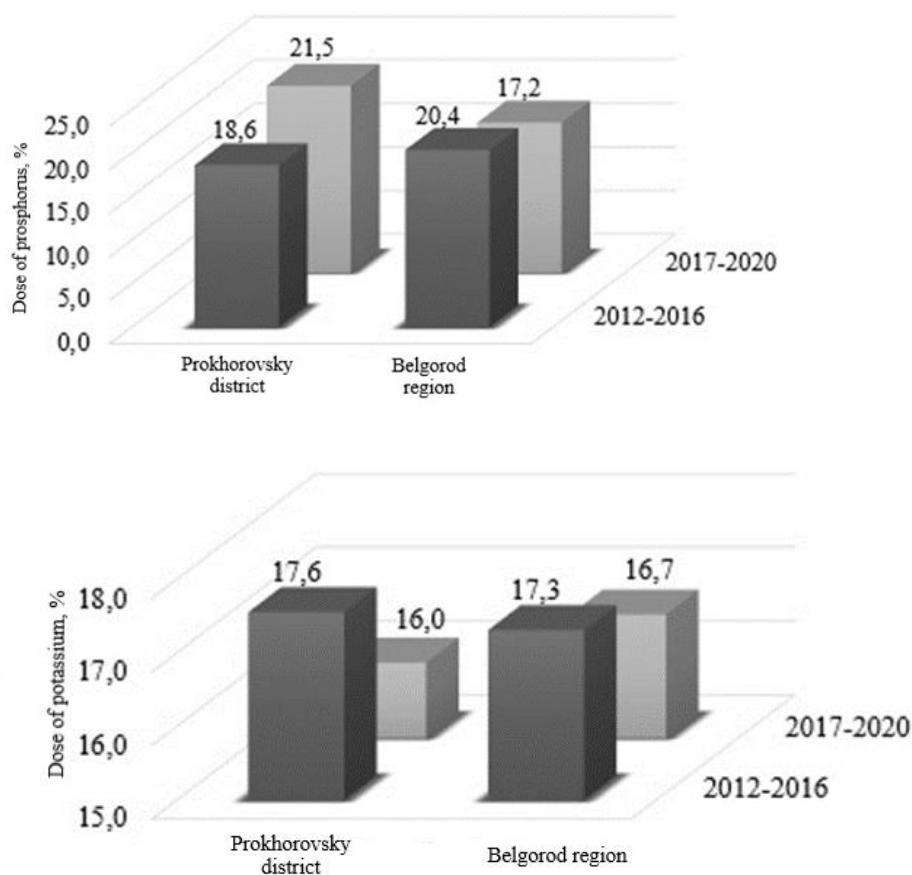
Belgorod region, the dose increased from 94.5 to 110.9 kg/ha (by 17.4%), in the Russian Federation - from 41.3 to 60.3 kg/ha (by 46.0%) (Figure 2).



**Figure 2.** Dynamics of mineral fertilizers' introduction, kg/ha

In recent years, domestic agriculture has tended to increase the nitrogen proportion in the structure of mineral fertilizers' usage. The dominant position of nitrogen over phosphorus and potassium is observed both in the Prokhorovsky district and throughout the entire Belgorod region. In the Prokhorovsky district, this indicator is somewhat contrary to the observed trend. Compared to 2012-2016, the share of nitrogen in 2017-2020 decreased from 63.8 to 62.6%, phosphorus - increased from 18.6 to 21.5%, potassium - decreased from 17.6 to 16.0%. In the Belgorod region, the share of nitrogen increased from 62.3% to 66.1%, the shares of phosphorus and potassium decreased from 20.4 to 17.2% and from 17.3 to 16.7%, respectively (Figure 3).

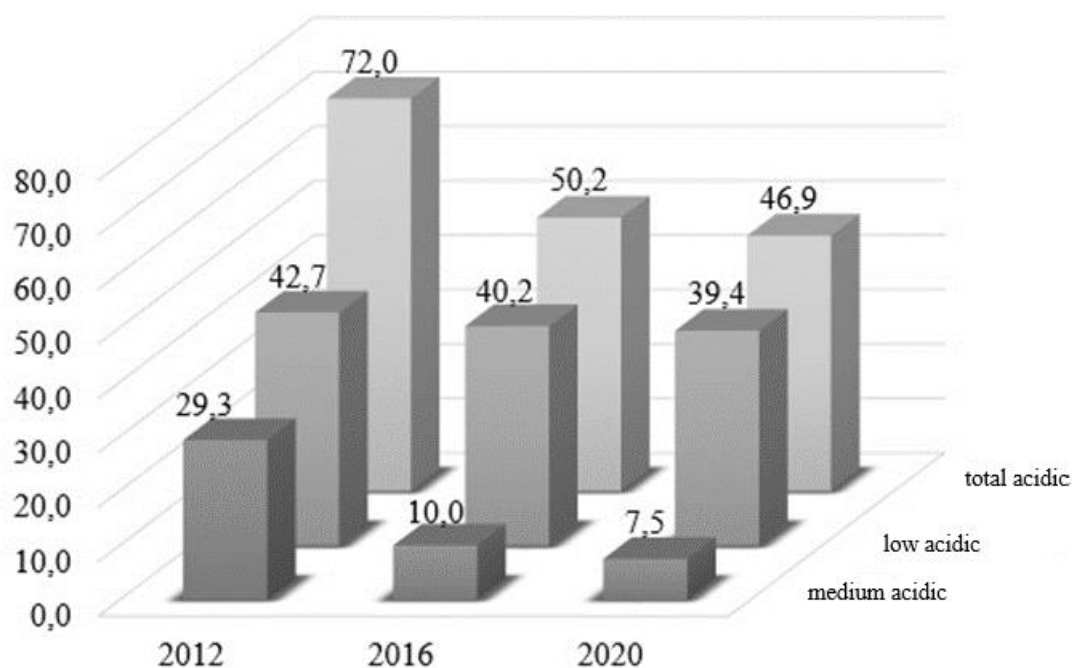




**Figure 3.** The share of nutrition elements in the structure of mineral fertilizers' use, % of the total volume

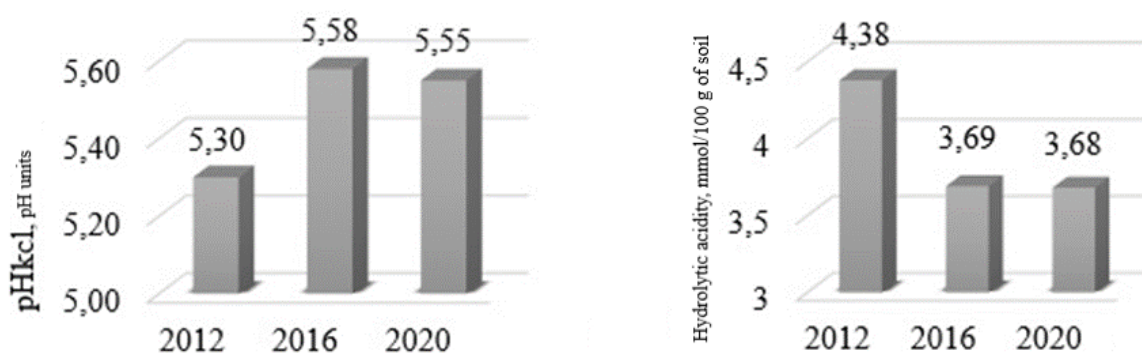
The data of the agrochemical survey indicate that as of 2012 (cycle 9), the Prokhorovsky district ranked first among all districts of the region in terms of medium acid soils amount – 29.3% of the surveyed arable land. In total, the proportion of acidic soils was 72.0% of the surveyed arable land. Increasing the liming rate allowed to influence the degree of acidity of the soil solution. During the period of 2012-2016, 31.2 thousand hectares of acidic soils were limed, from 2017 to 2020 - 15 thousand hectares, 307.4 and 68.9 thousand tons of ameliorant were introduced, respectively. For comparison: in 2010-2011, only one thousand hectares were limed, and 15.6 thousand tons of ameliorant were introduced.

The decrease in liming volumes in 2017-2020 was due to a reduction in the number of acidic soils and a change in the degree of soil acidity towards alkalization.



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

In 2012, the share of acidic soils was 72.0% (of which 29.3% were medium acidic), in 2016 - 50.2% (10.0% were medium acidic), in 2020 – 46.9% (7.5% were medium acidic) of the surveyed area of the district (Figure 4).

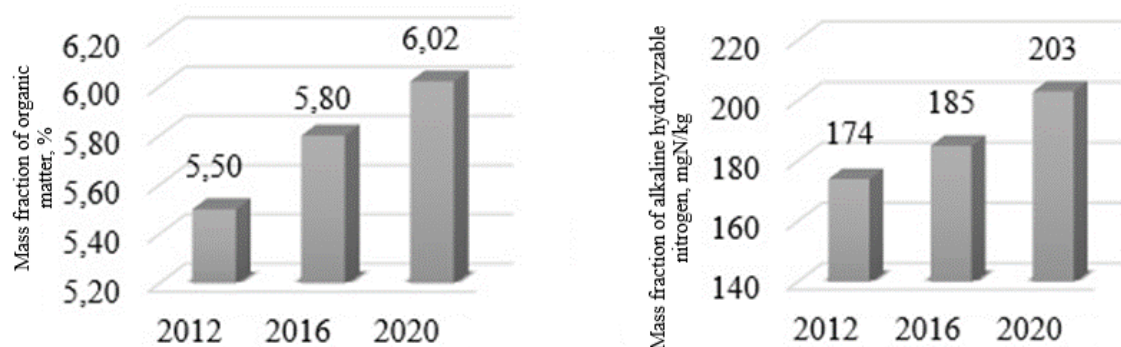


**Figure 5.** Dynamics of the acidity degree (pH<sub>kcl</sub>, unit pH) and hydrolytic acidity (Ng, mmol/100 g of soil)

The weighted average value of pH<sub>kcl</sub> changed from 5.30 to 5.55 units, hydrolytic acidity decreased from 4.38 to 3.68 mmol/100 g of soil (Figure 5).

Organic matter is an indispensable component of the entire universe. An important task of the agricultural industry is to maintain a stable state of the soils' humus reserve against the background of annual losses of the fertile layer. In virgin chernozem, the typical content of organic matter is 10.1% (in 10-20 cm layer) [9]. A complex of agrotechnical techniques and measures including fertilization, green manure crops sowing, etc. positively affected the change in agrochemical indicators of soil fertility; in particular, it contributed to the accumulation of organic matter in arable soils of the Prokhorovsky

district for the study period by 0.52% from 2012 to 2020, the nitrogen content also increased by 29 mgN/kg.

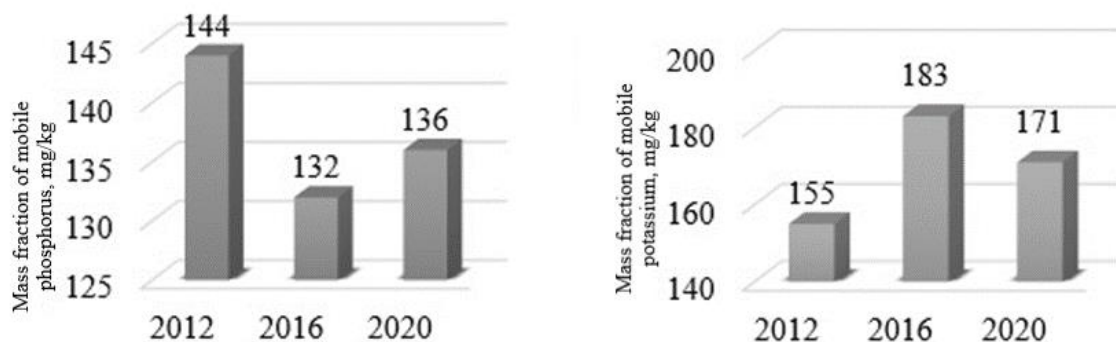


**Figure 6.** Dynamics of organic matter content (%) and alkaline hydrolyzable nitrogen, (mgN/kg)

The main increase in organic matter fell on the group with an increased content. During the study period, the area of soils with low content decreased by 0.6%, with average - by 36.3%, with increased - increased by 36.8% out of the surveyed arable land.

Phosphorus plays one of the fundamental roles in plant nutrition. In the scientific environment, it is customary to compare the cultivation of soils with the availability of mobile phosphorus forms [2, 9]. The middle of the last century was characterized by a low availability of mobile phosphorus forms among the old-arable chernozems of the CChR [2, 9]. The beginning of the current century is characterized by a tendency to reduce the level of fertilizers' use, which eliminated the achievements of the middle of the last century, when there was a tendency to increase volumes [9]. During the study period, 3 cycles of agrochemical examination were conducted in the Prokhorovsky district. During this period of time, there was an increase in the arable land area with low content by 2.9%, with average - by 13.5%, with very high - by 0.7%; there were fewer areas with increased (by 8.5%) and high (by 8.6%) content.

The weighted average content of mobile phosphorus forms decreased in the 10th cycle by 12 mg/kg in relation to the 9th cycle, in the 11th - increased by 4 mg/kg, which is associated with a decrease in the intensity of acidic soils' liming and an increase in phosphorus proportion in the structure of applied mineral fertilizers from 18.6% for the period 2012-2016 to 21.5% for 2017-2020



**Figure 7.** Mobile forms' dynamics of phosphorus and potassium, mg/kg



In the natural state, the upper horizons of chernozem soil types in the Belgorod region are characterized by a significant predominance of mobile potassium forms over phosphorus (101-105 versus 24-28 mg/kg); in typical chernozem, its gross content has a tenfold advantage [9]. Potassium removal with harvest exceeds the removal of phosphorus, sometimes nitrogen. In addition to reducing the productivity of cultivated crops, low potassium content lowers the economic and ecological functions of soils.

During the study period, the distribution of arable land into groups depending on the content of mobile potassium forms was as follows: soils with average potassium content decreased by 0.7%, with increased content - by 3.6%, with high content - by 1.1%, the area of soils with very high content increased by 5.3%. The weighted average content increased by 28 mg/kg in the 10th cycle relative to the 9th, in the 11th it decreased by 12 mg/kg. Among other things, such changes are caused by the proportion of potassium in the structure of mineral fertilizers' use. For the period of 2012-2016 (where the content increased), its share was 17.6%; for 2017-2020, it decreased to 16.0% with recorded decrease in the content of mobile potassium forms.

The optimal plant nutrition regime is a balanced ratio of macro- and microelements. Despite the low content of trace elements in the soil, they perform important functions in plant nutrition, enzymes activation, both the size and quality of the harvest depend on them. Optimal nutrition for plants does not do without sulfur, which is a mesoelement. Agrochemical soil examination confirms the low content of trace elements both on arable land and in soils unaffected by anthropogenic activity in the Central Chernozem region [12-15].

The following changes were revealed during the study period from 2012 to 2020: the weighted average value of mobile forms of sulfur increased by 3.2, manganese - by 3.08, copper - by 0.002 mg/kg, the values of cobalt and zinc decreased by 0.019 and 0.02 mg/kg, respectively.

According to the data of the 11th agrochemical survey cycle, the main part of the arable land fell into the group of low-availability soils in terms of mobile forms content of such elements as zinc (<2 mg/kg) - 94.83% of the surveyed soils, cobalt (<0.15 mg/kg) - 98.35%, copper (<0.2 mg/kg) - 92.67 %, sulfur (<6 mg/kg) - 81.34%. According to the content of manganese and molybdenum, most of the soils were included in the group of medium-rich: manganese (10-20 mg/kg) - 67.00%, molybdenum (0.10-0.22 mg/kg) - 88.54%.

The excess of the approximate permissible concentrations (APC) in the gross content of such toxic elements as arsenic, cadmium, lead, and mercury in arable soils of the Prokhorovsky district has never been detected, therefore all the crop products obtained meet the safety criteria [16-17].

The average yield of agricultural crops in the district is higher than the average for the region. In relation to the period of 2012-2016, the increase in yield in 2017-2020 amounted to: winter wheat - 27.0%, spring barley - 26.2%, grain maize - 6.2%, grain sunflower - 14.8%, soy - 16.8% (Table 1).

**Table 1.** Dynamics of crop yields, t/ha

Crops	Years		Deviation 2017-2020 to 2012-2016	
	2012-2016	2017-2020	t/ha	%
Prokhorovsky district				
Winter wheat	4.37	5.55	1.18	27.0
Spring barley	3.36	4.24	0.88	26.2
Grain maize	7.29	7.74	0.45	6.2
Grain sunflower	2.91	3.34	0.43	14.8
Soy	2.08	2.43	0.35	16.8
Belgorod region				
Winter wheat	4.11	4.99	0.88	21.4
Spring barley	3.13	3.67	0.54	17.3
Grain maize	6.05	7.00	0.95	15.7



Grain sunflower	2.38	2.79	0.41	17.2
Soy	1.79	2.07	0.28	15.6

#### 4. Conclusion

Thanks to reclamation techniques, it was possible to reduce the amount of acidic soils by 25.15%, of which strongly and moderately acidic - by 21.84%, hydrolytic acidity - by 0.70 mmol/100 g of soil, the degree of acidity pH<sub>KCl</sub> increased from 5.30 to 5.55 units. The growing volumes of fertilizers' application contributed to the accumulation of nutrients in the soil and the improvement of agrochemical soil indicators. The content of organic matter increased by 0.52%, alkaline hydrolyzable nitrogen - by 29 mgN/kg, mobile forms of potassium increased by 16, sulfur - by 3.2, manganese - by 3.08, copper - by 0.002 mg/kg. The zinc content decreased by 0.02 mg/kg, cobalt - by 0.019 and phosphorus - by 8 mg/kg. Yield indicators for all major crops gave an increase: winter wheat -27.0%, spring barley - 26.2%, grain maize - 6.2%, grain sunflower - 14.8%, soy - 16.8%.

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