Ecological Assessment of Sulfur Content in Agroecosystems of the Central Black Earth Region of Russia

Ecological Assessment of Sulfur Content in Agroecosystems of the Central Black Earth Region of Russia

S V Lukin[1*] and D V Zhuykov[2]

[1]Belgorod State National Research University, Belgorod, Russian Federation
[2]Agrochemical Service Center «Belgorodsky», Belgorod, Russian Federation

E-mail: serg.lukin2010@yandex.ru, oaem_agrohim_31@mail.ru

Abstract. Studies were carried out on the territory of the steppe and forest-steppe zones of the Central Black Earth Region of the Russian Federation. The objects of research were the soil of nature reserves and arable chernozems that were not touched by agricultural activity, typical and common, the vegetation cover of natural biocenoses and agroecosystems, and organic fertilizers. The studies found that the background content of mobile sulfur in virgin soils is at a low level: 2.31 mg/kg - in a typical chernozem and 1.83 mg/kg - in an ordinary chernozem. According to agrochemical monitoring of arable soils carried out during 2015-2018, an increase in the weighted average content of mobile sulfur by 0.7 mg/kg to 3.3 mg/kg was established, compared to 2005-2009. However, the proportion of soils low on this element remains quite high - 90.3%. The main source of sulfur supply to the soils of agroecosystems (7.52 kg/ha) are organic fertilizers, the doses of which in 2015-2018 increased to 8.1 tons/ha. The average sulfur content in the steppe mixture of herbs of reserves is 0.3-0.4 mg/kg. The highest sulfur content among perennial legumes is clover (0.61%) and alfalfa (0.60%), and among legumes - soybeans, containing 0.34% of the element in grain and 0.21% - in straw.

1. **Introduction**

Sulfur is the most important meso-element because it is a part of three essential amino acids (cysteine, cystine, methionine), enzymes, hormones, and many biologically active substances. In plants, sulfur is involved in such vital processes as respiration, photosynthesis (not a part of chlorophyll), synthesis of proteins and oils, primary assimilation of nitrogen from soil. Optimal sulfur nutrition enhances the development of nodule bacteria in legumes, thereby contributing to atmospheric nitrogen fixation. Sulfur content in plants can reach 1% [1-4].

Plants feed on sulfur mainly in the form of sulfuric acid salt - sulfate of sulfur (SO42-), a considerable part (up to a half of content) can be absorbed by leaves in the form of dioxide from the atmosphere. Reutilization of this element in plants is expressed rather poorly, so the lack of sulfur is usually noticeable on young leaves in the form of green discoloration. The higher the level of nitrogen nutrition, the greater the need for sulfur in plants. Nitrogen and sulfur are involved in the construction of proteins in a certain ratio. For example, in cereals, when the ratio of sulfur to nitrogen is less than 1:16, protein synthesis is reduced, and nitrogen is accumulated in nitrate form. However, for the plants of the cabbage family characterized by high content of this element, its deficiency is indicated by the ratio of sulfur to nitrogen less than 1:6 [1]. Sulfur is concentrated mainly in those plant organs where protein content is higher. Legumes are most sensitive to sulfur deficiency [5]. An excess of sulfur is

more harmful than its deficiency. With an excess of sulfur, which is observed in saline soils, oppression and even death of plants occurs [1].

Sulfur in soils is represented in the form of organic and inorganic compounds, and this ratio depends on the type of soil, the depth of the soil layer. Inorganic sulfur is represented in the soil solution sulfates Ca, K, Mg, Na and is about 20-30% of total sulfur content. The share of organic sulfur (contained in organic matter) can reach 70-80% of the gross content in the humus horizon. For most agricultural plants the optimal content of mobile sulfur in the soil is in the range from 7 to 12 mg/kg [1]. In the Russian Federation about 90% of arable soils have an average content of mobile sulfur less than 6 mg/kg and belong to the category of low provisioned with this element. The main losses of sulfur from soils occur as a result of removal with crops and leaching into the subsoil layers. Increased use of mineral fertilizers that do not contain sulfur and the increased size of its alienation with agricultural products led to a negative balance of this element in the Central, Volga-Vyatka, North Caucasus and West Siberian regions of Russia [6-12]. Therefore, monitoring of the mobile sulfur content in soils is an integral part of the agricultural lands' agrochemical inspection program of comprehensive. Low supply of soils with mobile forms of sulfur is the basis for the decision to use sulfur-containing fertilizers [13-15].

2. **Research Objective**

Ecological assessment of sulfur content in the main components of agricultural ecosystems of the Central Black Earth region on the example of Belgorod region.

3. **Materials and Methods**

The research was conducted throughout 2015-2018. The materials of the total agrochemical survey of arable soils and the local agroecological monitoring carried out at the reference sites were used in this work. The objects of the study were the soils and plants of the forest-steppe and steppe zones of the Belgorod region, which is part of the Central Black Earth region of Russia. In the territory of the Middle Russian forest-steppe province (Prokhorovsky district), 22 soil sections of the prevailing typical heavy-loamy chernozem were plotted; in the territory of the Middle Russian steppe chernozem province (Rovensky district), 22 sections of common light-loamy chernozem were plotted. The average content of physical clay in the arable horizons (0-25 cm) was 56.8% in typical chernozem and 72.5% in common chernozem. The studied soils are moderately humus soils with low and moderately humus content. The average thickness of such horizons as Apakh, A, AB, B_{Ca}, BC_{Ca}, C_{Ca} was 0-25, 26-36, 37-90, 91-111, 112-134, over 135 cm for typical chernozem, and 0-25, 26-43, 44-72, 73-90, 91-124, over 125 cm for common chernozem respectively. The average content of organic matter in the horizons Apakh, A, AB, B_{Ca}, BC_{Ca}, C_{Ca} of typical chernozem was 5.6, 5.0, 3.6, 2.1, 1.3, 1.0%, and that of common chernozem was 5.2, 4.8, 4.1, 2.9, 1.9, 1.6%, respectively.

To determine the background content of sulfur in the soils unaffected by agricultural activities, one transect was laid on the territory of the "Yamskaya steppe" area of the reserve "Belogorye", where the soil cover is represented by typical chernozems and on the territory of the natural park "Rovensky", where common chernozems prevail. Determination of the gross sulfur content in soil and organic fertilizers was carried out by turbidimetric method. Determination of mobile sulfur in soils was carried out by turbidimetric method after extraction with potassium chloride solution with soluble starch as a stabilizer (Russian State Standard GOST 26490-85).

Plant samples of steppe grasses from the territory of nature reserves were taken at the end of May. In agro-ecosystems, the samples of plant products were taken before harvesting from the territory of reference areas. The content of sulfur in crop products was determined by turbidimetric method using gelatin as a slurry stabilizer.

4. **Results and Discussion**

The main sources of sulfur in the agro-ecosystems of Belgorod region are organic fertilizers and emissions from industrial enterprises. The sulfur content in organic fertilizers varies greatly depending on the type of animals, feeding ration, amount of litter, and housing technology (Table 1). Technological methods of removal and storage of organic fertilizers have a significant impact on this parameter. To apply a dose of 100 kg/ha of nitrogen in the soil will require different amounts of organic fertilizers: manure runoff 47.6 t, cattle manure (cattle) - 13.2 t, straw manure compost - 3.3 t. Sulfur intake into the agro-ecosystem with these amounts of organic fertilizers was 11.4, 11.3 and 11.7 kg/ha, respectively. During 2015-2018, an average of 8.1 t/ha of organic fertilizers (in terms of cattle manure), 99.6 kg active substance/ha of mineral fertilizers and 0.49 t/ha of lime ameliorants (mainly defecate) were applied in the region. Ammonium sulfate (184 t) and sulfoammophos (158 t), with which about 42 g/ha of sulfur entered the soil were applied from sulfur-containing fertilizers. In total with the specified quantity of agrochemicals sulfur was applied 7.52 kg/ha. Sulfur intake with enterprise emissions for the same period is estimated at 3.75 kg/ha.

Table 1. Variation-statistics of sulfur content in organic fertilizers, mg/kg

Type of organic fertilizer	n	$\bar{x} \pm t_{05} s_{\bar{x}}$	lim	V, %
Straw compost (34% moisture content)	34	3535±440	1479-7071	35.7
Cattle manure (75% moisture content)	24	853±141	382-1622	38.8
Manure effluent (97.78% moisture content)	74	240±18.7	115-565	37.9
Defecate (13% moisture content)	10	1151±188	757-1664	22.8

The background gross sulfur content in the layer 10-20 cm of the humus-accumulative layer (A) of the typical chernozem plot "Yamskaya steppe" in the "Belogorye" reserve was 885 mg/kg, and in the layer 15-25 cm of the virgin common chernozem of the Rovensky nature park was 501 mg/kg. In the parent rock (C_{Ca} layer) of typical chernozem the total content of sulfur was 154, and that of common chernozem - 456 mg/kg. The content of mobile sulfur in the soils not involved in agricultural turnover is at a low level (less than 6.0 mg/kg). The upper layer of typical and common chernozem contained 2.31 and 1.83 mg/kg of mobile sulfur, respectively.

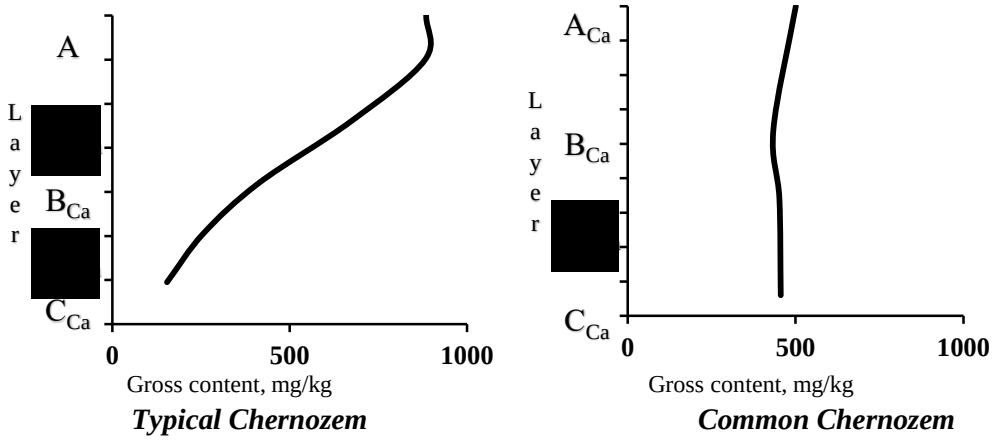
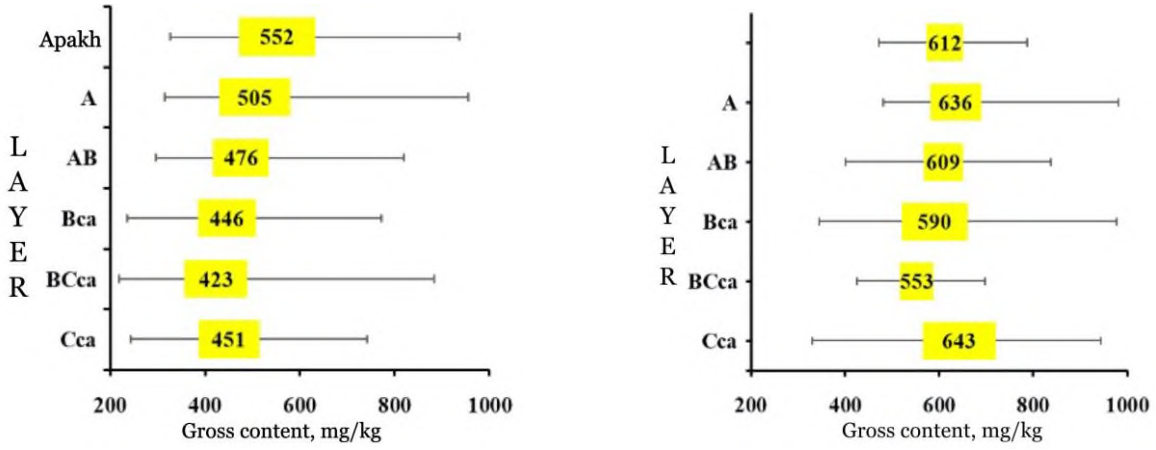


Figure 1. Gross sulfur content in the soils of natural ecosystems, mg/kg

The gross sulfur content in the arable typical chernozem was lower than in the common chernozem, and not only in the arable horizon (Apakh), but also in the parent rock (C_{Ca}). In typical chernozem, there was a tendency to decrease the total content of sulfur with depth, while in common chernozem, on the contrary, the average content of the element in the C_{Ca} layer tended to increase as compared with Apakh horizon (Fig. 2, Fig. 3).

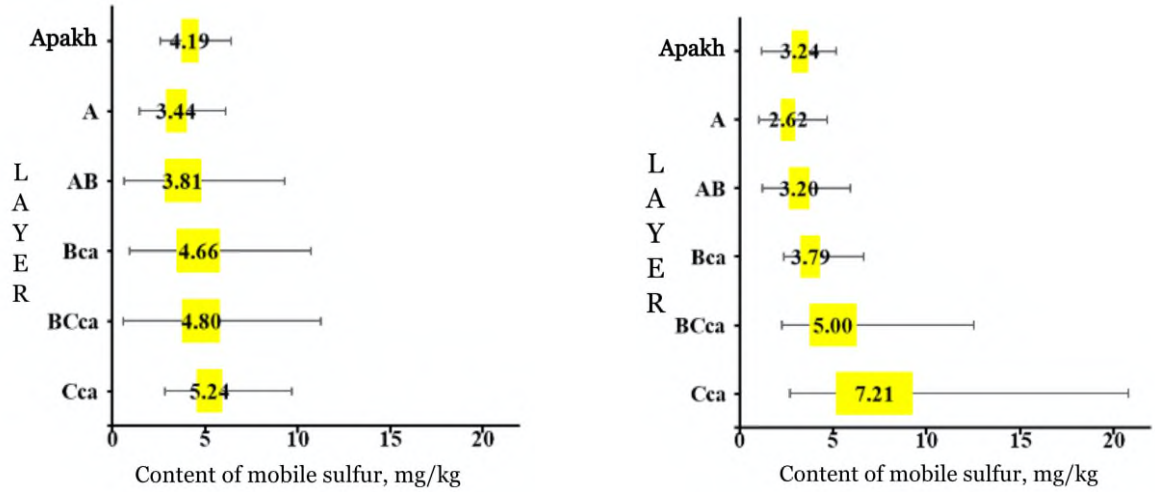
The average content of mobile forms of sulfur in the Apakh horizon of typical chernozem was 2.6 mg/kg, which is 2.2 times higher than in common chernozem, nevertheless, the content of this element

in these soils is characterized as low. The highest content of mobile sulfur was recorded in C_{Ca} layer of typical (5.24 mg/kg) and common (7.21 mg/kg) Chernozem.



Typical Chernozem ***Common Chernozem***

Figure 2. Gross sulfur content in the soils of agroecosystems, mg/kg



Typical Chernozem ***Common Chernozem***

Figure 3. Content of mobile forms of sulfur in the soils of agroecosystems, mg/kg

As a result of a comprehensive agrochemical survey of arable soils in 1990-1994, maximum weighted average content of this element in the soils of the region is 6.8 mg / kg, and the category of low-provision was 48.2% of arable soils. In the period from 1990 to 2009 there was a decrease of this indicator to a minimum - 2.6 mg/kg. Then there was a steady upward trend in the content of mobile sulfur in soils, which is associated with an increase in the volume of organic fertilizers used in the region (Fig. 4). According to the soil fertility monitoring results in 2015-2018, the weighted average content of mobile sulfur compounds increased by 0.7 mg/kg to 3.3 mg/kg. The share of soils classified as low-supplied with this element was at the level of 90.3%. When cultivating on such soils most demanding to sulfur nutrition crops, it is recommended to use sulfur-containing fertilizers.

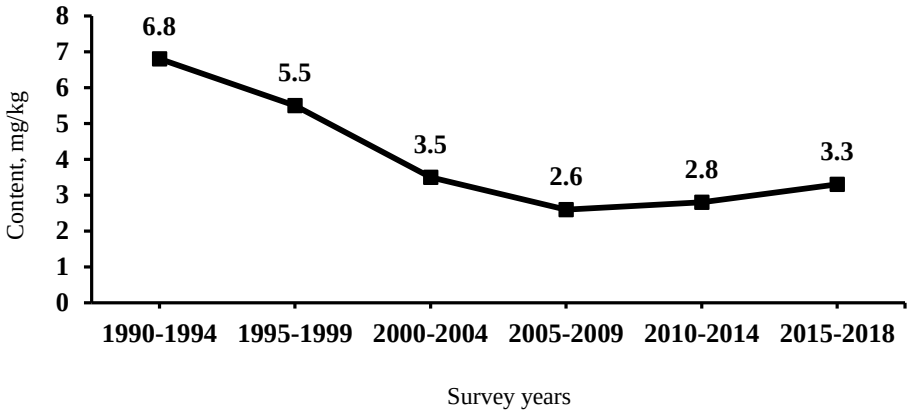


Figure 4. Dynamics of the weighted average content of mobile forms of sulfur in arable soils of Belgorod region, mg/kg

The background average sulfur content in the steppe grasses of the "Belogorye" reserve was 0.3, and in the natural park "Rovensky" - 0.4%. The highest content of sulfur was observed in hay of clover and alfalfa (0.61 and 0.60%, respectively), and the concentration of this element in sainfoin hay was significantly lower (0.47%). In terms of this element content in grain, the studied crops can be arranged in a decreasing series: soybean > white lupine > pea > winter wheat. In soybean, white lupine, and winter wheat, the content of sulfur in the main product was higher than in the by-product, while in pea it was vice versa (Table 2).

Table 2. Variation-statistics of sulfur content in plants, %

Agricultural crop		n	$\bar{x} \pm t_{05} s_{\bar{x}}$	lim	V, %
Winter wheat	Grain	22	0.13±0.01	0.05-0.19	23.4
	straw	22	0.10±0.01	0.07-0.17	23.8
White Lupine	Grain	20	0.22±0.01	0.17-0.28	14.1
	straw	20	0.07±0.01	0.05-0.11	26.5
Soybean	Grain	22	0.34±0.02	0.27-0.40	11.4
	straw	22	0.21±0.01	0.19-0.24	7.7
Pea	Grain	22	0.14±0.004	0.13-0.15	6.5
	straw	22	0.16±0.003	0.15-0.17	4.1
Clover	hay	22	0.61±0.04	0.46-0.82	16.4
Sainfoin	hay	22	0.47±0.04	0.36-0.66	19.1
Lucerne	hay	22	0.60±0.06	0.36-0.98	23.8
Steppe forbs (Belogorye Reserve, Yamskaya steppe section)	hay	22	0.30±0.02	0.21-0.45	18.3
Steppe forbs (Rovensky Nature Park)	hay	22	0.40±0.06	0.23-0.66	31.6

5. Conclusions

The ambient mobile sulfur content in the virgin soils of Belgorod region is low: 2.31 mg/kg - in typical chernozem and 1.83 mg/kg - in common chernozem. According to agrochemical monitoring of arable soils conducted during 2015-2018, an increase in the weighted average content of mobile sulfur by 0.7 mg/kg to 3.3 mg/kg, compared to 2005-2009, was found. However, the proportion of soils low in this element remains quite high - 90.3%. The main source of sulfur in the soils of agro-ecosystems (7.52 kg/ha) is organic fertilizers, the doses of which in 2015-2018 increased to 8.1 t/ha. The average sulfur

content in steppe grasses of reserves is 0.3-0.4 mg/kg. The highest sulfur content among perennial leguminous grasses is characterized by clover (0.61%) and alfalfa (0.60%), and among grain legumes - soybean, containing 0.34% element in grain and 0.21% - in straw.

References

[1] Aristarkhov A.N. Agrochemistry of sulfur. Moscow: All-Russian Research Institute of Agrochemistry, 2007. 272 p.
[2] Aristarkhov A.N. Sulfur in agroecosystems of Russia: monitoring of content in soils and the effectiveness of its use // International Agricultural Journal. 2016. No. 5. Pp. 39-47.
[3] Zhuikov D.V. Sulphur and trace elements in agrocenoses (review) // Achievements of Science and Technology of AICis, 2020. No. 11. Pp. 32-42.
[4] Zavalin A.A., Sokolov O.A., Shmyreva N.Ya., Lukin S.V. Legume reactionto soil asidity // Amazonia Investiga, 2019. Vol. 8. No. 23. Pp. 162-170.
[5] Lukin S.V., Selyukova S.V., Prazina E.A., Chetverikova N.S. A comparative evaluation of macro- and microelement composition of plants of white lupine and soybean // Indo American journal of Pharmaceutical sciences, 2018. No. 05(06). Pp. 6133-6137.
[6] Lukin S.V., Zhuikov D. V. Monitoring of the contents of manganese, zinc, and copper in soils and plant of the Central Chernozemic region of Russia // Eurasian Soil Science, 2021. Vol. 54. No. 1. Pp. 63-71. DOI: 10.1134/S1064229321010099.
[7] Lukin S.V. Dynamics of the agrochemical fertility parameters of arable soils in the southwestern region of Central Chernozemic zone of Russia //Eurasian Soil Science, 2017. Vol. 50. No. 11. Pp. 1323-1331.
[8] Kostin I.G, Malysheva E.S. Monitoring of basic parameters of soil fertility using geoinformation systems Vestnik of Kazan State Agrarian University, 2020. No. 2(58). Pp. 96-101. DOI: 10.12737/2073-0462-2020-96-101.
[9] Surinov A. Dynamics of fertility of agricultural chernozems of forest – steppe zone of the central chernozem regions of Russia Vestnik of Kazan State Agrarian University, 2021. Vol.16. No. 1 (61). Pp. 57-61. DOI: 10.12737/2073-0462-2021-57-61.
[10] Sokaev K.E. Sulfur in the soils of the Republic of North Ossetia Alania // Agrochemical Bulletin, 2003. No. 6. Pp. 11-12.
[11] Korneyko N.I. Agrochemical state of arable soils of Belgorod region // Journal of Modern Natural Science, 2014. No. 9-2. Pp. 120-124.
[12] Poddubnyi A.S. Dynamics of an agrochemical state of arable lands in the forest-steppe of Belgorod region // Achievements of Science and Technology of AICis, 2018. No. 6. Pp. 15-17.
[13] Tandelov Yu.P., Patrina M.S. Sulfur – containing fertilizer role in optimization of the grey forest and sod-podzol soil mineral nutrition in Krasnoyarsk region subtaiga // The bulletin of KrasGAU, 2011. No. 11 (62). Pp. 66-70.
[14] Panasin V.I., Slobozhaninova V.D., Lopatina N.V. Sulfur and harvest. Kaliningrad: publishing house «KGT», 1999. 150 p.
[15] Maslova I.Ya. Optimization of spring wheat nutrition // Zemledelie, 2010. No. 1. Pp. 16-17