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The effect of straw on the humus state of chernozem

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Abstract. **The purpose** of the research is to present the results of studies obtained in the long-term stationary experience of the Geographical Network of Experiments with Fertilizers of the Russian Federation on the effect of various methods of straw, crop residues and nitrogen fertilizers utilization on the humus state of leached black soil. Establish the effect of the systematic introduction of straw and crop residues on the content of total and labile humus in leached black soil, provide data on the fractional composition of humus. **Methods.** There were used conventional methods: total nitrogen by the method of indophenol greens, humus according to Tyurin in Simakov's modification; fractional group composition according to Ponomareva and Plotnikova; labile carbon – by the release of humic substances during treatment with 0.1n NaOH, soil treatment with sodium pyrophosphate 0.1m $Na_4P_2O_7$ (Dyakonova's method) and hot water (Schulz's method). **Results.** The results of studies obtained in a long-term stationary experiment on the study of the effect of straw and crop residues on the humus state of the soil are presented. It has been established that the annual introduction of straw and crop residues into the soil makes it possible to maintain the humus state of the leached black soil at the level of the initial content. Significant differences in the humus reserves in the arable soil layer according to the methods of utilization of organic residues were not revealed, they were assessed as very high. On a long fallow, humus reserves were high, on virgin lands they were ultra-high. The results of the studies showed that the fractional composition of fulvic acids depended on the method of using straw and stubble residues; the fractional composition of humic acids did not differ from the method of utilizing straw and stubble residues. A decrease in the content of total humus was revealed against the background of burning and removing straw and stubble, while an increase in its content was noted during the systematic plowing of post-harvest residues. **Scientific novelty** consists in changing the fractional-group composition of humus when using organic residues (straw, stubble) for the reproduction of soil organic matter.
Keywords: organic matter, humus, labile humus, nitrogen, fractional composition of humus, humic acids, fulvic acids, nitrogen fertilizers.

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Introduction

The earth as a natural body and the main means of agricultural production is a constantly changing system. All atmospheric processes, physical phenomena, flora, fauna affect the state of the earth, especially its upper layer. Reproduction of soil fertility is one of the most important tasks of agriculture. Under conditions of intensive use of arable land, especially in areas prone to erosion processes, the problem of restoring the loss of soil organic matter remains without the necessary attention, dehumification is noted, expressed in a noticeable decrease in natural humus reserves. The low ability of soils to form humus is explained by the insufficient supply of fresh organic matter to the soil. With low reserves of organic matter, especially during the growing season and under adverse weather conditions, plants are prone to depression. According to many researchers, the annual loss of organic matter in Russia reaches 0.3–0.4 t/ha, significantly increasing in areas with the manifestation of erosion processes [1–3]. The decrease in the number of livestock in the farms of the region, the increase in prices for fuel and lubricants have sharply reduced the volume of organic fertilizers applied to the soil. In this situation, it was important to find alternative ways to replenish the reserves of organic matter in soils on arable land. At the same time, straw, tops and other production wastes become the cheapest and most accessible source of organic carbon replenishment. However, information about the role of straw used as organic fertilizer is highly conflicting. This is explained mainly by the difference in soil-climatic and technogenic conditions in experiments carried out by various scientific institutions.

Humic substances are the dominant factor in the state of natural soil fertility. The agrophysical and agrochemical properties of the soil, the state of its biological activity depend on the content of humus and its qualitative characteristics. In well-humused soils, the processes of mobilization of plant nutrients proceed better, such soils are less prone to overconsolidation, and are better aerated. The natural-historical process caused differences in the reserves and qualitative composition of the humus in the soil cover of the earth. In agricultural soil science, humus is considered as an integrated indicator of the economic value of the soil. The chemical composition, physical condition, biological activity, energy potential and other properties of the soil depend on the content of humus in it, the ratio of its various components – humic and fulvic acids, humates, etc. [3–9].

In the natural environment, the stationary equilibrium state of humic substances is maintained by the phytocenosis characteristic of this soil-climatic zone. Quantitative and qualitative changes, together with erosion and deflation, contribute to the imbalance of organic matter, the activation of destruction processes, and, ultimately, the decrease in the humus reserves inherent in this soil. Under the conditions of extensive farming on fields not fertilized with manure and composts, the most radical and, at the same time, affordable and low-cost means of enriching the soil with organic matter is straw cutting, introduced into the soil when harvesting grain crops.

Methods

The experiment was carried out on permanent sowing of spring wheat. The arrangement of options is randomized, the backgrounds are sequential. The experience is laid by the method of split plots: the plots of the first order are the backgrounds for the use of straw, the second – the doses of nitrogen fertilizers. Harvesting in the experiment was carried out by direct combining, while leaving chopped straw on the field surface. In parallel with this, the removal and burning of the entire non-grain part of the crop is carried out.

Background 1 is a traditional, accepted practice, when the straw is removed from the field.

On background 2, chopped straw is annually left, which is incorporated into the soil by repeated (2–3 tracks) disking with a heavy disc harrow.

On background 3, the entire non-grain part of the crop is removed by combing (multiple harrowing).

On background 4, the straw is evenly spread out over the experimental plots by hand and burned, after which disking is carried out in order to prevent the spread of ash and ashes by the wind.

On backgrounds 2 and 4, the same amount of straw is left.

Subsequently, moldboard plowing of all backgrounds to a depth of 23–25 cm is carried out across the plots.

The amount of straw introduced into the soil is determined by meter platforms and weighed on scales with an accuracy of 0.1 kg.

Mineral fertilizers are spread into the soil for presowing cultivation.

Repetition 4-fold. The total number of plots in the experiment was 64. The area of the elementary plot of the first order was 800 m^2, the area of the second order was 200 m^2 (50 × 4), and the accounting plot was 190 m^2 (50 × 3.8).

In studies of soil organic matter, generally accepted methods are used: total nitrogen – by the indophenol green method; humus – according to Tyurin in Simakov's modification, fractional-group composition of humus – according to Ponomareva and Plotnikova. To extract labile carbon, the following methods were used: isolation of humic substances during treatment with 0.1 N NaOH, soil treatment with sodium pyrophosphate 0.1 M $Na_4P_2O_7$ (Dyakonova's method) and hot water (Schulz's method).

Results

As a result of long-term studies, a decrease in the content of total humus was revealed compared to the control (5.72 %) against the background of burning and removing straw and stubble to 5.45 and 5.51 %, respectively. While with the systematic plowing of post-harvest residues, the humus content increased to 6.03. For comparison, the results of observations of the humus state of the soil in a state of long-term fallowing and on a virgin analogue of the studied type are given. With prolonged fallowing, the content of total humus decreased to 4.22 %; on the virgin analogue of leached black soil, the content of total humus was 10.2 %. Against the background of nitrogen fertilizer, in the variants with the studied methods of straw utilization, the humus content was higher, which is due to the large amount of fresh organic matter entering the soil in the form of crop and root residues (Table 1). The same results were obtained in studies by other scientists, including German ones [14–16].

The main source of nitrogen in the soil is humus. Humus nitrogen passes into soluble and accessible forms as a result of a number of complex and lengthy microbiological transformations. Soil nitrogen, presented in the form of complex organic substances of humus, becomes available to plants only after its mineralization. The intensity of mineralization of humus nitrogen depends on the physical and chemical properties of the soil, climatic and agrotechnical conditions. When studying the humus state of the soil in long-term experiments, it is advisable to determine the enrichment of humus with nitrogen and the content of labile, easily transformable humus in it, which is very important for assessing the nearest reserve of nitrogen necessary for the growth and development of plants [3; 7; 8].

Table 1

Influence of straw utilization methods on the humus state of the soil (average for 1971–2020)

Option	Nitrogen dose, kg/ha	Humus content, %	Humus reserves (0–30 cm), t/ha	Enrichment of humus with nitrogen, C:N	Labile humus, %
The straw is removed, the stubble is plowed	0	5.72 Below the average	238.5 Very high	10.0 Average	0.40
	80	5.79 Below the average	241.4 Very high	10.5 Average	0.46
Systematic plowing straw and stubble	0	6.03 Below the average	251.4 Very high	11.4 Low	0.44
	80	5.93 Below the average	247.3 Very high	10.8 Average	0.45
Straw and stubble removal	0	5.45 Below the average	227.3 Very high	9.0 Average	0.42
	80	5.58 Below the average	232.7 Very high	10.0 low	0.41
Systematic burning of straw and stubble	0	5.51 Below the average	229.8 Very high	9.6 Average	0.36
	80	5.74 Below the average	239.4 Very high	11.8 low	0.36
Long steam	–	4.22 Below the average	175.6 High	11.3 Low	0.39
Virgin soil	–	10.2 High	425.3 Ultra-high	12.2 Low	1.01

Studies have shown that the humus content in all studied variants of a long-term stationary experiment was assessed as below average, only on the virgin soil analog, the humus content was high. The reserves of humus in the arable layer of the soil did not differ significantly according to the methods of utilization of organic residues and were assessed as very high, while they were high on a long-term fallow, and ultra-high on virgin lands.

The enrichment of humus with nitrogen characterizes the nitrogen regime of the soil, which is formed after the mineralization of organic matter.

The data in Table 1 show that when a large amount of organic matter enters the soil, humus with a low nitrogen enrichment is formed, while humus with an average degree of enrichment is formed in the variants with straw removal.

The low enrichment of humus with nitrogen in the variants with long-term fallow and virgin soil is explained by the limited supply of organic matter. In the virgin lands, despite the richness in nitrogen, in the balance of nitrate nitrogen available to plants, according to A. E. Vozbutskaya, there is a predominance of the expenditure part (consumption by plants, restoration) over the incoming part (nitrification).

One of the important points in the study of the qualitative characteristics of humus is the determination of mobile, labile forms, water-soluble components of the composition of humus as the most sensitive to natural and agrogenic influences [5; 12; 15].

The results of the determination of easily transformed organic matter, presented in Table 1, show the undoubted advantage of the variant with the systematic plowing of straw and stubble; the content of labile carbon, determined in the pyrophosphate extract, was the highest here and amounted to 0.44 %, while in the control variant it was only 0.40. The least labile carbon is in the variant with systematic burning of the entire non-grain part of the crop and perpetual fallow (0.36–0.39 %, respectively).

In the study of soil organic matter, according to the methods proposed by the Geoset laboratory, we carried out laboratory studies on the extraction of labile (transformable) humus from the soil with various reagents in order to unify the methods for determining labile humus.

The highest total carbon content was noted on the virgin analogue of leached chernozem, it amounted to 5.55 %; the smallest – with the annual removal and burning of straw and stubble without the introduction of nitrogen (2.93 and 3.11 %, respectively); when applying nitrogen fertilizer, it increased to 3.02 and 3.14 %, which was caused by the influx of more root residues in these options. Against the background of the annual plowing of straw and stubble, the content of total carbon without nitrogen was 3.38 %.

Studies have shown a different degree of extraction of labile organic matter during extraction with various preparations. So, when extracting 0.1 N NaOH on virgin soil, up to 24.0 % of carbon was extracted, in other options in this extract, from 16.1 to 20.1 % of the total soil carbon was extracted.

When extracting labile organic matter with a pyrophosphate extract (0.1 m $Na_4P_2O_7$) without applying nitrogen fertilizer against the background of straw and stubble plowing, the content of labile carbon was

14.8 % of the total; against the background of straw and stubble burning only 13.2%. Also, little soluble organic matter was extracted from virgin soil, which is due to the greater stability of organic matter in virgin soil.

Easily decomposable organic matter was extracted least of all with hot water according to the method of E. Schulz [20], the content of easily decomposable organic matter did not exceed 2–3 % of the total soil carbon (Table 2).

The dynamics of changes in the humus content in the leached black soil over the entire period of research, presented in Figure 1, shows that the systematic plowing of straw and crop residues makes it possible to stabilize the humus content at the level of the initial content. The remaining options, in particular the removal and burning of straw and crop residues, leading to a gradual decrease in humus reserves, the control option also shows the processes of humus degradation, manifested in a decrease in its content.

Humus is not only involved in the supply of plants with nitrogen, phosphorus, potassium and other important macro- and microelements of nutrition, its role is also undeniable in other important processes of soil formation and ensuring soil fertility, such as protecting soils from weathering, creating their granular structure, supplying plants carbon dioxide necessary for photosynthesis, biologically active growth substances. Therefore, the preservation and enhancement of humus reserves is one of the priorities of farmers.

The quality of humus is characterized by the content and ratio of humic and fulvic acids in it, their individual groups, which differ in solubility in weak acids and alkalis. Fractionation makes it possible to assess the trends in the development of humus formation under the influence of such a powerful agrogenic factor as the long-term systematic introduction of straw, crop residues and nitrogen fertilizers into the soil. With the same content of humus in the soil, there can be significant differences in the ratios of S_{gc}:S_{phc} and C:N, the content of different Cc and Cfc groups in relation to the content of total organic carbon in the soil [3; 5; 10].

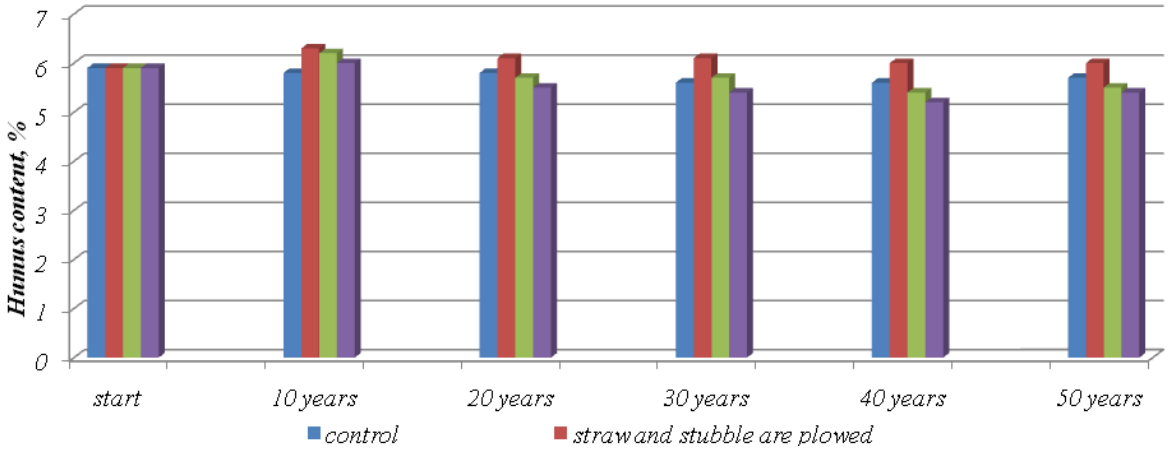

Fig. 1. Dynamics of changes in the content of humus in leached chernozem depending on the method of utilization of straw and crop residues (for 1971–2020)

Table 2

The content of organic carbon during extraction with various reagents depending on the amount of fresh organic matter entering the soil, %

Option		C total according to Tyurin	Extraction					
			Hot water (according to Schultz)		0.1 m $Na_4P_2O_7$		0.1 N NaOH	
			C	% of general	C	% of general	C	% of general
Virgin soil		5.55	0.17	3.1	0.77	13.9	1.32	23.8
The straw is removed, the stubble is plowed	N_0	3.25	0.07	2.1	0.49	15.1	0.59	18.2
	N_{120}	3.18	0.06	1.9	0.52	16.3	0.60	18.9
Systematic plowing straw and stubble	N_0	3.38	0.07	2.1	0.50	14.8	0.59	17.4
	N_{120}	3.39	0.07	2.1	0.52	15.3	0.67	19.8
Straw and stubble removal	N_0	2.93	0.06	2.0	0.47	16.0	0.59	20.1
	N_{120}	3.02	0.06	2.0	0.51	16.9	0.60	19.9
Systematic burning of straw and stubble	N_0	3.11	0.06	1.9	0.41	13.2	0.50	16.1
	N_{120}	3.14	0.05	1.6	0.38	12.1	0.51	16.2

Table 3

Fractional composition of humic acids in leached chernozem (0–30 cm) with various methods of utilization of organic residues and nitrogen fertilizer, (C, % to total soil C) (2000)

Background	Nitrogen dose, k/ha of a. i.	$C_{average}$ in soil, %	GK fraction				FC fraction					$G_A + F_A$	G_A / F_A	$E_{mg/ml}$	Humification indikator
			1	2	3	Sum	1a	1	2	3	Sum				
The straw is removed, the stubble is plowed	0	3.00	4.4	22.9	4.7	32.0	2.5	7.9	4.3	6.3	21.0	53.0	1.5	0.27	8.6
	120	3.14	2.9	22.8	2.0	27.7	1.9	10.2	2.8	8.9	23.8	51.5	1.2	0.26	7.2
Systematic plowing straw and stubble	0	3.57	2.7	21.1	3.2	27.0	1.9	10.2	0.8	9.5	22.4	49.4	1.2	0.27	7.3
	120	3.00	4.5	27.0	2.2	33.7	2.8	11.7	4.2	12.1	30.8	64.5	1.1	0.27	9.1
Straw and stubble removal	0	2.92	1.6	25.8	3.1	30.5	2.3	8.6	3.1	8.8	22.8	53.3	1.3	0.25	7.6
	120	3.07	2.6	21.5	2.6	26.7	2.0	9.8	2.6	9.7	24.1	50.8	1.1	0.25	6.7
Systematic burning of straw and stubble	0	3.06	2.5	22.9	2.5	27.9	2.0	9.1	0.5	10.3	21.9	49.8	1.3	0.24	6.7
	120	2.85	3.5	16.5	2.3	22.3	2.8	9.0	10.2	12.8	34.8	57.1	0.6	0.24	5.3

Black soils of the Chelyabinsk region are the most valuable and fertile in comparison with other types of soils. The formation of these soils is associated with the development of forb-grass vegetation, which has a significant effect on the processes of humification of organic matter (together with climatic conditions).

Determination of the fractional composition of humus is one of the important indicators of the humus status of soils. In the described stationary experiment, the fractional composition of humic substances, which characterizes the distribution of substances included in certain groups of soil humus according to the forms of their compounds with the mineral components of the soil, basically corresponds to the characteristics of black soils.

The composition of humic acids is dominated by humic acids of fraction 2, soluble in 0.1 N NaOH, associated mainly with calcium, they have the property of almost complete solubility in water. The remaining two fractions of humic acids account for approximately equal amounts. The total amount of humic acids without the use of fertilizers is 27–32 %, with the use of nitrogen fertilizers, the content of humic acids decreased. Differences due to the use of different technologies for the use of straw and crop residues have not been identified (Table 3).

Fulvic acids of various fractions are the most mobile and "young" forms of humic acids. Against the background of straw and stubble plowing, SFA accounts for 22.4–30.8 % of fulvic acid carbon in relation to the total soil carbon. Characteristically, against this background, there is a narrower ratio of humic acids to fulvic acids, respectively 1.2–1.1 versus 1.5–1.2 against the control background, where the straw is removed and the stubble is plowed (Table 3).

Against the background of the plowing of straw and stubble, the biological absorption of mineral nitrogen increased in the process of decomposition of cellulose and fiber, while the amount of humic acids decreased, the application of nitrogen fertilizer at a dose of 120 kg/ha a. i. contributed to an increase in the amount of humic acids.

As for the fractional composition of S_{gc} and S_{phc}, the differences in the content of groups of acids soluble in NaOH and H_2SO_4 of various concentrations should be considered insignificant, with the exception of fulvic acids in the extract of 0.1 N NaOH (No. 1) and 0.02 N NaOH (No. 3). Against the background of plowing into the soil of straw and stubble, its content in relation to the amount of S_{phc} was higher. These S_{gc} groups are associated with free and mobile sesquioxides, clay fraction and stable forms of soil sesquioxides. The ratio of carbon of humic acids to the total carbon of the soil reflects the degree of humification of organic matter, and the ratio S_{gc}:S_{phc} is the degree of maturity or hydrolyzability of humic acids. Against the background of straw and stubble and in the control, the type of humus is fulvate-humate (S_{gc}:S_{phc} less than 2.0). Some tendencies can be noted in differences in the degree of humification and in the ratio of humic acid carbon to total organic carbon; in the enrichment of humus with nitrogen (in the control variant, the C:N ratio was 10.0–10.5, while against the background of straw and stubble plowing it was 11.4–10.8) (Table 1). This phenomenon quite fully fits into the concept of the inevitable decrease in the content of nitrogen, primarily its mineral forms, in the process of biological decomposition of cellulose by cellulose-decomposing bacteria [13; 17; 18].

The smallest difference between the carbon of humic acids (S_{gc} + S_{phc}) and organic carbon (S_{org}.) manifested itself against the background of straw and stubble plowing + N_{120}, which is also quite natural in view of a noticeable increase in the content of humic acid carbon in humus.

Discussion and Conclusions

The problem of replenishing the reserves of soil organic matter remains one of the priority areas. With the systematic introduction of straw and crop residues into the soil, the content of both total and labile (easily transformable) humus increases, while when straw and crop residues are removed and burned, the indicators characterizing the humus content of the soil decrease. The fractional composition of humus showed differences in the content of various fractions of total carbon, the fractional composition of humic acids did not differ from the method of utilization of straw and crop residues, the fractional composition of fulvic acids depended on the method of using straw and crop residues.

It is well known that not all soil organic matter directly affects plant productivity, but only its easily transformed part, which takes part in nutrient cycling. In this regard, the determination of the easily transformable soil substance was carried out. Straw utilization methods influenced the content of easily transformable carbon in the soil. Thus, when plowing straw and stubble, its content was higher than in the variants with burning and removal of organic residues.

References

1. Sychev V. G., Shevtsova L. K., Merzlaya G. E. Issledovaniye dinamiki i balansa gumusa pri dlitel'nom primenenii sistem udobreniya na osnovnykh tipakh pochv [Study of the dynamics and balance of humus during long-term use of fertilizer systems on the main types of soils] // Agrokhimiya. 2018. No. 2. Pp. 3–32. (In Russian.)

2. Popova V. I., Chudinov V. A., Boldysheva E. P., Bekmagambetov A. I. Ekonomicheskaya effektivnost' primeneniya mineral'nykh udobreniy v polevom zernoparovom vos'mipol'nom sevooborote na obyknovennom chernozeme pri traditsionnoy i resursosberegayushchey sistemakh zemledeliya [Economic efficiency of the use of mineral fertilizers in the field grain-fallow eight-field crop rotation on ordinary chernozem with traditional and resource-saving farming systems] // Vestnik KrasGAU. 2020. No. 7. Pp. 16–25. (In Russian.)

3. Fad'kin G. N., Lupova E. I., Vinogradov D. V., Ushakov R. N. Obosnovaniye primeneniya razlichnykh form azotnykh udobreniy pod sel'skokhozyaystvennyye kul'tury i ikh vliyaniye na plodorodiye seroy lesnoy pochvy [Justification of the use of various forms of nitrogen fertilizers for agricultural crops and their impact on the fertility of gray forest soil] // Vestnik KrasGAU. 2020. No. 7. Pp. 63–71. (In Russian.)

4. Sorokin I. B., Nikolayeva N. Yu., Valetova E. A., Chudinova Yu. V. Vliyaniye mnogoletnego vneseniya solomy i zelenogo udobreniya na urozhaynost' zernovykh kul'tur v zernoparovom sevooborote [The effect of long-term application of straw and green fertilizer on the yield of grain crops in the grain-steam crop rotation] // Vestnik NGAU. 2021. No. 3. Pp. 65–72. (In Russian.)

5. Kuzina E. V. Vliyaniye obrabotki pochvy i udobreniy na urozhaynost' i kachestvo zerna yarovoy pshenitsy [The effect of tillage and fertilizers on the yield and quality of spring wheat grain] // Vestnik Kazanskogo GAU. 2021. No. 1 (61). Pp. 28–33. (In Russian.)

6. Tulina A. S. Vliyaniye temperatury, vlazhnosti i vneseniya solomy na dinamiku mineralizatsii organicheskogo veshchestva i pochvennyye puly ugleroda i azota [Influence of temperature, humidity and straw application on the dynamics of mineralization of organic matter and soil pools of carbon and nitrogen] // Agrokhimiya. 2019. No. 3. Pp. 3–18. (In Russian.)

7. Shevtsova L. K., Chernikov V. A., Sychev V. G. Vliyaniye dlitel'nogo primeneniya udobreniy na sostav, svoystva i strukturnyye kharakteristiki gumusovykh kislot osnovnykh tipov pochv. Soobshcheniye 1 [The effect of long-term use of fertilizers on the composition, properties and structural characteristics of humic acids of the main types of soils. Message 1] // Agrokhimiya. 2019. No. 10. Pp. 3–15. (In Russian.)

8. Shevtsova L. K., Belichenko M. V. Gumusnoye sostoyaniye pochv pri dlitel'nom primenenii razlichnykh sistem udobreniy [Humus state of soils with prolonged use of various fertilizer systems] // Plodorodiye pochv Rossii: sostoyaniye i vozmozhnosti: sbornik statey (k 100-letiyu so dnya rozhdeniya Tamary Nikandrovny Kulakovskoy). Moscow, 2019. Pp. 79–86. (In Russian.)

9. Zavalin A. A., Sokolov O. A., Shmyreva N. Ya. Azot v agrosisteme na chernozemnykh pochvakh. K 125-letiyu ekspeditsii V. V. Dokuchayeva v Kamennuyu Step': monografiya. [Nitrogen in the agricultural system on chernozem soils. To the 125th anniversary of the expedition of V.V. Dokuchaev to Kamennaya Steppe: monograph]. Moscow, 2018. 180 p. (In Russian.)

10. Kogut B. M. Organicheskoye veshchestvo chernozema [Organic matter of chernozem] // Bulletin of the V. V. Dokuchaev Soil Science Institute. 2017. No. 90. Pp. 39–55. (In Russian.)

11. Chebotarev N. T., Konkin P. I., Zaynullin V. G. Izmeneniye fraktsionno-gruppovogo sostava i balansa gumusa pod vliyaniyem udobreniy na dernovo-podzolistoy pochve Evro-Severo-Vostoka [Changes in the fractional-group composition and balance of humus under the influence of fertilizers on the sod-podzolic soil of the Euro-Northeast] // Plodorodiye. 2019. No. 6. Pp. 25–28. (In Russian.)

12. Zakharova I. A., Yumashev Kh. S. Izmeneniye gumusnogo sostoyaniya chernozemnykh pochv Chelyabinskotsy oblasti v rezul'tate sel'skokhozyaystvennogo ispol'zovaniya [Changes in the humus state of chernozem soils of the Chelyabinsk region as a result of agricultural use] // Vestnik Krasnoyarskogo GAU. 2022. No. 2. Pp. 3–11. (In Russian.)
13. Surinov A. V. Dinamika plodorodiya pakhotnykh chernozemov lesostepnoy zony tsentral'no-chernozemnykh oblastey Rossii [Dynamics of fertility of arable chernozems of the forest-steppe zone of the central chernozem regions of Russia] // Vestnik Kazanskogo GAU. 2021. Vol. No. 1 (61). Pp. 57–61. (In Russian.)
14. Khryukin N. N., Dedov A. V., Nesmeyanova M. A. Dinamika razlozheniya rastitel'nykh ostatkov v chernozeme tipichnom [Dynamics of decomposition of plant residues in typical chernozem] // Agrochemical Herald. 2018. No. 1. Pp. 24–29. (In Russian.)
15. Perederiyeva V. M., Vlasova O. I., Dorozhko G. R., Petrova L. N., Vol'ters I. A. Dinamika rastitel'nykh ostatkov v zavisimosti ot tekhnologii vozdelyvaniya kul'tur na chernozeme obyknovennom [Dynamics of plant residues depending on the technology of cultivation of crops on ordinary chernozem] // Agrochemical Herald. 2018. No. 4. Pp. 38–45. (In Russian.)
16. Coppens F., Garnier P., De Gryze S., Merckx R., Recous S. Soil moisture, carbon and nitrogen dynamics following in corporation and surface application of labeled crop residues in soil columns // European Journal of Soil Science. 2006. No. 57 (6). Pp. 894–905.
17. Asmus F., Völker U. Einfluβ von Strohdüngung auf Ertrag und Bodeneigenschaften in Fruchtfolgen mitunter schiedlichen Getreideanteil // Arch. Acker – u. Pflanzenbau u. Bodenkd. 1984. Vol. 28. No. 7. Pp. 411–417. (In German.)
18. Völker U., Asmus F., Görlitz H. Wirkung von Stalldung, Gülle und Stroh auf die Reproduktion der organischen Substanz von Tieflehm-Fahlerde und Sandlehm-Parabraunerde // Arch. Acker – u. Pflanzenbau u. Bodenkd. 1984. Vol. 28. No. 7. Pp. 595–601. (In German.)
19. Köershens M., Weigel A., Schulz E. Turnover of soil organic matter and longterm balances – tools for evaluating sustainable productivity of soils // Z. Pflanzenernä Bodenk. 1998. Vol. 161. Pp. 409–424.

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