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Optimization of biological processes of transformation of organic substance into leached chernozem

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The purpose. To study features of emission of nitrous oxide from leached chernozem under the influence of increasing doses of fertilizers and receipt of fresh organic substance of various parentage; to determine necessary amount of carbon for optimization of biological processes at use of solid mineral fertilizers. **Methods**. Field experiments, gas-stratographic analysis, agrochemical, computational. **Results**. Specific losses (g N-N2O/kg C-CO2) of nitrogen from soil are diminished at manuring (dung, straw, mass of Lupine green manure crop and their combinations). The greatest specific losses of N-N2O in experiments were registered in alternatives with fertilizers. At the same time application of solid mineral fertilizers in low (100 kg/hectare a.a. in the link of crop rotation) and average (200 kg/hectare a.a.) doses on the background of straw (5 t/hectare) and Lupine green manure crop (13 t/hectare) secured decrease of indexes (even below control). That testified to fixation of part of mineral nitrogen compounds not used by plants. Thus for optimization of C/N ratio it is not required additional application of mineral nitrogen. Combination of the highest dose of fertilizers in experiment (300 kg/hectare in the link of crop rotation) with straw and green manure crop does not allow to lower specific losses of nitrogen to the level of control. That testifies to redundancy of mineral nitrogen in soil in that case. The formula of calculation of necessary amount of carbon for optimization of C/N ratio is offered at use of different doses of nitrogen fertilizers in crop production technologies. It ensures balance of mineralizing and synthetic processes in soil. **Conclusions**. Application of calculated doses of fresh organic substance (dung, straw, Lupine green manure crop and their combination, including mineral fertilizers) secures optimization of microbiologic processes in agro-ecosystems at cultivation crops on leached chernozem. In such conditions the nitrogen of mineral joints not used by plants metabolically linked (immobilized) by microorganisms. Emission of N2O, and doses of fertilizers, which do not exceed 200 kg/hectare a.a. in crop rotation, decreased, and became environmentally sound.

Keywords: *fertilizer system, organic and mineral fertilizers, humus, emission of N2O and* CO2*, C/N ratio.*

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Introduction. The issues of reproduction of soil fertility are being raised today, as they are deficient in fresh organic matter, distorting the structure and functions of groups of microorganisms with one-sided interpretation of the principles of providing cultural plants with nutrients. As a result, humus stocks in arable soils are steadily declining. This makes it necessary to provide the soil with fresh organic matter (manure, straw, green manure, etc.) and optimize nitrogen/carbon ratio.

Analysis of recent studies and publications. It is known that humus is both a carbon storage (and, consequently, energy) and carrier of temporally bound compounds of biogenic elements [1; 2]. In turn, synthesis of humic compounds is only possible if fresh organic matter is present in the soil. However, its entry to the soil today is limited due to a sharp decrease in the use of manure, ignoring crop rotation, minimizing the areas of cultivation of grass, burning straw, etc. At the same time, the processes of dehumification are active [2-5]. Humus degradation is also enhanced by soil acidification due to the weakening of the bond of humic acids with Ca^{2+}, which increases the mobility and mineralization of humus compounds [6; 7]

These processes are further enhanced by the introduction of increased doses of nitrogen fertilizers, which leads to the intense destruction of all high molecular weight humic acid fractions [8-10]. Today, it can also be argued that high levels of mineral nitrogen biological soil result in intense dehumification of soil, since excess of mobile nitrogen in soil causes an increased need for carbon in soil microorganisms and, in the absence of fresh organic matter, some of their representatives use humic compounds as a source of carbon and energy [11-13].

In this regard, studies aimed at searching ways to provide soil with organic matter and to optimize humus formation processes has become a live issue.

Objective – determine the orientation of individual biological processes in the soil under different crop fertilizing systems and develop a model of optimization of carbon/nitrogen ratio for different rates of mineral nitrogen used in agricultural technologies.

Materials and methods. The studies were conducted in 2016-2018 in a field stationary experiment on leached chornozem of the experimental field of the Institute of Agricultural Microbiology and Agroindustrial Manufacture of the National Academy of Agrarian Sciences under conditions of short rotation (potatoes – spring barley – peas – winter wheat) in agrocenoses of potatoes, spring barley and pea.

Agrochemical characteristics of soil: $pH_{sal.}$ – 5.3; humus content – 3.03 %; easily hydrolysable nitrogen – 95 mg/kg of soil; mobile phosphorus compounds (P_2O_5) – 150 mg/kg of soil; content of exchangeable potassium (K_2O) – 108 mg/kg of soil.

Crops were grown under the following fertilizing systems: without fertilizers; straw; green manure; manure; straw + green manure; manure + green manure; mineral low (100 kg/ha NPK in crop rotation chain); mineral low + straw + green manure; mineral medium (200 kg/ha NPK in crop rotation chain); mineral medium + straw + green manure; mineral intense (300 kg/ha NPK in crop rotation chain); mineral intense + straw + green manure; organo-mineral (manure + 100 kg/ha NPK); organo-mineral + green manure.

Respectively, the cultivation of potatoes was carried out under the following agrarian backgrounds: 1. Without fertilizers; 2. Straw; 3. Green manure; 4. Manure; 5. Straw + green manure; 6. Manure + green manure; 7. $N_{40}P_{40}K_{40}$; 8. $N_{40}P_{40}K_{40}$ + straw + green manure; 9. $N_{80}P_{80}K_{80}$; 10. $N_{80}P_{80}K_{80}$ + straw + green manure; 11. $N_{120}P_{120}K_{120}$; 12. $N_{120}P_{120}K_{120}$ + straw + green manure; 13. Manure + $N_{40}P_{40}K_{40}$; 14. Manure + green manure + $N_{40}P_{40}K_{40}$.

Fertilization of spring barley was performed as follows: 1. Without fertilizers; 2. Straw*; 3. Green manure*; 4. Manure*; 5. Straw* + green manure*; 6. Manure* + green manure*; 7. $N_{30}P_{30}K_{30}$; 8. Straw* + green manure* + $N_{30}P_{30}K_{30}$; 9. $N_{60}P_{60}K_{60}$; 10. Straw* + green manure* + $N_{60}P_{60}K_{60}$; 11. $N_{90}P_{90}K_{90}$; 12. Straw* + green manure* + $N_{90}P_{90}K_{90}$; 13. Manure* + $N_{60}P_{60}K_{60}$; 14. Manure* + green manure* + $N_{60}P_{60}K_{60}$. Where: * - first year after-effect of organic fertilizers.

Pea was cultivated under the following agrarian backgrounds: 1. Without fertilizers; 2. Straw**; 3. Green manure**; 4. Manure**; 5. Straw** + green manure**; 6. Manure** + green manure**; 7. $N_{30}P_{30}K_{30}$; 8. Straw** + green manure** + $N_{30}P_{30}K_{30}$; 9. $N_{60}P_{60}K_{60}$; 10. Straw** + green manure** + $N_{60}P_{60}K_{60}$; 11. $N_{90}P_{90}K_{90}$; 12. Straw** + green manure** + $N_{90}P_{90}K_{90}$; 13. Manure** + $N_{30}P_{30}K_{30}$; 14. Manure** + green manure** + $N_{30}P_{30}K_{30}$. Where: ** - second year after-effect of organic fertilizers.

Fresh organic matter was introduced under potatoes. Shredded straw in the amount of 5 t/ha was placed in the soil immediately after harvesting winter wheat (late July) by disking, and then narrow leaf lupine was sown in the appropriate variants on intermediate green manure. A green manure mass of lupine (an average of 13 t/ha over the years of study) was placed in the soil by disking followed by low till (15 cm) late in autumn (late November). At the same time, litter manure of cattle at the rate of 40 t/ha, was introduced in the soil in appropriate variants.

Using the gas chromatographic methods, the intensity of N_2O and CO_2 emission from the soil was determined over time depending on the agrarian backgrounds, specific losses of nitrogen per unit of carbon dioxide (g $N\text{-}N_2O$/kg $C\text{-}CO_2$) were calculated [14].

The experiment kept trace of crop yields, root weight, post-harvest residues, and determined the carbon content in them (as well as in manure, straw and lupine green manure mass). The content of C in the roots of potatoes was at the level of 35.4 ± 0.5 %, barley – 29.8 ± 0.3 %, pea – 33.0 ± 0.4 %; in post-harvest residues: potatoes – 33.1 ± 0.2 %, barley – 39.3 ± 0.4 %, pea – 39.9 ± 0.4 %; in winter wheat straw – 41.9 ± 0.3 %, lupine green manure 38.4 ± 0.5 %, cattle manure – 24.0 ± 0.5 %.

By the content of carbon and nitrogen content in organic fertilizers, plant residues, including root ones, as well as taking into account entry of technical nitrogen to the soil, carbon/nitrogen ratio for fresh organic matter that entered the soil was calculated. Based on the obtained results, a model of optimization of carbon/nitrogen ratio in agrocenoses was developed.

The results were statistically processed using Office Excel 2003-2007 software program.

Results and discussion. Studies of the functional activity of microorganisms involved in the processes of transformation of nitrogen and carbon (emissions of N_2O and CO_2, respectively) in the soil under the potatoes over time, depending on the agrarian backgrounds, confirm their different intensity. However, the more carbon enters the soil, the higher the carbon dioxide emission is. Accordingly, the more nitrogen compounds are brought in with fertilizers, the greater the losses of this element are. These are quite natural dependencies. However, quite different features are followed in determining the emission ratio of gases. This calculation allows us to determine the specific nitrogen losses in the form of N_2O (per unit of lost CO_2). The results obtained allow us to judge the extent to which nitrogen is immobilized depending on the soil provision with fresh organic matter, that is, characterize *de novo* state of the primary stages of the synthesis of organic matter.

According to the data obtained, straw application contributes to the reduction of the specific losses of N-N_2O in comparison with the control parameters, i. e., this is a manifestation of nitrogen immobilization (Table 1). Some excess of specific losses of gaseous nitrogen is observed with manure and lupine green manure. However, the highest losses of N-N_2O compared to the control are noted in the variants using mineral fertilizers. At the same time, the use of mineral fertilizers in the low and medium rates ($N_{40}P_{40}K_{40}$ and $N_{80}P_{80}K_{80}$) against the background of straw and lupine green manure contributes to the reduction of parameters even below the control. And only combination of the highest rate of mineral fertilizers in the experiment with straw and green manure does not allow to reduce specific losses of nitrogen to the level of control, which indicates the excess of mineral nitrogen compounds in the soil in this case.

The unambiguous conclusion of the conducted studies is the following: for the rates of mineral fertilizers, which do not exceed $N_{80}P_{80}K_{80}$ when applied against the background of 5 t/ha of straw and 13 t/ha of green manure mass, mineral compounds of nitrogen in the soil unused by potatoes, are metabolically bind (immobilize) resulting in the reduction of N_2O emission.

The study of the emission of nitrous oxide and carbon dioxide in the soil under the next crop rotation – spring barley shows that the specific losses of gaseous nitrogen are insignificant in the variants with the after-effects of straw and green manure biomass. It should be noted that they are even lower than the parameters of the control variant, which undoubtedly indicates the immobilization of nitrogen compounds and, accordingly, the avoidance of their significant losses under these conditions (Table 1).

During the first year after-effect of manure, there is a slight increase in the specific losses of gaseous nitrogen compared to the control, however, the studied parameters in this variant of the experiment are the lowest in the experiment.

Specific losses of gaseous nitrogen with the use of $N_{30}P_{30}K_{30}$ increase significantly. However, the application of this rate of fertilizers against the background of the after-effect of straw and green manure biomass provides a reduction in the specific losses of nitrogen (even lower than control values). A similar situation is observed with the use of the medium rate of mineral fertilizers in the experiment. Only the introduction of $N_{90}P_{90}K_{90}$ against the background of the after-effects of straw and green manure does not allow to reduce the specific losses of nitrogen beyond the control.

The unambiguous conclusion of these analyses is that the rates of mineral fertilizers, which do not exceed $N_{60}P_{60}K_{60}$ when applied against the background of after-effects of 5 t/ha of straw and 13 t/ha of green manure mass, contribute to the optimization of immobilization processes. $N_{90}P_{90}K_{90}$ for spring barley upon cultivation of leached chornozem is environmentally unfavourable, however the introduction of this rate of fertilizers against the background of the first year of after-effect of straw and green manure biomass contributes to improving the course of biological processes in the soil. The specified rate of fertilizers under these conditions is an environmental balance.

The study of the total specific losses of N-N_2O from soil under peas shows the same features as in the agrocenoses of spring barley (Table 1).

Improvement of nutrition of potato plants with organic, mineral and organo-mineral fertilizers has a positive effect on potato productivity (Table 2). At the same time, only the application of 5 t/ha of straw does not ensure a reliable increase in crop yields. At the same time, the combination of straw with a lupine green manure mass promotes a marked increase in the productivity of agrocenosis. The most efficient in influencing potato yields are: introduction of manure – 9.8 t/ha increase, combined use of manure with green manure mass – 11.0 t/ha yield increase; introduction of $N_{80}P_{80}K_{80}$ (increase of yield by 11.6 t/ha) and especially in combination with straw and lupine green manure (16.1 t/ha); introduction of $N_{120}P_{120}K_{120}$ (increase of yield by 16.2 t/ha) and especially when combined with fresh organic matter (increase to control is at the level of 21.2 t/ha).

High productivity parameters were also obtained for the combination of manure with mineral fertilizers (increase of 16.4 t/ha), as well as for the combination of manure with green manure mass and mineral fertilizers at the rate of $N_{40}P_{40}K_{40}$ (increase of 18.6 t/ha).

When growing spring barley, the straw after-effect does not provide a reliable increase in crop yield, but the after-effect of the combination of straw with the intermediate green manure mass helps to obtain a reliable increase in the grain of this crop.

Some of the highest crop yields are observed under the use of mineral fertilizers against the background of the first year after-effect of organic fertilizers. Thus, in particular, introduction of the lowest rate of mineral fertilizers provides an increase of 23.7 %, and introduction of the same rate against the background of the after-effect of straw with green manure – by 57.5 %. The yield level even exceeds that in the variant with $N_{60}P_{60}K_{60}$ fertilizer rate.

1. Emission of N_2O and CO_2 from soil and specific losses of N-N_2O depending on the agrarian background

Variants of experiment (fertilizing systems)	Crops								
	potatoes			spring barley			peas		
	emission of N-N_2O, g/ha daily	emission of C-CO_2, kg/ha daily	specific losses of nitrogen*	emission of N-N_2O, g/ha daily	emission of C-CO_2, kg/ha daily	specific losses of nitrogen	emission of N-N_2O, g/ha daily	emission of C-CO_2, kg/ha daily	specific losses of nitrogen
Without fertilizers (control)	91.6	45.4	2.02	88.2	40.8	2.16	40.7	21.5	1.90
Straw	98.9	66.5	1.49	91.3	50.8	1.80	38.5	33.0	1.17
Green manure	152.5	71.8	2.12	104.2	52.1	2.00	33.6	31.8	1.06
Manure	219.2	99.1	2.21	174.8	77.1	2.27	74.7	50.6	1.48
Straw + green manure	147.1	80.9	1.82	135.0	58.9	2.29	33.9	28.3	1.20
Manure + green manure	205.1	117.3	1.75	157.3	83.3	1.89	79.0	52.6	1.50
Mineral low	182.2	65.8	2.32	125.5	45.2	2.78	79.5	34.2	2.32
Mineral low + straw + green manure	164.9	108.2	1.52	120.9	78.6	1.54	63.5	43.8	1.45
Mineral medium	191.5	78.7	2.43	162.8	50.87	3.20	143.7	44.5	3.23
Mineral medium + straw + green manure	170.1	97.6	1.74	142.4	70.6	2.02	118.0	66.7	1.77
Mineral intense	211.1	83.2	2.54	206.4	56.9	3.63	219.4	53.45	4.11
Mineral intense + straw + green manure	196.9	93.8	2.10	184.3	65.4	2.82	182.5	81.1	2.25
Organo-mineral (manure + NPK)	254.1	123.3	2.06	185.9	89.3	2.08	82.2	51.4	1.60
Organo-mineral + green manure	232.6	152.8	1.52	178.3	97.0	1.84	78.0	62.4	1.52
HIP_{05}									

*) g N-N_2O/kg C-CO_2 daily

2. Crop yields depending on the agrarian background, t/ha (average for three years)

Variants of experiment (fertilizing systems)	Crops								
	potatoes			spring barley			peas		
	yield	increase to control		yield	increase to control		yield	increase to control	
		t/ha	%		t/ha	%		t/ha	%
Without fertilizers (control)	13.0	-	-	2.07	–	-	1.68	–	–
Straw	13.4	0.4	3.1	2.21	0.14	6.8	1.95	0.27	16.1
Green manure	14.6	1.6	12.3	2.41	0.34	16.4	1.98	0.30	17.9
Manure	22.8	9.8	75.4	3.40	1.33	64.3	2.12	0.44	26.2
Straw + green manure	16.2	3.2	24.6	2.67	0.60	29.0	2.01	0.33	19.6
Manure + green manure	24.0	11.0	84.6	3.64	1.57	75.9	2.34	0.66	39.3
Mineral low	15.7	2.7	20.8	2.56	0.49	23.7	2.57	0.89	53.0
Mineral low + straw + green manure	21.1	8.1	62.3	3.26	1.19	57.5	2.81	1.13	67.3
Mineral medium	24.6	11.6	89.2	2.94	0.87	42.0	2.85	1.17	69.6
Mineral medium + straw + green manure	29.1	16.1	123.8	3.56	1.49	72.0	3.06	1.38	82.1
Mineral intense	29.2	16.2	124.6	3.57	1.50	72.5	3.11	1.43	85.1
Mineral intense + straw + green manure	34.2	21.2	163.1	3.89	1.82	87.9	3.28	1.60	95.2
Organo-mineral (manure + NPK)	29.4	16.4	126.2	4.02	1.95	94.2	2.88	1.20	71.4
Organo-mineral + green manure	31.6	18.6	143.1	4.17	2.10	101.5	2.94	1.26	75.0
HIP_{05}	1.13			0.21			0.16		

The combination of mineral fertilizers in the medium rate with the after-effect of straw with lupine green manure helps to obtain the same level of yield as for the introduction of mineral fertilizers at the rate of $N_{90}P_{90}K_{90}$ – 3.56 and 3.57 t/ha, respectively (Table 2).

Improvement of nutrition of pea plants under after-effect of organic, direct impact of mineral fertilizers, as well as under organo-mineral system positively influenced the crop productivity (Table 2). The most efficient in terms of influence on pea yield is: introduction of $N_{40}P_{40}K_{40}$ against the background of after-effect of manure with green manure mass – increase of 1.26 t/ha; introduction of $N_{60}P_{60}K_{60}$ under after-effect of straw and lupine green manure (increase of 1.38 t/ha); introduction of $N_{90}P_{90}K_{90}$ (increase of 1.43 t/ha) and especially under after-effect of organic matter (increase to control at the level of 1.60 t/ha).

It is known that in the implementation of measures to improve the productivity of agrocenoses, first of all, it is necessary to stabilize or increase the content of humus in the soil [4; 5; 15]. Accordingly, a balanced carbon/nitrogen ratio for fresh organic matter entering the soil should be maintained to promote the synthesis of humus compounds.

In this regard, we have studied C/N ratio in the organic matter entered the soil when growing crops under different agrarian backgrounds, and we've followed to what extent this is consistent with the results of study of biological processes described above.

Taking into account the biomass of potato roots, barley, peas, post-harvest residues and determining in them (as well as in manure, straw and lupine green manure) the carbon content, allows to determine the size of the profit part in the carbon balance in agrocenoses.

The total carbon inputs to the soil show the highest results when organic fertilizers are used in the experiment. This makes total sense, since in this case the soil is provided with additional carbon.

In addition, organic fertilizers affect the rhizogenesis and development of the aerial part of plants, which causes an increase in entry of organic matter to the soil.

Carbon entry is also, to some extent, increasing with increasing in mineral fertilizers rate. This is explained by the influence of fertilizers on the development of the root system and on the increase in post-harvest residues weight.

Determination of nitrogen content in root and post-harvest residues, in manure, straw and green manure mass, as well as introduction of mineral nitrogen (we take into account well-known agrochemical data on the degree of consumption of nitrogen from fertilizers by plants – 50 %) shows different values on entry of this element in agrocenosis, which is due to the different possibilities in crop cultivation technologies. However, the most interesting is "carbon entry/nitrogen entry" ratio (Table 3).

As it is known, the rate of mineralization of plant residues depends on C/N ratio. The narrower it is, the more intense and more complete is the mineralization of organic matter. It is believed that the optimization of the processes of mineralization-synthesis of organic matter in the soil is developed for C/N ratio at the level of 20-30/1 [11; 16].

According to our results, the optimum carbon/nitrogen ratio for fresh organic matter entering the soil is characterized by variants that include the use of straw, green manure biomass, their combinations, as well as the use of cattle manure of 40 t/ha as a fertilizer. The results clearly correspond with specific nitrogen losses in the form of N_2O described above.

Under the introduction of mineral nitrogen without providing the soil with fresh organic matter, mineral nitrogen compounds unused by plants, first of all, narrow C/N ratio for the small amount of organic matter that is provided by plant residues (which in turn leads to its rapid mineralization); secondly, mineral nitrogen, which has not been used by plants and which microorganisms have not been able to immobilize in the presence of a small amount of fresh organic matter, is lost in the form of nitrous oxide (some of it can also be washed out). Third, nitrogen, which is not used by plants or microorganisms, can lead to the mineralization of conservative organic compounds – humus, under conditions of deficiency of fresh organic matter [13].

The use of mineral fertilizers against the background of straw in combination with the lupine biomass contributes to a significant adjustment of the situation. Thus, in the variant with the lowest rate of mineral fertilizers, additional soil supply with fresh organic matter extends C/N ratio to 21.5/1, which virtually creates ideal conditions for mineralization-synthesis processes of organic matter. In the variant with the medium rate of mineral fertilizers in the experiment, carbon/nitrogen ratio is at 16.8/1. Such a narrow ratio of elements leads to rapid mineralization of the organic matter present in the soil and, potentially, to its dehumidification. However, the combination of the specified rate of mineral fertilizers with 5 t/ha of straw and 13 t/ha of lupine green manure biomass significantly improves the situation – C/N ratio under these conditions is 19.9/1 and virtually approaches the optimum.

The use of the high rate of mineral fertilizers even against the background of additional organic matter does not provide the desired parameters – carbon/nitrogen ratio with fresh organic matter available in the soil is narrowed, which can provide rapid mineralization of the already deficient organic carbon. This orientation of biological processes may be one of the reasons for the decrease of humus content in soils of modern agrocenoses.

Considering the above values of carbon and nitrogen entry in agrocenoses, we have propose a formula for calculating the desired amount of carbon to optimize C/N ratio when introducing different rates of technical nitrogen:

$$C = CN \cdot k_1 \cdot k_2 - k_3$$

where:

- C – amount of carbon that should be introduced with organic fertilizers per 1 kg of introduced technical nitrogen to achieve scheduled C/N ratio, kg;
- CN – value of scheduled C/N ratio;
- k_1 – correction factor that takes into account content of nitrogen and carbon in organic fertilizers and their additional entry due to the effect of organic fertilizers on the production process of cultivated crops.
- k_2 – entry of nitrogen to agrocenosis upon introduction of 1 kg of technical nitrogen (it takes into account: 50 % of introduced mineral nitrogen that participates in the production process of cultures; nitrogen of root and post-harvest residues, and by-products, kg;
- k_3 – entry of carbon to agrocenosis upon introduction of 1 kg of technical nitrogen (it takes into account carbon of root and post-harvest residues, and by-products, kg.

In simplified form, the recommended carbon rates for soil fertility reproduction (in this case, leached chornozem) when applying certain rates of mineral nitrogen used by us in the field stationary experiment, are presented in Table 3.

From the table, we can see that with the increase in mineral fertilizer rates, the amount of carbon required to bind a kilogram of nitrogen decreases. This is due to the positive impact of fertilizers on the development of the root system and, in particular, on the receipt of post-harvest residues of crops. However, the total amount of carbon dioxide required to optimize carbon organic matter increases with the increase of technical nitrogen rate.

Comparing the calculated carbon values with the actual ones in the experiment, we can draw the following conclusions. For the lowest rate of mineral nitrogen for the crop rotation chain in the experiment – 100 kg/ha (40 kg for potatoes + 30 kg for barley + 30 kg for peas) entry of 3,038 kg/ha of carbon (from 5 t/ha of wheat straw and 13 t/ha of biomass of the intermediate lupine green manure) provides C/N optimization in abundance (1,964 kg/ha of crop rotation area is required).

3. Recommended rates for carbon introduction with organic fertilizers in crop rotation chain for appropriate amount of technical nitrogen to provide optimal C/N ratio

Introduced technical nitrogen in crop rotation chain, kg	Carbon required for introduction, kg		Estimated C/N
	per 1 kg of technical nitrogen	in crop rotation chain	
100	**19.64**	**1,964**	**20.6**
110	19.29	2,122	20.5
120	18.94	2,273	20.5
130	18.59	2,417	20.4
140	18.24	2,554	20.4
150	17.89	2,684	20.3
160	17.54	2,806	20.3
170	17.19	2,922	20.2
180	16.84	3,031	20.1
190	16.49	3,133	20.0
200	**16.06**	**3,212**	**20.0**
210	15.71	3,299	20.0
220	15.36	3,380	20.0
230	15.01	3,453	20.0
240	14.66	3,519	20.0
250	14.32	3,579	20.1
260	13.97	3,631	20.1
270	13.62	3,677	20.1
280	13.27	3,715	20.1
290	12.92	3,747	20.1
300	**12.57**	**3,771**	**20.1**

For the medium mineral nitrogen rate for the crop rotation chain in the experiment – 200 kg/ha (80 kg for potatoes + 60 kg for barley + 60 kg for peas), the carbon requirement of fresh organic matter is 3,212 kg/ha of crop rotation area. Since 3,038 kg of carbon comes from 5 t/ha of straw and 13 t/ha of intermediate green manure mass, a slight carbon deficiency (174 kg) will be observed in the soil for the desired C/N ratio (3,212 – 3,038 = 174).

For the highest rate of mineral nitrogen in the experiment – 300 kg/ha for the crop rotation chain, 3,771 kg/ha of carbon of fresh organic matter is required. With the use of 5 t/ha of straw and 13 t/ha of lupine green manure, it is not possible to achieve optimal C/N ratios. Carbon deficiency is 733 kg (3,771 – 3,038 = 733). This amount of carbon can be ensured by introducing straw of barley or peas grown in the studied crop rotation chain to the soil.

It should be emphasized that the conclusions about the orientation of biological processes in soil are completely confirmed by the developed model of carbon/nitrogen ratio optimization.

Conclusion

Provision of leached chornozem with fresh organic matter (manure, straw, lupine green manure and their combination, including mineral fertilizers) helps to optimize the course of microbiological processes in agrocenoses. Under these conditions, the excess of mineral compounds of nitrogen is metabolically bound (immobilized) by microorganisms, N_2O emission is reduced and rates of mineral fertilizers not exceeding 60-80 kg/ha (depending on culture) become environmentally acceptable. Introduction of straw does not require additional mineral nitrogen to optimize C/N ratio.

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