Dynamics of humus content during long-term application of fertilizers on gray forest soils of the Vladimir Opolye

Okorkov Vladimir Vasilyevich

Doctor of Agricultural Sciences, Head Research Officer

Upper Volga Federal Agrarian Scientific Center

Abstract. In a long-term stationary field experiment on gray forest soils, Vladimir Opolye studied the effect of prolonged use of fertilizers on the dynamics of the humus content in the arable layer. It was found that in the 1st rotation of an 8-field grain-grass-cultivated crop rotation, 1 ton of cattle manure increased the stock of humus by 55 kg/ha, and 1 kg of nitrogen of mineral fertilizers - by 9.8 kg/ha. For the 2nd (8-field) and 3rd (7-field) rotation and for the 2nd through 4th (7-field) rotation, the increase in humus reserves from 1 ton of manure and 1 kg of nitrogen of mineral fertilizers was 2 -3 times lower than in the 1st rotation. Without the use of mineral fertilizers and with the introduction of RK fertilizers after the 1st rotation, the humus reserves decreased annually by 270-310 kg/ha. It was revealed that the zero humus balance for the 2nd - 4th rotation was achieved with a nitrogen balance that was practically equal to zero. A further increase in the positive nitrogen balance only slightly increased the humus reserve in the soil.

Keywords: gray forest soil Vladimir Opolye, content and reserves of humus, organic and mineral fertilizers, regression equations.

In the fertility of most soils and agriculture in Russia, humus plays an extremely important role. It is the main source of nutrition for cultivated plants, the basis for regulating the physicochemical, colloidal-chemical and agrophysical properties of soils [1-4]. In recent years, with the growth in the use of chemical plant protection products in a market economy, its ecological role has significantly increased and with an increase in the humus content, the price of land [3, 5]. Therefore, the most important task of agriculture is its simple or extended reproduction. Domestic researchers have developed models of changes in the humus content for various agricultural uses [6-11].

The consumption of soil humus for the creation of a crop in the models is determined by the consumption of nitrogen by the crop, taking its content in humus to be about 5% [11]. It is estimated that in the Russian Federation, 0.6-1.1 t/ha of humus is annually spent on the formation of the crop. Due to stubble-root residues and organic fertilizers in the 80s of the XX century, it was replenished only in the Northern and North-Western economic regions due to the high number of livestock (one conventional head per 1 hectare of arable land) and the widespread use of peat. In other regions, humus reproduction was 55-85% [10].

On arable soddy-podzolic soils of the Non-Black Earth Region, the annual humus mineralization under various agricultural crops, calculated on the basis of the removal of soil nitrogen by them and refined by the materials of domestic and foreign long-term experiments, was (t/ha) under grain crops 0.5-1.0, tilled 1.5-2.5, pure pairs 2-3.5.

On gray forest soils, Vladimir Opolye also conducted studies on the effect of organic and mineral fertilizers on changes in the content and quality of humus [12-14]. However, these studies continued, and the models needed clarification and adjustment.

The purpose of the research is to assess the effect of fertilization systems on the dynamics of humus content and nitrogen balance for crop rotation, the conditions for ensuring a deficit-free humus balance in a long-term stationary experiment on the gray forest soils of Vladimir Opolye.

Methodology. The studies were carried out in a long-term stationary experiment, laid down in 1991-1993 [15]. The soil of the experimental fields is gray forest medium loamy with the following initial characteristics of the arable layer: humus content 2.9 ... 4.0%; rN_{KS1} - 5.1 ... 5.5; hydrolytic acidity (N_G) 3.2 ... 3.5, the amount of absorbed bases - 19.4 ... 22.4 mg-eq/100 g; the content of mobile phosphorus (according to Kirsanov) - 130 ... 200, exchangeable potassium (according to Maslova) - 150 ... 180 mg/kg of soil.

At the beginning of the 1st rotation, liming was carried out for complete hydrolytic acidity. Against this background, we studied the effect of various doses of bedding manure (0, 40, 60 and 80 t/ha), which was applied after harvesting annual grasses on hay, the effect of mineral fertilizers (0, RK, NPK, 2NPK) and their combination on the yield of field crops, changes in the agrochemical and chemical properties of gray forest soil.

In the first and second rotations, observations were carried out in an 8-field crop rotation with the following crop rotation: occupied fallow (vetch-oat mixture) - winter rye - potatoes - oats with over-sowing of grasses - grasses of the 1st year of use - grasses of the 2nd year of use - winter rye (spring wheat in the 2nd rotation) - barley.

In the 1st rotation, a single dose of NPK for cereals, annual and perennial grasses was equal to 40 kg/ha of each nutrient, for potatoes - 60, 60 and 80 kg/ha; for grasses of the 1st year of use, a double dose of full mineral fertilizer was N40P80K80. For spring wheat after grasses of the 2nd year of use in the 2nd rotation, N60P60K60 was used as a single dose, and N120P120K120 was used as a double dose. In 2000-2008, phosphorus-potassium fertilizers were not used for annual grasses; instead of N40P40K40 and N80P80K80, only N60 and N75 were applied in the spring.

Ammonium nitrate, double superphosphate (simple superphosphate) and potassium chloride or potassium salt were used. Phosphorus-potassium fertilizers were applied in the fall for the main soil cultivation, nitrogen fertilizers - in the spring for pre-sowing cultivation, for feeding winter and perennial grasses, for potatoes - in the spring for plowing.

In the 3rd and 4th rotations, after a busy fallow, winter (spring) wheat was sown, cultivated crops were excluded, the following fertilizer doses were used for winter and spring wheat after grasses of the 2nd year of use: P40K40, N40P40K40 and N80P80K80 (double dose).

During harvesting, the straw of grain crops was crushed and scattered over the field, then plowed.

The humus content in the soil was determined by the Tyurin method modified by Nikitin.

Results and its discussion. At the end of the 1st rotation of an 8-field crop rotation in fields 1 and 2, we studied the relationship between the humus content and the average annual use of organic (cattle manure) and mineral fertilizers per rotation. The humus content increased from the use of both organic and mineral fertilizers (tab. 1).

Table 1 - Influence of fertilization systems on the change in the content and reserves of humus for the 1st rotation of an 8-field crop rotation in the topsoil

Indicator	Relationship equation (n = 16)	R^2
Field 1 (1998)		
Humus, %	$3.48 + 0.0197\ x_1 + 0.0025\ x_2$	0.929
Field 2 (1999)		
Humus, %	$3.25 + 0.0136\ x_1 + 0.0034\ x_2$	0.837
	$3.22 + 0.0048\ x_2 + 0.0023\ x_1^2 - 0.0002\ x_1x_2$	0.947
Average for fields 1 and 2 (1998-1999)		
Humus, %	$3.36 + 0.0169\ x_1 + 0.0030\ x_2$	0.952
	$3.38 + 0.0030\ x_2 + 0.0017\ x_1^2$	0.974
Humus reserves in the soil layer 0-20 cm, kg/ha	***Field 1 (1998)***	
	$90480 + 64.0\ z_1 + 8.12\ z_2$	0.929
	Field 2 (1999)	
	$84500 + 44.2\ z_1 + 11.0\ z_2$	0.837
	Average for fields 1 and 2 (1998-1999)	
	$87360 + 54.9\ z_1 + 9.8\ z_2$	0.947
Note. x_1 - average annual dose of manure application, t/ha; x_2 – average annual application rate of ammonium nitrate nitrogen, kg/ha; z_1 and z_2 – total doses of manure (t/ha) and N fertilizers (kg/ha) per crop rotation.		

It should be borne in mind that in the relationship between the humus content (%) and the average annual doses of manure and mineral fertilizers, the coefficients in front of x_1 and x_2 represent the sum of their influence on the change in the humus content during rotation (in this case, over 8 years). So, for example, the effect of 1 ton of organic fertilizers on the increase in humus reserves in the 0-20 cm layer per rotation for the 1st field can be calculated as follows (coefficient at z_1):

$z_1 = 0.0197: 8 \times 26000 = 64.2$ (kg/ha of humus), where 26000 kg/ha is the mass of humus corresponding to 1% of its content in the soil layer 0-20 cm (bulk density of the soil layer 0-20 cm 1.3 g/cm^3).

1 ton of manure containing 4.2 kg of nitrogen, on average in 2 fields, increased the humus content in the arable layer by 55 kg, and 1 kg of ammonium nitrate nitrogen - by 9.8 kg. The value of the standard coefficient of humus formation from 1 ton of manure coincided with the results of generalization by the ARRIOFP researchers [9].

The degree of nitrogen immobilization of mineral fertilizers in the 1st rotation of the crop rotation varied from 47 to 65%. Its high average size (56%) for gray forest soils of Opolye (in comparison with light soddy-podzolic soils of the southern taiga subzone [16]) is quite consistent with the increased absorption properties of soils with a heavier granulometric composition. Gray forest soils contained mixed-layer clay minerals in the silty fraction and were characterized by a high degree of AUC saturation with calcium and magnesium ions.

Since the balance of humus in the soil closely correlates with the balance of nitrogen, the balance of the latter in the variants of using only organic fertilizers was used to calculate the annual dose of manure, which ensures a deficit-free balance of humus. So, according to the results of the experiment described above in an 8-field crop rotation (field 1), when 40, 60 and 80 t/ha of bedding manure were applied in a busy pair per rotation, the nitrogen balance was –10.4, –3.4 and + 6, respectively, 7 kg/ha. Hence, a deficit-free balance of nitrogen and, accordingly, humus on gray forest soils of Opolye in the 1st rotation was observed at an average annual dose of manure of 8.3-8.5 t/ha, which coincided with the results of the model developed for the Vladimir region with the initial content of C humus 2.0% [10].

From the data (tab. 2), which shows the dynamics of the humus content in the arable layer at the end of the 1st through 4th rotations of crop rotation in field № 1, it can be seen that the maximum decrease in the humus content in the 4th rotation in comparison with the 1st d was observed in variants without the use of mineral and organic fertilizers, as well as the application of phosphorus-potassium fertilizers (-0.21 ... -0.28%). The use of a single dose of complete mineral fertilizer kept the amount of humus loss down to -0.09%. A double dose of NPK already provided a positive balance of organic matter (+ 0.04%).

Table 2 - Dynamics of humus content by crop rotation rotations in field № 1, %

Test option	Crop rotation, year			
	1-st, 1998	2-nd, 2006	3-rd, 2013	4-th, 2020
1. Control	2.88	2.89	2.69	2.60
2. Lime (background – B)	3.79	3.82	3.61	3.52
3. B + RK	3.70	3.71	3.61	3.49
4. B + NPK	3.16	3.09	3.15	3.07
5. B + 2 NPK	3.06	3.08	3.12	3.10
6. B + H40	3.08	3.04	2.96	2.87
7. B + H60	3.28	3.28	3.24	3.28
8. B + H80	3.08	3.04	3.10	3.07

9. B + H40 + RK	3.12	3.03	3.00	2.95
10. B + H40 + NPK	3.56	3.49	3.58	3.56
11. B + H40 + 2 NPK	3.59	3.62	3.64	3.63
12. B + H60 + RK	3.34	3.34	3.29	3.30
13. B + H60 + NPK	3.53	3.52	3.65	3.54
14. B + H60 + 2 NPK	3.44	3.43	3.52	3.44
15. B + H 80 + RK	3.42	3.40	3.43	3.44
16. B + H80 + NPK	3.72	3.75	3.78	3.70
17. B + H80 + 2 NPK	3.42	3.40	3.52	3.53
Average per rotation	3.37	3.35	3.35	3.30

When using a single dose of NPK, the yield of cultivated crops increased sharply [15], which ensured a noticeable increase in the supply of stubble-root residues. Their transformation led to the replenishment of soil humus reserves, mineralized during the growing season of crops. With the introduction of a double dose of complete mineral fertilization, the annual productivity of crops in the crop rotation increased by 2-3 c/he of soil, which increased the amount of humus replenishment due to plant residues. This was also facilitated by the higher participation of mineral fertilizers in the nutrition of crops in comparison with soil nitrogen.

It was also revealed that in the 4th rotation the humus content in the variants without the use of mineral fertilizers (1st and 2nd), the use of RK fertilizers continued to decrease. In comparison with the 3rd rotation in the 4th due to the increase in crop yields, the removal of nutrients, including nitrogen, increased. This led to a slight decrease in the humus content in this rotation in the applications of a single dose of NPK, its combination with organic fertilizers.

The processing of the data on changes in the humus content for 15 and 22 years (tab. 3) according to the parameters of the two-factor field experiment confirmed the decisive role of complete mineral and organic fertilizers in the influence on this parameter of fertility. On average, according to the variants of application of 0, 40, 60 and 80 t/ha of manure per rotation, a tendency for a higher decrease in the humus content in the variants without the use of nitrogen mineral fertilizers was observed, by 1.54-1.59 and 1.52 times, respectively.

Table 3 - Change in the content of organic matter in the 3rd and 4th rotations in comparison with the 1st,% (in the control, respectively -0.19 and -0.28%), field № 1

Manure dose per rotation, t/ha	**Mineral fertilizers**				Average for manure
	0	R240K240	N300P240K240	N515P480K480	
3rd rotation compared to 1st (1998-2013)					
0	-0.18	-0.09	-0.01	+0.06	-0.055
40	-0.12	-0.12	+0.02	+0.05	-0.043
60	-0.04	-0.05	+0.12	+0.08	+0.028
80	+0.02	+0.01	+0.06	+0.10	+0.048
Average for min. fertilizers	-0.080	-0.063	+0.048	+0.073	

4th rotation compared to 1st (1998-2020)					
0	-0.27	-0.21	-0.09	+0.04	-0.132
40	-0.21	-0.17	+0.00	+0.04	-0.082
60	+0.00	-0.04	+0.01	0.00	-0.008
80	-0.01	+0.02	-0.02	+0.11	+0.025
Average for min. fertilizers	-0.123	-0.100	-0.025	+0.048	

From phosphorus-potassium fertilizers, compared with options without mineral fertilizers (for the same options for using manure), a slight slowdown in the decrease in humus content was observed (from -0.080 to -0.063% for the 2nd and 3rd rotations and from -0.123 to -0.100 % for the 2nd, 3rd and 4th rotations). A more noticeable effect on the change in this parameter was observed from the use of a single dose of NPK. During the 2nd and 3rd rotations, the change in the humus content increased to 0.048%, during the 2nd to 4th rotations - from -0.123 to -0.025%. The use of a double dose of NPK increased this parameter to 0.073 and 0.048%, respectively (from -0.080 and -0.123%).

From the use of organic fertilizers in doses of 40 and 80 t/ha for the 2nd to 4th rotations (on average for 4 levels of application of mineral fertilizers), the decrease in the humus content was 1.9 times higher than for the 2nd and 3rd rotation (tab. 3).

Models of changes in humus content depending on fertilization systems (tab. 4) confirmed the decisive influence of the use of organic and nitrogen fertilizers on its increase. So, for the 2nd and 3rd rotations, 83.6% of the variation in the change in the humus content accounted for these fertilizers, the effect of phosphorus-potassium and their combination with organic - no more than 11.2%. For 1998-2020, this parameter changed by 86-89% under the influence of organic and nitrogen fertilizers and their interactions. Phosphorus-potassium fertilizers, in comparison with the background of liming, had little effect on the formation of humus.

Table 4 – Correlation of changes in the content and reserves of organic matter in the arable layer for the 3rd (over 15 years) and 4th (22 years) rotation of crop rotations compared to the 1st with the average annual use of fertilizers in field № 1

Parameter change over years of research	Number of years	Relationship equation	n	R^2	Dov. interval
% of humus for 1998-2013	15	$-0.13 + 0.0096x_1 + 0.0019x_2$	16	0,836	0,07
		$-0.16+0.0017x_2+0.0015x_3+0.0016x_1^2 – 0.0002x_1x_3$		0,948	0,04
% of humus for 1998-2020	22	$-0.204 + 0.0153x_1 + 0.0020x_2$	16	0,732	0,12
		$-0.256+0.0240x_1+0.0037x_2-0.0003x_1x_2$		0,857	0,092
% of humus for 1998-2020	22	$-0.22 + 0.0167x_1 + 0.0021x_2$	17	0,771	0,12
		$-0.26 + 0.0247x_1+0.0038x_2-0.0003x_1x_2$		0,887	0,09

humus reserves per year, kg/ha (1998-2013)	15	$-218 + 16.3x_1 + 3.21\ x_2$	16	0,842	120
		$-266+2.90x_2+2.30x_3+2.68x_1^2-0.31x_1x_3$		0,952	72
humus reserves per year, kg/ha (1998-2020)	22	$-241 + 18.2x_1 + 2.4x_2$	16	0,732	140
		$-303 + 28.3x_1 + 4.4x_2 - 0.36x_1x_2$		0,857	107
humus reserves per year, kg/ha (1998-2020)	22	$-260 + 19.8x_1 + 2.5\ x_2$	17	0,771	140
		$-307 + 29.4x_1 + 4.5x_2 – 0.36x_1x_2$		0,887	104
Notes. x_1 – average annual dose of organic fertilizers application, t/ha; x_2 – average annual application rate of ammonium nitrate nitrogen, kg/ha; x_3 – average annual dose of phosphorus-potassium fertilizers per P_2O_5, kg/ha. At n = 16, changes in the content and reserves of humus were calculated from the background of liming.					

In the 2nd and 3rd rotations in options without the use of organic and mineral fertilizers, there was an annual decrease in humus reserves in the 0-20 cm layer in the amount of about 270 kg/ha, and in the 2nd through 4th rotations - about 310 kg/ha. In the first case, 1 ton of cattle manure increased humus reserves in the soil by at least 16.3 kg/ha, in the second - 18.2-29.4 kg/ha, and 1 kg of nitrogen of mineral fertilizers - by 2.9-3, respectively, 2 and 2.4-4.5 kg/ha. These parameters are 2 times or more lower than in the 1st rotation of the crop rotation. These data indicate that without the use of mineral and organic fertilizers with existing agricultural technologies, the humus state deteriorates and the fertility of the gray forest soil in grain-grass crop rotations decreases. The use of fertilizers helps to reduce biological erosion of Opolye gray forest soils. Therefore, it is necessary to determine the conditions under which a zero or positive humus balance is achieved. One of the ways to solve this problem is to study the relationship between nitrogen and humus balances.

Table 5 presents data on the weighted average annual nitrogen balance for 3 rotations (2-4) and the average annual humus balance for the same period, calculated by the quadratic dependence for 17 variants (tab. 4). Their analysis showed that for 14 of 17 variants, excluding variants 14, 16 and 17, a close linear relationship was obtained between the nitrogen and humus balances:

$$y = -13{,}0 + 13{,}1\ x,\ n = 14,\ \ r = 0{,}983,\ r^2 = 0{,}967,\ \text{conf. int.} = 50,$$

where 4.5>x>-23.7 (kg/ha nitrogen) is the weighted average annual nitrogen balance for 2-4 crop rotations; 55>y> -307 (kg/ha of humus) - the average annual balance of humus for 2-4 rotations of crop rotations.

The zero humus balance is set at an average weighted annual nitrogen balance of 1.0 kg/ha.

Table 5 – Influence of fertilizers on the weighted average annual nitrogen balance and the average annual humus balance for the 2nd to 4th rotation of crop rotations on gray forest soils, kg/ha

Option №	Weighted average nitrogen balance	Average annual humus balance	Option №	Weighted average nitrogen balance	Average annual humus balance
1	-23.6	-307	10	-2.5	-36

2	-20.8	-307	11	3.4	51
3	-23.7	-307	12	-1.8	-71
4	-9.9	-110	13	1.8	0
5	3.5	44	14	13.9	54
6	-8.9	-149	15	-0.5	8
7	-0.3	-24	16	5.0	36
8	4.5	55	17	25.0	58
9	-6.6	-149			

Note. The designation of the options is the same as in table 2.

Consequently, the zero humus balance on the gray forest soils of Vladimir Opolye is achieved when the nitrogen balance is practically equal to zero. Further growth of the positive nitrogen balance only slightly increased the humus balance in the soil. A fairly stable dynamic equilibrium is established between the formation of humus and its mineralization. It depends on the soil and climatic conditions and agricultural technologies for the cultivation of agricultural crops (crop rotation, fertilization and processing systems, protective measures), primarily on the type of crop rotation.

References

1. Orlov, D.S. Soil Chemistry / D.S. Orlov. – M.: Publishing house of MSU, 1985. – 376 P.

2. Assessment of soils by the content and quality of humus for production models (Recommendations). Responsible editors: corr.-member VASKhNIL L. L. Shishov, cand. agr. sci. K.V. Dyakonov. Soil Institute named after V.V. Dokuchaev. M.: VO "Agropromizdat", 1990. – 28 P.

3. Lykov A.M., Eskov A.I., Novikov N.M. Organic matter of arable soils in the Non-Black Earth Region (relevance and state of the problem, working hypotheses of research, conjugation of agronomic and ecological functions, dynamics in agrocenoses, principles of modeling and reproduction technologies). – Moscow: Russian Agricultural Academy – GNU ARRIOFP, 2004. – 630 P.

4. Okorkov V.V., Okorkova L.A., Fenova O.A. Changes in the physicochemical properties of gray forest soils Opolye with prolonged use of fertilizers // Russian agricultural science, 2015, № 3. – P. 34-38. DOI 10.3103/S1068367415040151.

5. Danilova N.I., Sapozhnikov P.M. Comparative characteristics of the cadastral value of soils of agricultural lands in the Kaliningrad and Pskov regions // Modern trends in scientific support of the agro-industrial complex. Ivanovo. 2020. P. 20-25.

6. Kulakovskaya, T.N. Soil and agrochemical bases for obtaining high yields. - Minsk: Harvest, 1978. – 272 P.

7.Lykov A.M. Humus and soil fertility. – M.: Moscow worker, 1985. – 192 P.
8. Mineev, V.G. Studies of the balance of humus in sod-podzolic soils based on mathematical modeling / V.G. Mineev et al. // Reports of VASKhNIL, 1986, № 2. – P. 7-10.
9. Popov, P.D. Organic fertilizers: Handbook / P.D. Popov, V.I. Khokhlov, A.A. Egorov et al. – M.: Agropromizdat, 1988. - 207 P.
10. Romanenkov, V.A. Methodology for using information from long-term field experiments for solving monitoring problems and issuing well-grounded forecasts of the dynamics of carbon stocks in agroecosystems of the ETR. Romanenkov, L.K. Shevtsova, O.D. Sirotenko // Influence of long-term use of fertilizers on soil organic matter. M.: VNIIA, 2010. – 352 P.
11. Dynamics of the humus balance in the arable lands of the Russian Federation. M.: Ros-NIIzemproekt, 1998. – 60 P.
12. Korchagin A.A., Ilyin L.I., Okorkov V.V., Vinokurov I.Yu. Influence of long-term use of fertilization systems on the content and quality of humus-gray forest soils Vladimir Opolye // Achievements of science and technology of the agro-industrial complex. 2013. № 4. P. 3-6.
13. Okorkov V.V., Okorkova L.A., Fenova O.A. Changes in humus content on gray forest soils with prolonged use of fertilizers // Russian agricultural science. 2016. № 1. P. 21-26.
14. Okorkov V.V., Okorkova L.A., Fenova O.A. The influence of long-term use of fertilizers on the group composition of the organic matter of gray forest soils of Opolye // Agrochemistry. 2017. № 10. P. 3-15. DOI: 10.7868/S0002188117100027.
15.Okorkov V.V., Fenova O.A., Okorkova L.A. Methods for the integrated use of chemicals in crop rotation on gray forest soils of the Upper Volga region in agricultural technologies of varying intensity. FSBSI "Vladimir RIA". – Suzdal, 2017. 176 P.
16. Mineev V.G. Chemicalization of agriculture and the natural environment. – M.: Agropromizdat, 1990. – 287 P.