

Assessment of the impact of agricultural technologies on the fertility, health and stability of chernozem

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Abstract. This study aimed to comprehensively evaluate the effects of agricultural technologies on the quality, health, and stability of slightly eroded chernozem in grain crop rotation using the author's methodology. The research was conducted on the experimental field of the Kursk FANC from 2018 to 2021. Three agricultural technologies were tested: a traditional method with crushed by-products (PP), agrobiotechnology-1 (PP and microbiological preparations), and agrobiotechnology-2 (agrobiotechnology-1 + 10 kg a.i. N per 1 t of PP). The results showed that all technologies had a satisfactory impact on soil fertility, health, and stability, with most indicators remaining unchanged. Agrobiotechnology-1 had a good impact on soil fertility and stability and an excellent impact on soil health. Agrobiotechnology-2 had an excellent impact on soil, with significant and highly significant increases in most indicators. The comprehensive assessment indicated that agrobiotechnology-2 had the highest overall impact, with a Kcomp value of 21.4%.

1 Introduction

Irrational agricultural use of soils with insufficient supply of organic fertilizers, intensification of crop cultivation technologies, frequent mechanical tillage, use of pesticides, expansion of the cultivation of row crops and a decrease in perennial grasses leads to degradation and a decrease in their fertility and quality [1]. The most common main types of soil degradation in the Central Chernozem region are acidification, dehumification, destructuring and water erosion.

Due to the constant increase in anthropogenic pressure on soils caused by agricultural work, the issue of assessing their condition is acute. The problem of land valuation, due to its complexity, is distinguished by a wide variety of approaches and methods. V. I. Kiryushin [2] points out that in modern environmental management, land valuation is becoming increasingly differentiated. As noted by A.G. Konovalov et al. [3], the ecosystem approach, which is based on the hypothesis that only such a state of ecosystems can be normal, is becoming increasingly widespread among approaches to regulating soil quality, in which

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they maintain their integrity and the closedness of the cycle of substances. It is proposed to use as indicators of ecosystem stability: the balance of humus in the soil, indicators of the preservation of the vertical and horizontal structure of the phytocenosis, indicators of soil productivity and fertility (closedness of biogeochemical cycles of the main elements of nutrients, etc.) [4].

Currently, important attention in the scientific literature is paid to the comprehensive assessment of agricultural lands, modern approaches to environmental regulation of soil quality, including environmental monitoring of soil condition, the importance of chemical, physical and biological indicators in assessing soil quality [2-9]. Recently, when developing approaches to assessing the ecological state of soils, scientists are increasingly focusing on methods based on diagnosing changes in the biotic and abiotic components of soils. It is noted that in Russia, comprehensive studies using bioindication indicators, in particular, soils in agroecosystems, have not yet acquired a systematic form, and the existing studies are fragmentary.

Under these conditions, it is very important to control the impact of applied agricultural technologies on changes in the fertility of chernozem soils. However, issues of a comprehensive assessment of the impact of agricultural technologies on fertility,

Soil health and resilience are not well understood.

The purpose of these studies was to conduct a comprehensive and differentiated assessment of the impact of agricultural technologies in grain crop rotation on the fertility, health and sustainability of typical slightly eroded chernozem based on the author's methodology [9].

2 Materials and methods

Changes in soil properties and crop yields under the influence of agricultural technologies were studied in 2018-2021. on the experimental field of the Federal State Budgetary Institution "Kursk FARC" (Kursk region, Kursk district, Panino village) on an experiment with biological products in grain crop rotation with the following crop rotation: spring barley (*Hordeum vulgare L.*) varieties Suzdalets - buckwheat (*Fagopyrum esculéntum L.*) varieties Demeter – broad beans (*Vicia Faba L.*) Streletskie variety - winter wheat (*Triticum aestivum L.*) Leonid variety.

The assessment of the impact of agricultural technologies in grain crop rotation on the quality, health and stability of typical slightly eroded chernozem was carried out using three agricultural technologies: 1. agricultural technology - generally accepted for the region with the introduction of crushed by-products; 2. agrobiotechnology-1, including the treatment of seeds, soil with biological preparations before sowing, sowing twice, crushed by-products after harvesting and their incorporation into the soil; 3. agrobiotechnology-2 includes agrobiotechnology-1 + 10 kg a.i. N per 1 ton of crushed by-products.

The microbiological preparation Gribofit (G) was used as biological preparations, containing spores and mycelium of the fungus *Trichoderma viride*, as well as biologically active substances produced by the fungus during industrial cultivation (antibiotics, enzymes, vitamins, phytohormones), environmentally friendly, with biofungicidal, growth-stimulating and phosphate-mobilizing properties. The second was the microbiological preparation Imunazot (I), containing the rhizosphere bacteria *Pseudomonas aureofacieens*, a biofungicide, growth stimulant, phosphate mobilizer of contact and systemic action [10]. Seeds of agricultural crops were treated with 2 l/t G + 3 l/t I, soil before sowing 3 l/ha G + 2 l/ha I, crops 3 l/ha G + 2 l/ha I twice during the growing season, crushed by-products after harvesting 5 l/ha G + 3 l/ha and before incorporation into the soil.

The counting area of the plots was 600 m² (12×50), repetition - 3. The processing of crushed by-products with biological products was carried out with an OP-2000/24 sprayer,

the application of ammonium nitrate was carried out with a mounted spreader RN-0.8, and the incorporation of crushed plant residues into the soil was carried out with disc harrows to a depth of 10-12 cm.

The soil of the experimental plot is typical slightly eroded, heavy loamy chernozem. Agrochemical characteristics of the arable (0-20 cm) soil layer: humus content according to Tyurin - 5.13-5.61%; alkaline hydrolyzable nitrogen – 162-168 mg/kg, mobile (according to Chirikov) phosphorus – 102-128 mg/kg and potassium – 115-181 mg/kg; exchangeable calcium – 214-216 mEq/kg, the reaction of the medium is slightly acidic (pHKCl – 5.3±0.1).

In soil samples taken in a layer of 0-20 cm from 5 points in 2018 and 2021. in the fall, 1.5 months after the incorporation of crushed by-products into the soil, the following was determined: the humus content according to the Tyurin method (GOST 26213-91), the content and composition of mobile humic substances - in a 0.1 N NaOH extract from the soil without decalcification as modified by the V.V. Dokuchaev Soil Institute with preliminary composting, the carbon content of microbial biomass in fresh soil samples - by the rehydration method, alkaline hydrolyzed nitrogen (Nshg) - according to Kornfield; pH aq. – potentiometrically, pHKCl – in 1.0 N KCl extract (GOST 26483-85); exchangeable calcium and magnesium – according to GOST 26487-85, mobile phosphorus and potassium – according to the Chirikov method (GOST 26204-91); structural and aggregate composition - according to the method of N.I. Savvinova - dry and wet sifting; the number of microorganisms involved in the carbon and nitrogen cycle, by sowing a soil suspension on appropriate nutrient media: ammonifying, using organic nitrogen, on meat-peptone agar (MPA), amylolytic, using mineral nitrogen, on starch-ammonia agar (CAA), microscopic mushrooms (micromycetes) - on Chapek's medium; the rate of decomposition of plant residues in the soil - according to the author's method [12]; indicator of the stability of organic matter in the soil according to the author's method [1]; soil phytotoxicity - according to the international standard ISO 11269-2:2012, absolute control was the results obtained when using distilled water. Radish seeds (*Raphanus sativus L.*) were used as a test culture.

A comprehensive and differentiated assessment of the impact of agricultural technologies in grain crop rotation on the quality, health and stability of typical slightly eroded chernozem was carried out based on the author's methodology [10]. A comprehensive indicator for assessing the impact of agricultural technologies on the fertility, health and sustainability of chernozem soils was determined using the formula we developed: $K_{comp} = 0 \cdot P_1 + 0,1 \cdot P_2 + 0,2 \cdot P_3 + 0,3 \cdot P_4$, where K_{comp} is a complex indicator for assessing agricultural technologies, %; P_1, P_2, P_3, P_4 - occurrence of levels of change in indicators, %; 0; 0.1; 0.2; 0.3 - weighting coefficients of the levels of change in indicators, respectively, first, second, third, fourth. The occurrence of indicators of each level is determined by the formulas: $P_1 = (a_1 \cdot 100)/n$; $P_2 = (a_2 \cdot 100)/n$; $P_3 = (a_3 \cdot 100)/n$; $P_4 = (a_4 \cdot 100)/n$; where a_1, a_2, a_3, a_4 – the number of indicators found in each level; n – total number of indicators; 100 – conversion to %. The impact of agricultural technologies on the fertility, health and stability of chernozem soils was assessed using a scale we developed depending on the value of the complex indicator: <9 – unsatisfactory, 9-14 – satisfactory, 14-19 – good, >19 – excellent [10].

3 Results and discussion

For a differentiated assessment of the impact of agricultural technologies in grain crop rotation on the fertility of chernozem soils based on the author's methodology and private assessment criteria [10] for the 13 most significant indicators of soil fertility, closely related to the productivity of agricultural plants, depending on the degree of their change in relation to the control or to initial state for 2018-2021. the levels of change in indicators for three agricultural technologies were determined (Table 1).

Table 1. Levels of change in indicators of fertility, health and stability of typical slightly eroded chernozem for 2018-2021. depending on the agrogenic impact in the arable layer to evaluate agricultural technologies according to private criteria.

#	Indicator	Agro-technology	Agro-technology 1	Agro-technology 2
According to soil fertility indicators				
1	Organic carbon content	3	4	4
2	Content of mobile humic substances	1	2	2
3	Quality of mobile humic substances	1	2	4
4	Microbiological indicators (MPA, KAA, micromycetes)	2	3	3
5	Rate of decomposition of plant residues	1	4	4
6	Alkali hydrolyzable nitrogen content	2	3	3
7	Mobile phosphorus content	2	3	3
8	Mobile potassium content	2	3	3
9	Exchangeable calcium content	2	2	2
10	pH _{H2O}	2	2	2
11	pH _{KCl}	2	2	2
12	Sum of agronomically valuable aggregates	3	4	4
13	Sum of water-resistant units	2	3	3
Based on soil health				
1	Humus content	2	3	3
2	Microbial biomass content	2	3	3
3	Humus balance, t/ha	2	3	4
4	Carbon content of non-humified soil organic matter, % of soil organic carbon	3	4	4
5	Soil toxicity	2	3-4	3-4
On soil resistance to agrogenic influences				
1	Changes in soil organic carbon content over time	2	3	4
2	Indicator of stability of organic matter in soil	2	2	2
3	Crop yield	2	3	4

For agricultural technology, the change in the content and quality of mobile humic substances, as well as the rate of decomposition of plant residues corresponded to the first level ($a_1=3$, where a is the number of indicators found in each level), i.e. decrease. Changes in the amount of microbiological indicators (MPA, KAA, micromycetes), alkaline hydrolyzable nitrogen, mobile phosphorus and potassium, exchangeable calcium, pH_{H2O}, pH_{KCl} and the sum of water-stable aggregates are assigned to the second level ($a_2=8$), i.e. remained at the same level. The degree of change in organic carbon content and the sum of agronomically valuable aggregates corresponded to the third level ($a_3=2$) and a significant increase in indicators $> HCP_{05}$.

With agrobiotechnology-1, a decrease in the values of indicators ($a_1=0$) was not noted, i.e. no decrease was observed. Five indicators ($a_2=5$), while maintaining their values at the same level, are assigned to the second level, these are: the content and quality of mobile humic substances, the content of exchangeable calcium, pH_{H2O}, pH_{KCl}. The degree of change

in the number of microbiological indicators (MPA, KAA, micromycetes), the content of alkali-hydrolyzable nitrogen, mobile phosphorus and potassium, exchangeable calcium, the sum of water-resistant aggregates corresponded to the third level ($a_3=5$) and a significant increase $> HCP_{05}$; and for three indicators ($a_4=3$) a high significant increase of $\geq 1.3 \cdot HCP_{05}$ was noted, these are: for the content of organic carbon, the rate of decomposition of plant residues and the amount of agronomically valuable aggregates.

A decrease (level 1) in the values of soil fertility indicators with agrobiotechnology-2 was not detected ($a_1=0$). Four indicators are assigned to the second level ($a_2=4$) while maintaining the values at the same level, these are: the content of mobile humic substances, exchangeable calcium, pH_{H_2O} , pH_{KCl} . Five indicators corresponded to the third level and a significant increase in $>NSR_{05}$ in terms of the degree of change: the number of microbiological indicators (MPA, CAA, micromycetes), the content of alkaline hydrolyzable nitrogen, mobile phosphorus and potassium, and the sum of water-stable aggregates ($a_3=5$). And for four indicators ($a_4=4$) a high significant increase of $\geq 1.3 \cdot HCP_{05}$ was established, this is: for the content of organic carbon, the quality of mobile humic substances, the rate of decomposition of plant residues and the sum of agronomically valuable aggregates.

For a differentiated assessment of the impact of agricultural technologies in grain crop rotation on the state of soil health based on the author's methodology and assessment scales [9] for their five most significant properties that determine the fertility and quality of the soil, closely related to the productivity of agricultural soils, affecting the living inhabitants of the soil (soil microbiocenosis and mesofauna), depending on the degree of their change in relation to the control or to the initial state for 2018-2021. the levels of change in indicators for three agricultural technologies were determined (Table 1).

With agricultural technology, the soil in terms of content (low humus) and balance of humus (slightly deficient), soil toxicity ($ITF = 0.5-0.9$), maintaining microbial biomass values at the same level is limitedly healthy ($a_2 = 4$) (level 2), and according to the carbon content of non-humified organic matter in the soil (5-7%) – healthy ($a_3=1$) (level 3). For agrobiotechnology-1, the soil is healthy in terms of humus content (medium humified), humus balance (non-deficient), in terms of a significant increase $>HCP_{05}$ in microbial biomass, soil toxicity (0.91-1.10) ($a_3=4$) (level 3), and in terms of the carbon content of non-humified organic matter in the soil ($>7\%$), it is also healthy, but belongs to level 4. With agrobiotechnology-2, the soil is healthy (level 3) in terms of humus content (medium humified), soil toxicity (0.91-1.10), in terms of a significant increase in $> HCP_{05}$ microbial biomass ($a_3=3$), in terms of humus balance (positive) and the carbon content of non-humified organic matter in the soil ($>7\%$) is also healthy at level 4 ($a_4=2$).

For a differentiated assessment of the impact of agricultural technologies in grain crop rotation on soil resistance to agrogenic influences based on the author's methodology and assessment scales for the three most significant properties and indicators that determine it and are closely related to the productivity of agricultural soils, depending on the degree of their change in relation to the control or to the initial state for 2018-2021. the levels of change in indicators for three agricultural technologies were determined (Table 1).

With agricultural technology with the incorporation of crushed by-products, the second level of change ($a_2=3$) was revealed for all three indicators of soil resistance to agrogenic influences. At the same time, the content of organic carbon in the soil remained at the same level, the stability of organic matter in the soil was average (61-90%), and crop yields corresponded to the control. For agrobiotechnology-1, for one indicator of soil resistance to agrogenic influences, namely the indicator of stability of organic matter in the soil (average = 61-90%), a second level of change was identified ($a_2 = 1$). At the same time, the content of organic carbon in the soil increased significantly $> HCP_{05}$, and the yield of agricultural crops was significantly higher $> HCP_{05}$ than in the control, which corresponded to the 3rd level of changes ($a_3 = 2$). With agrobiotechnology-2 soil, the indicator of stability of organic matter

in the soil was average (61-90%) and corresponded to the second level ($a_2=1$). And the increase in the content of organic carbon in the soil over the assessed period was highly significant $\geq 1.3 \cdot HCP_{05}$, the crop yield (U) was significantly greater than $U \geq 1.2 \cdot U_c$ compared to the control (U_c), which corresponded to the 4th level of changes ($a_4=2$).

Based on the assessed levels of change in indicators using the formula presented above and developed by us, we calculated a comprehensive indicator of differentiated assessment of agricultural technologies for changes in soil fertility indicators (Kcomp1), soil health status (Kcomp2), soil stability (Kcomp3), as well as a comprehensive assessment of agricultural technologies (Kcomp) for changes in all studied indicators (Table 2). The complex indicator was assessed using the scale presented in Section 2.

According to differentiated (Kcomp1=9.2%; Kcomp2=12.0%, Kcomp3=10.0%) and complex (Kcomp=10.0%) assessments, a satisfactory impact of agricultural technology on the fertility, health and stability of typical slightly eroded chernozem has been established. This indicates that most indicators of soil fertility, health and stability remained at the same level and there was no deterioration in some indicators. The impact of agrobiotechnology-1 on the fertility and stability of typical chernozem according to a differentiated assessment (Kcomp1 = 18.4%; Kcomp3 = 16.6%) is characterized as good, and on soil health (Kcomp2 = 22.0%) is excellent. The results of a comprehensive (Kcomp = 19.0%) assessment for all indicators indicate a good impact of agrobiotechnology-1 on the fertility, health and stability of typical slightly eroded chernozem, while most indicators of fertility, health and stability of the soil corresponded to the third level, there was a significant increase in them ($>HCP_{05}$).

Table 2. Differentiated and comprehensive assessment of agricultural technologies using a comprehensive indicator (Kcomp).

Agrotechnology	Calculation of the components of a complex indicator				Complex indicator, %	Mark
	1	2	3	4		
Differentiated - according to soil fertility indicators (Kcomp1)						
Agrotechnology	0	6.1	3.1	0	9.2	satisf
Agrobiotechnology -1	0	3.8	7.7	6.9	18.4	good
Agrobiotechnology -2	0	3.1	7.7	9.2	20.0	exc
Differentiated - according to soil health (Kcomp2)						
Agrotechnology	0	8.0	4.0	0	12.0	satisf
Agrobiotechnology -1	0	0	16.0	6.0	22.0	exc
Agrobiotechnology -2	0	0	12.0	18.0	30.0	exc
Differentiated - according to soil resistance to agrogenic influence (Kcomp3)						
Agrotechnology	0	10.0	0	0	10.0	satisf
Agrobiotechnology -1	0	3.3	13.3	0	16.6	good
Agrobiotechnology -2	0	3.3	0	20.3	23.6	exc
Comprehensive assessment of all indicators (Kcomp)						
Agrotechnology	0	7.14	2.86	0	10.0	satisf
Agrobiotechnology -1	0	2.9	10.4	5.7	19.0	good
Agrobiotechnology -2	0	2.4	7.6	11.4	21.4	exc

It has been established that the impact of agrobiotechnology-2 on the fertility, health and stability of typical slightly eroded chernozem is differentiated (Kcomp1=20.0%; Kcomp2=30.0%; Kcomp3=23.6%) and complex (Kcomp=21.4%) the ratings were excellent. This means that more than 60% of the indicators of fertility, health and stability of the soil corresponded to the third and fourth levels, their significant ($> HCP_{05}$) and high significant increase ($> 1.3 HCP_{05}$) was noted, and in terms of crop yields (U), accordingly, a significant increase compared to the control ($> HCP_{05}$) or a high significant increase compared to the control ($U \geq 1.2 \cdot U_k$).

4 Conclusion

Thus, the results of a comprehensive and differentiated assessment of the impact of agricultural technologies for 2018-2021. in grain crop rotation on typical slightly eroded chernozem, based on the author's methodology, they showed the following. The agricultural technology generally accepted for the region using crushed by-products had a satisfactory effect on the soil, while the values of most indicators did not change. Agrobiotechnology-1, including agricultural technology and treatment with biological preparations Gribofit (based on *Trichoderma viride*) and Imunazot (based on *Pseudomonas aureofaciens*) of soil before sowing, sowing 2 times, crushed by-products after harvesting and incorporating it into the soil, provides a differentiated assessment of indicators the effect on soil fertility and stability is good, the effect on soil health is excellent; and according to a comprehensive assessment, it is good for all indicators and most of them showed a significant increase. The impact of agrobiotechnology-2 (agrobiotechnology-1 + 10 kg a.i. N per 1 ton of crushed by-products) on soil fertility, health and stability according to differentiated and comprehensive assessments was excellent, with most indicators showing significant and high significant increases.

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