Resource-saving technologies for the basic cultivation of chernozem typical in the northeastern region of the Central Chernozem region

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Abstract. The research was carried out with the aim of solving the problem of optimizing the system of basic tillage, providing a reduction in energy costs, obtaining high crop productivity and profitability of production in a grain-fallow crop rotation in the conditions of the northeast of the Central Chernozem Region. The work was carried out in 2013-2021, in a stationary field experiment on a typical heavy loamy chernozem with a high supply of mineral nutrients with a humus content in the arable layer of 6.8-7.0%. The scheme of the experiment included the following options for the main tillage systems: traditional mid-depth moldboard, for soybean at 25-27 cm (control); resource-saving: surface (disking by 10-12 cm) for all crops and non-moldboard mid-depth, 25-27 cm for soybeans and 20-22 cm for cereals; combined: moldboard-less plowing (25% plowing for soybeans + 75% non-moldboard semi-deep plowing for cereals) and moldboard-surface (25% plowing for soybeans + 75% surface plowing for cereals). Against the background of treatments for crop rotation, fertilizers and plant protection products were used. It was found that resource-saving non-moldboard and combined tillage for sowing, on average, for crop rotation crops, accumulated more moisture in the arable layer by 12.1-13.8%, by 3.9-7.8% in the meter layer, compared with traditional moldboard cultivation. . Surface tillage reduced the reserve of productive moisture in the arable layer by 4.4%, in the meter layer - by 5.1%. It has been studied that the best nitrogen, phosphorus and potassium regimes are established with traditional dump and combined dump-surface treatments. In the variants with surface and non-moldboard tillage, a decrease in the content of mineral nutrition elements in the arable soil layer is noted. At the same time, there was an increase in the process of differentiation of the arable layer by fertility with a concentration of nutrients in the layer of 0-10 cm and a significant decrease in them in the layer of 20-30 cm. 2.1 times without herbicides, 2.2 times against the background of herbicide treatment, in terms of the number of weeds and 1.4 and 1.5 times in terms of their mass, in comparison with traditional moldboard treatment. The use of herbicides contributed to a decrease in the number of weeds and the mass of the weed component on average for the variants of the experiment by 55.4 and 60.0%, respectively. It was analyzed that the use of surface

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and non-moldboard tillage systems led to a decrease in the productivity of a hectare of arable land in crop rotation by 0.09 tons of grain units without protection and by 0.11-0.14 tons in combination with plant protection. The combined (dump-surface) system of tillage ensured the productivity of arable land at the level of the traditional dump system at different depths. It has been proved that the highest profitability of production in crop rotation (250.3%) was achieved using a combined (dump-surface) tillage system in combination with the use of complex protection products (seed dressing + pesticides for crop vegetation). Resource-saving processing systems (surface and non-moldboard) worsened economic performance. Income from the use of these tillage systems decreased by 4.8-5.5%, profitability decreased by 1.6-2.7% compared to the traditional mid-depth moldboard tillage system in crop rotation.

1 Introduction

In recent years, the problem of reducing costs and increasing the profitability of crop production has become more and more urgent. The solution to this problem largely depends on the methods and systems of tillage, which are the main technological operations of all agriculture and in the technologies of growing field crops, as a rule, make up the bulk of the costs [2, 14]. The productivity of crops, energy consumption, and the profitability of production depend on tillage [1, 11, 15]. Studies have established that chernozem soils have a stable composition, their density changes little over time and is optimal for the development of grain crops, which is the basis for minimizing tillage [7].

In modern agriculture, the main tillage in agrotechnological complexes of crop cultivation is carried out mainly with the use of plowing, surface and non-moldboard methods, which, with a certain combination, form a system of tillage in crop rotation [12]. Minimization of tillage in crop rotations leads to conflicting results on crop productivity [9, 13].

Studies have established that the most effective combined systems of tillage [5-6, 8, 10, 16].

The main processing in a certain way affects the fertility of the soil, as well as the phytosanitary state of agrocenoses, which significantly affects their productivity. At the same time, it is important that tillage is economically justified.

In connection with the transition to resource-saving technologies, there is a need to study various methods and systems of soil cultivation and determine the most effective ones, with the maximum use of the natural and climatic potential, ensuring the reduction of weeds, high yields, increasing the profitability of production and maintaining soil fertility.

The purpose of the research was to solve the problem of optimizing the main tillage system, which ensures a reduction in energy costs, obtaining high crop productivity and profitability of production in a grain-fallow crop rotation (black fallow - winter wheat - soybean - barley) on typical heavy loamy chernozem in the conditions of the northeast of the Central Chernozem Region.

2 Materials and methods

The studies were carried out in 2013-2021 on the experimental field of the Tambov Research Institute of Agriculture, a branch of the Federal State Budgetary Scientific Institution “FNTs im. I.V. Michurin", in a stationary field experiment in crop rotation: black fallow - winter wheat - soybeans - barley. The scheme of the experiment (Table 1) provided for the study of five systems of basic tillage in the technologies of field crops

cultivation: traditional moldboard at different depths (control), surface and moldboardless at different depths (resource-saving), combined 75% non-dump, dump-surface - 25% dump + 75% surface).

Within the framework of the traditional moldboard system (control), the main tillage was carried out by plowing with a mounted plow PLN-5-40. The main processing in the surface system was carried out by disking with a BDM disk (3/4). The non-moldboard mid-depth system provided for the main processing with a PLN-5-40 plow without mouldboards. The main processing in combined systems was carried out using the PLN-5-40 plow during moldboard and non-moldboard tillage and the BDM harrow (3/4) - surface treatment.

The studies were carried out on a fertilized background; under the main treatment, mineral fertilizers were applied at a dose of $N_{60}P_{30}K_{30}$, including ammonium nitrate for winter wheat (N_{30}) as a spring top dressing during the resumption of vegetation; $N_{30}P_{30}K_{30}$, and soybeans were cultivated without the use of fertilizers. Thus, the level of fertilization of a hectare of arable land in the crop rotation was $N_{20}P_{10}K_{10}$.

Table 1. Technology of cultivation of agricultural crops.

Technologies	Options	Agrotechnical characteristics
Traditional	1 option	Medium-depth plowing (20-22 cm for cereals, 25-27 cm for legumes) + fertilizers + plant protection during the growing season
Resource saving	2 option	Surface (disking 10-12 cm for all crops of the crop rotation) + fertilizers + plant protection during the growing season
	3 option	Moldboardless mid-depth (20-22 cm for cereals, 25-27 cm for leguminous crops) + fertilizers + plant protection during the growing season
Combined	4 option	Moldboard-less moldboard (25% plowing for legumes, 75% non-moldboard plowing for grain crops) + fertilizers + plant protection during the growing season
	5 option	Moldboard-surface (25% plowing for legumes, 75% surface plowing for grain crops) + fertilizers + plant protection during the growing season

The crop protection system of crop rotation consisted of two levels:

- Seed dressing - background.
- Background + pesticides (fungicides, insecticides, herbicides) for the vegetation of crops in the fight against diseases, pests and weeds, for this, highly effective chemical protection agents registered in Russia were used.

Agrotechnics for growing crops of crop rotation is generally accepted for the study region, with the exception of the studied tillage systems.

The repetition in the experiment is threefold. The placement of plots in the experiment is systematic (consecutive). Plots of the first order (tillage) - 52 by 7.20 m, area 374 m^2. Plots of the second order (plant protection) - 25 by 7.20 m, area 187 m^2. The accounting area of the plot is 75 m^2 (17 m by 5 m).

In the experiment, crop varieties released for the region were used for sowing: winter wheat - variety Scepter, barley - Chakinsky 221 and soybean - variety Avanta.

The soil of the experimental plot is a typical, thick, heavy loamy chernozem, with the content of 6.8-7.0% humus in the arable layer (0-30 cm), mobile phosphorus - 15.0-17.0, exchangeable potassium - 13-15 mg /100 g of soil; p^H (sol.) - 6.6-6.8.

Observations, analyzes and records were carried out according to the current methods adopted in field and laboratory research on agriculture [3, 4].

Soil moisture was determined before sowing crop rotation crops in a meter layer with an interval of 10 cm, using the thermostatic-weight method, GOST 282687-89.

Soil samples for analysis were taken in the spring on fixed plots in variants of soil cultivation in a soil layer of 0–30 cm with an interval of 10 cm. Weed infestation of crop

rotation crops was determined during the harvesting period using the quantitative-weight method according to the methods of VNIIZ and ZPE (Kursk).

Accounting for the yield of crops was carried out by the method of continuous harvesting of the accounting area of the plots with the SAMPO-500 combine. Yield data resulted in 14% moisture and 100% purity.

The years of the study varied according to weather conditions. Growing seasons (May-August) 2014 and 2018-2020 were characterized by insufficient precipitation - 23.9-77.0% of the average long-term norm (204 mm). In these years, an increased air temperature regime was noted, and the HTC value varied from 0.2 to 0.7. In 2013 and 2015-2017 precipitation during the growing season was much higher than the norm (1.2-2.1 times), the average daily air temperature exceeded the long-term average by 0.80 C, HTC (according to Selyaninov) was 1.1; 1.6; 2.0 and 2.4, respectively, by years, with a long-term average of 1.0.

3 Results

In the soil and climatic conditions of the region, soil moisture serves, in most cases, as a limiting factor for the formation of crop yields. The main moisture charging of the soil occurs in the autumn-winter-spring periods and reaches a maximum by the beginning of spring field work.

The obtained experimental material on the accumulation of available moisture, depending on the main tillage, showed that the greatest accumulation of autumn-spring precipitation, on average for crop rotation crops, both in the arable and meter soil layers is 60.9-61.8 mm and 191.3-198.4 mm were noted in variants 3.4.5 with non-moldboard mid-depth and combined systems of the main processing, with indicators in the control (option 1) - 54.3 and 184.1 mm (Figure 1). Surface treatment (option 2) worsened the filtration capacity of typical chernozem. The stock of spring productive moisture during surface treatment was minimal in the experiment - 51.9 mm in the arable layer and 174.8 mm in the meter layer, which is less than the control by 2.4 and 9.3 mm, respectively.

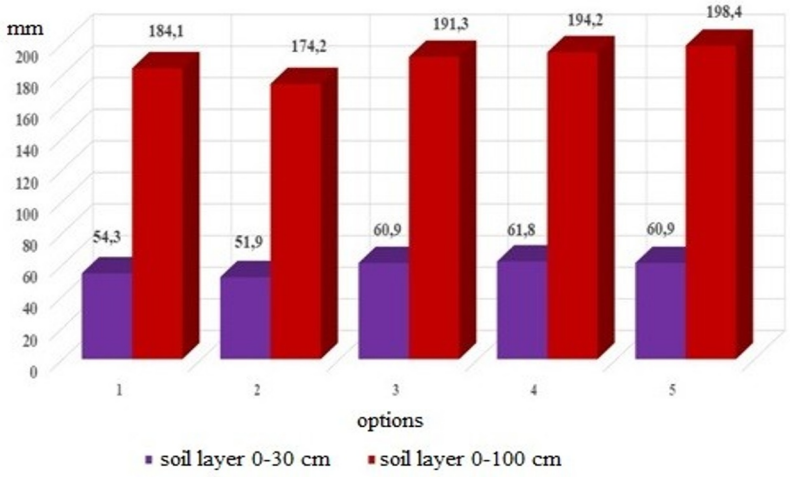

Fig. 1. The content of productive moisture in the soil under various systems of basic cultivation of typical chernozem in grain-fallow crop rotation (2013-2020).

Studies on the study of the nutritional regime of typical chernozem in crop rotation found that the highest concentration of nitrate nitrogen in the soil was achieved with the

traditional moldboard and combined moldboard-surface cultivation systems - options 1 and 5 (Table 2). In these options, its content in the arable layer (0-30 cm) of the soil before sowing crops, on average, was in the range of 25.1-25.3 mg/kg of soil. The lowest content of nitrate nitrogen was noted for surface treatment (option 2) - 21.7 mg/kg of soil, which is less than the control (option 1) by 3.4 mg/kg of soil or by 13.5%.

Determining the availability of mobile phosphorus and exchangeable potassium showed a decrease in these elements in options 2 and 3 with surface and non-moldboard mid-depth processing systems. The content of these elements was 11.0 and 16.0 mg/kg of soil for mobile phosphorus, 15.0 and 9.0 mg/kg of soil for exchangeable potassium, compared with the control (option 1).

The use of combined tillage systems in crop rotation (options 4 and 5) ensured the maximum content of phosphorus and potassium in the arable soil layer before sowing crops.

Table 2. The content of mineral nutrition elements in the soil, before sowing crops, with various systems of basic processing, on average for the crop rotation of 2013-2020. (mg/kg absolutely dry soil).

Options	Soil layer, cm	Indicators		
		NO_3	P_2O_5	K_2O
1	0-10	23.1	186	175
	10-20	26.6	178	178
	20-30	25.7	179	160
	0-30	25.1	181	171
2	0-10	23.8	199	193
	10-20	21.2	164	147
	20-30	20.0	148	128
	0-30	21.7	170	156
3	0-10	25.8	177	187
	10-20	24.1	173	163
	20-30	20.5	144	136
	0-30	23.5	165	162
4	0-10	23.6	184	186
	10-20	22.3	176	181
	20-30	23.9	179	183
	0-30	23.2	180	183
5	0-10	26.4	193	188
	10-20	25.7	182	180
	20-30	23.7	192	172
	0-30	25.3	189	180

The main tillage system in crop rotation without wrapping and mixing the wrapped layer leads to a greater concentration of nutrients in the upper (0-10 cm) soil layer and a noticeable decrease in them in the lower (20-30 cm) layer, that is, they increased the differentiation of the arable layer in terms of fertility.

In options 1, 4, 5 with traditional mid-depth dump and combined tillage systems, a more homogeneous arable soil layer is created in terms of the content of nutrients, which has a positive effect on the formation of crop yields, especially in years with insufficient moisture supply.

In the agrocenoses, during the research, there were weeds belonging to three ecological and biological groups. The type of infestation can be characterized as juvenile-root shoots. At the same time, up to 80% of the total amount of the weed component was accounted for by annual grasses and dicotyledonous species. Of that group of weeds, dicotyledonous species predominated (white gauze, tenacious bedstraw). Of the perennial weeds, field bindweed dominated.

The results of the research showed that by harvesting crops, the least weediness of crops was noted against the background of traditional moldboard mid-depth cultivation - option 1 (Figure 2).

Surface tillage (option 2) led to a significant increase in weed infestation of crops of crop rotation in terms of weed numbers by 2.0 times, by air-dry weight - by 1.4 times without chemical weeding and by 2.2 and 1.5 times against a herbicide background compared with control (option 1). The combined moldboard-surface tillage system with 75% saturation with surface treatment (option 5) increased the number of weeds without herbicides by 1.9 times, against the background of herbicide treatment - by 1.5 times. At the same time, the mass of the weed component was at the level with the control.

On variants with non-moldboard mid-depth and combined moldboard-non-moldboard systems, an increase in the number of weeds was also noted, but to a lesser extent than with surface cultivation. The air-dry mass of weeds in these variants was at the control level with a traditional mid-depth tillage system.

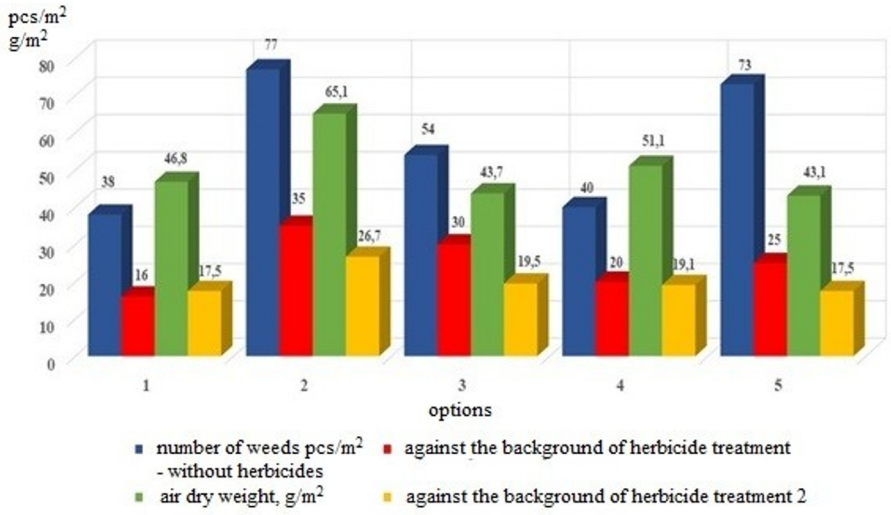

Fig. 2. Infestation of crops of crops of grain-fallow crop rotation depending on the systems of the main processing and their combination with herbicides (2013-2020).

Chemical weeding of crops ensured a decrease in the number of weeds by an average of 55.8% for tillage options, their air-dry mass decreased by 2.4 times.

Analyzing the value of the productivity of a hectare of arable land in a grain-fallow crop rotation in terms of the yield of grain units (Figure 3), it can be noted that the traditional mid-depth dump with 100% saturation with plowing and the combined dump-surface with 75% saturation with surface tillage (options 1 and 5) ensured the equal and highest yield of grain units, which amounted to 2.29 t/ha without means of protection and 2.57-2.58 t/ha in combination with crop protection during vegetation.

A lower yield of grain units was noted in options 2, 3, 4 with surface, moldboardless mid-depth and combined moldboard-less moldboard processing systems - 2.20-2.23 t/ha and 2.44-2.47 t/ha without protection and with protection of crops during the growing season, respectively. Compared with the control, the traditional mid-depth moldboard tillage system, the decrease in the productivity of a hectare of arable land was 0.06-0.09 t/ha without protection and 0.07-0.14 t/ha against the background of the use of complex protection products (seed dressing + pesticides crop vegetation).

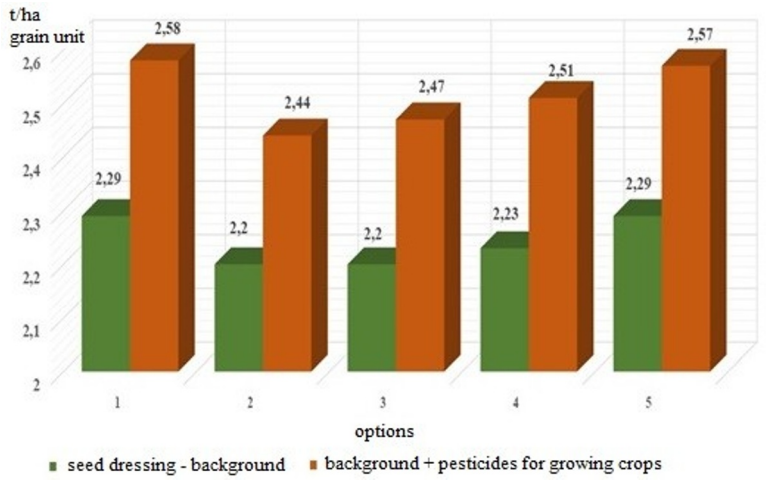

Fig. 3. The productivity of a hectare of arable land depending on the systems of basic tillage and their combination with plant protection products of crops in the grain fallow crop rotation (2013-2020).

The use of the second level of crop protection in technological complexes of crop cultivation in crop rotation (seed dressing + pesticides for crop vegetation) ensured an increase in yield per hectare of arable land. The increase in average for the options for tillage systems was 0.27 t/ha, compared with the first level of protection (seed dressing).

The task of modern technologies for the cultivation of agricultural crops is not only to ensure high productivity, but also the maximum possible profit and profitability at a minimum cost per unit of production.

The use of one or another system of basic tillage is largely determined by economic indicators, which include an increase in profits and an increase in the profitability of production.

The systems of basic tillage and plant protection agents studied in the grain-fallow crop rotation in the cultivation of crops had a certain impact on profit and profitability (Figure 4).

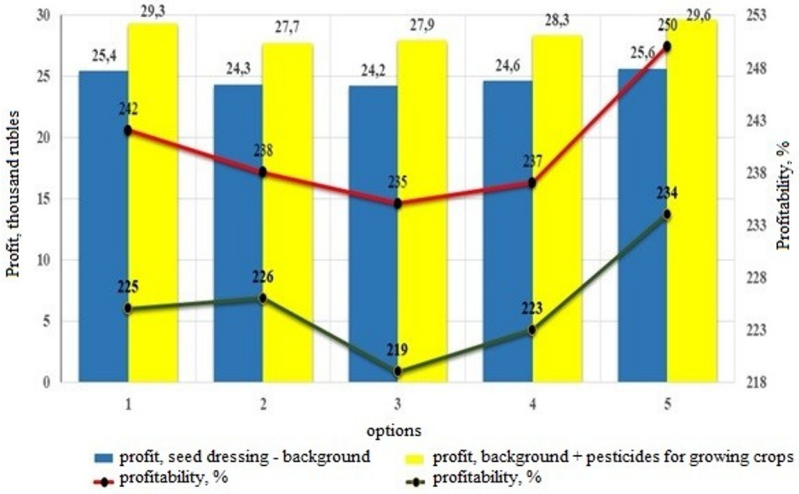

Fig. 4. Economic indicators of the production of a grain unit with various systems of basic tillage and their combination with crop protection agents in grain-fallow crop rotation (2013-2020).

They were higher in option 5 with a combined moldboard-surface treatment system with 75% saturation of surface treatment in combination with a complex of crop protection products (seed treatment + pesticides for crop vegetation from harmful objects of diseases, pests and weeds). Profit per hectare of arable land amounted to 29.59 thousand rubles, the level of profitability - 250.3%, with indicators under control (option 1) - 29.28 thousand rubles. and 241.8%.

The lowest values of these indicators of economic efficiency were characterized by resource-saving processing systems - surface and non-moldboard mid-depth (options 2, 3). Compared to the control (option 1), profit decreased by 1620 and 1420 rubles/ha, profitability decreased by 1.7 and 2.7%.

In the absence of plant protection products in crop cultivation technologies, during their growing season, not only a decrease in crop productivity and output per hectare of arable land occurred, but also the economic indicators of production in crop rotation worsened. The established regularity was typical for all studied technologies.

4 Discussion

The highest productivity of a hectare of arable land in the grain-fallow crop rotation was obtained in the variants with traditional moldboard plowing at 100% saturation and combined moldboard-surface (25% plowing + 75% surface) systems of basic tillage.

When using resource-saving processing systems, crop rotation productivity decreased. Higher profit and profitability level of production of a grain unit was ensured by a combined dump-surface treatment system in combination with a complex of plant protection products (seed dressing + fungicides, insecticides and herbicides for crop vegetation). The least economically profitable were the technologies of cultivation of field crops with a resource-saving system of basic tillage

5 Conclusion

In the soil and climatic conditions of the northeast of the Central Chernozem region in field crop rotations, tillage should be differentiated and built taking into account the agroecological requirements of crops. In the grain-fallow crop rotation (black fallow - winter wheat - soybean - barley), the most agro-economically profitable is the combined dump-surface system of the main tillage, where 25-27 cm plowing is carried out for leguminous crops (soybeans), and disk plowing for grain winter wheat and barley processing to a depth of 10-12 cm, in combination with means of protecting crops from harmful objects.

References

1. L.N. Vislobokova, Yu.P. Skorochkin, V.A. Vorontsov, Influence of elements of agricultural technology on the yield of barley, Agriculture, **6**, 25-27 (2010)
2. A.N. Vlasenko, I.N. Sharkov, L.N. Iodko, Economic aspects of minimizing the main tillage, Agriculture, **4**, 18-20 (2006)
3. B.A. Dospekhov, Methods of field experience. Ed. 5th add. and reworked (Agropromizdat, Moscow, 1985)
4. B.A. Dospekhov, I.P. Vasiliev, A.I. Tulikov, Workshop on agriculture. Ed. 2nd add. and reworked (Agropromizdat, Moscow, 1987)

5. M.K. Dracheva, V.A. Vorontsov, A.D. Denisov, Agrotechnical aspects of the cultivation of spring barley in the northeastern region of the Central Chernobyl (Tambov Research Institute of Agriculture, Tambov, 2012)
6. V.I. Kiryushin, The problem of soil tillage minimization, development prospects and research objectives, Agriculture, **7**, 3-6 (2013)
7. E.V. Kuzina, Influence of the main tillage on the reserves of productive moisture and agrophysical properties of leached chernozem, Perm agrarian bulletin, **3**, 35-41 (2016)
8. Yu.P. Kuzichenko, Soil cultivation systems in the tilled link of crop rotation in the zone of the Central Ciscaucasia, Bulletin of the Kazan State Agrarian University **15**, **2**, **58**, 25-28 (2020)
9. D.N. Nikitin, T.I. Chernov, N.D. Zheleznova, Seasonal dynamics of microbial biomass in soddy-podzolic soils, Soil Science, **11**, 1356-1364 (2019)
10. I.G. Pykhtin, A.V. Gostev, Nitchenko, Theoretical foundations of the systematization of tillage in agrotechnologies of the new generation, Agriculture, **5**, 13-15 (2015)
11. M.M. Sabitov, R.B. Sharipova, Efficiency of methods of tillage and means of chemicalization in grain-fallow crop rotation, Achievements of science and technology of the agrarian and industrial complex, **29**, **10**, 31-34 (2015)
12. E.S. Sdobnikov, To plow or not to plow, M. Russian Agricultural Academy, 296 (2000)
13. T.A. Trofimova, S.I. Korzhov, V.A. Gulevsky, Evaluation of the degree of physical degradation and the suitability of chernozem to minimize the main tillage, Soil Science, **9**, 1080-1085 (2018)
14. V.I. Turusov, V.M. Garmashov, N.V. Dronova, Efficiency of systems of basic tillage and means of intensification in the cultivation of winter wheat in the conditions of the Central Chernobyl, Achievements of science and technology of the agro-industrial complex, **29**, **7**, 68-70 (2015)
15. G.N. Cherkasov, I.G. Pykhtin, A.V. Gostev, The possibility of using zero and surface methods of tillage in various regions, Agriculture, **5**, 13-16 (2014)
16. A.V. Shabalkin, M.K. Dracheva, V.A. Vorontsov, Yu.P. Skorochkin, The reaction of barley to the means of intensification and methods of processing chernozem soils in the northeastern region of the Chernozem region, Agriculture, **6**, 41-45 (2022)