Agricultural Communication

Expanded Reproduction of Chernozem Fertility in Biological Agriculture

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ABSTRACT

The current stage of development of zonal farming systems in the Central Black Earth region involves the creation of balanced, highly productive, and sustainable agricultural landscapes, maximally adapted to the natural conditions of the region and ensuring the preservation and improvement of soil fertility. The solution to the problem of reproduction of soil fertility in traditional agriculture is associated with the use of a large number of energy-intensive resources and, first of all, irreplaceable ones. However, the level and direction of soil/biological processes are not sufficiently taken into account, whereas they to a certain extent ensure the reproduction of soil fertility. In this regard, the problem of the formation of the scientific foundations of the reproduction of soil fertility through the integrated use of methods of biologization of agriculture in the Central Black Earth Region and the activation on this basis of the soil/biological factor in the long-used chernozems acquires special importance. The purpose of the study is to review the changes in soil fertility indicators in conditions of biological agriculture. The paper presents the results of a study to determine changes in soil fertility indicators in typical chernozem of the Belgorod region (Russia) in a field experiment with various technologies of crop cultivation. The study demonstrates the regularities of the transformation of the fertility of chernozem. In terms of its fertilizing efficiency, compost in the applied norm turned out to be equivalent to a half dose of mineral fertilizers since both variants under consideration provided equivalent increases in the corn yield. The full dose of mineral fertilizers on the background of organic matter turned out to be excessive since its introduction did not contribute to a reliable increase in corn productivity.

KEY WORDS: COMPOST, GRAIN PRODUCTIVITY, MINERAL NUTRITION, THREE-FIELD CROP ROTATIONS.

INTRODUCTION

During the transition of agricultural production to an ecological basis, the main objective seems to be the expanded reproduction of the fertility of chernozems, improving their productivity in specific conditions and at the same time, obtaining agricultural raw materials that meet the most demanding quality requirements, optimizing material, labor and other types of costs (Azarov 2004; Kloster and Azarov 2015). The main soils of the region, chernozems, due to long-term agricultural use, suffer from degradation: their reserves of organic matter, biogenic elements are reduced, and their physical and other characteristics deteriorate (Linkov et al. 2012; Kuznetsova and Akinchin 2014; Linkov et al. 2016). In the Belgorod region, over the 30 years preceding the study, about 280 thousand hectares of unsuitable land were withdrawn from agricultural use. Their irrational use leads to a violation of the stability of the entire ecosystem of the region (Kuznetsova and Akinchin 2014; Linkov et al. 2016; Gorodov et al. 2017; Prodana et al. 2021; Lee et al. 2021).

In these circumstances, the optimization of arable land productivity, reproduction of the fertility of chernozems dictates the need to develop and implement innovative energy-saving elements of agricultural technologies, with the introduction of which, to obtain profitable, stable yields, and rational use of soil resources would occur, which would

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resolve the issues of preserving soil fertility indicators, replenishing stocks of nutrients and humus (Linkov et al. 2012; 2016). In the Belgorod region, the closest attention is paid to solving this problem. The solution can be the introduction of biologization elements into the technology of cultivation of the main grain crops of the region, such as soybeans and corn, namely the introduction of organic fertilizers, the use of minimal soil preparation, and sowing of after-harvest and post-cut crops (Turyansky et al. 2014; Orazaeva et al. 2017; Ippolito et al. 2021). The main objective of our study is to review the trend of the influence of the components of biologization in the technologies of cultivation of grain crops on the ecological state of arable land, the nature of the rationality of their use as an irreplaceable natural resource, the environmental friendliness of the proposed agricultural technologies.

MATERIAL AND METHODS

The experiment was carried out during the full rotation of experimental three-field crop rotations, corresponding to the general specialization of the farm, recognized to provide full-fledged high-quality feed to the main production of the company group (poultry). The experiment was stationary and two-factor, developed in time and space. Variants of the experiment are as :

1. Control without fertilizers (variant 11)
2. Mineral fertilizers at a ½ dose calculated for the planned yield (wheat: 5 t/ha, corn: 6 t/ha of grain) (variant 12)
3. Mineral fertilizers at a full dose calculated for the planned yield (soybeans: 2.5 t/ha, wheat: 5 t/ha, corn: 6 t/ha of grain) (variant 13)
4. Organic fertilizers (compost based on poultry manure) at a dose of 14 t/ha (variant 21)
5. Organic fertilizers (compost based on poultry manure) at a dose of 14 t/ha + Mineral fertilizers at a ½ dose calculated for the planned yield (variant 22)
6. Organic fertilizers (compost based on poultry manure) at a dose of 14 t/ha + Mineral fertilizers at a full dose calculated for the planned yield (variant 23)

The fundamental indicators of soil fertility, which were not subject to significant fluctuations during the period of the experiment, such as the humus content, hydrolytic acidity, nitrification ability of the soil, were determined at the beginning and the end of the crop rotation to establish the nature of the dynamics of these indicators depending on the factors studied.

RESULTS AND DISCUSSION

As the results of the study showed, the humus content in the arable (0-20 cm) and sub-arable (20-40 cm) soil horizons averaged 5.13%, and in the sub-arable horizon, it equaled 4.35%, which corresponds to the gradation of the average organic matter content in the soil. Down the soil profile, humus reserves were reduced due to the lack of an influx of fresh organic matter due to the accumulation of root plant residues.

Table 1. Humus content in the soil in the experimental field, %

Organic fertilizers, t/ha	Nitrogen, phosphorus, and potassium (NPK)	Soil layer, cm	humus content, %		
			2016	2019	changes
0	0	0-20	4.92	4.56	-0.36
		20-40	4.09	3.62	-0.47
	0.5 dose	0-20	5.09	4.58	-0.49
		20-40	4.45	4.13	-0.32
	1 dose	0-20	5.01	4.78	-0.23
		20-40	4.16	3.99	-0.17
1 dose	0	0-20	5.08	5.09	+0.01
		20-40	4.57	4.68	+0.13
	0.5 dose	0-20	5.22	5.32	+0.10
		20-40	4.39	4.91	+0.52
	1 dose	0-20	5.53	5.58	+0.07
		20-40	4.48	4.88	+0.51

Upon completion of the phases of the three-field experimental crop rotation on control variants or variants with NPK, there was a decrease in humus content by an amount from 0.23 to 0.49% in the upper soil layer and by 0.17-0.47% in the soil layer up to 40 cm. The explanation for this fact should be sought in the intensive mineralization of soil organic matter during the cultivation of grain crops without fresh organic matter entering the soil (Table 1). In the variants of the experiment, where an organic fertilizer complex was used (compost based on poultry manure), the trend was radically changing: the disposition to some stabilization and increased in humus content has been noted in all biological variants.

In this case, it should be noted that there was a pattern of a significant increase in humus reserves in the lower soil layer in the variants with an organic mineral fertilizer system by about 0.5%. On these plots, when sealing organic matter with heavy disk machines, most of it fall into the underlying layers and, when assimilated by plants, it was easily turned into humus and increases the fund of organic matter of the soil. Table 2 presents the experimental data on the value of the hydrolytic acidity of the soil in the experimental field (Gutorova et al. 2021).

Table 2. Hydrolytic acidity of chernozem (mmol/100g) in the experimental field

Organic fertilizers, t/ha	NPK	Soil layer, cm	Hydrolytic acidity (mmol/100g)		
			2016	2019	+/-
0	0	0-20	2.64	2.68	+0.03
		20-40	2.78	2.86	+0.06
	0.5 dose	0-20	3.18	3.12	-0.08
		20-40	1.97	2.05	+0.06
	1 dose	0-20	2.55	2.56	-0.01
		20-40	2.62	2.64	0.00
1 dose	0	0-20	2.38	1.98	-0.40
		20-40	1.90	1.87	-0.03
	0.5 dose	0-20	2.55	2.42	-0.15
		20-40	1.81	1.83	+0.02
	1 dose	0-20	2.18	2.15	-0.05
		20-40	2.04	2.12	+0.06

Table 3. Soil nitrification capacity (mg/kg) in the experimental field

Organic fertilizers, t/ha	NPK	Soil layer, cm	Nitrification capacity, mg/kg		
			2016	2019	+/-
0	0	0-20	7.28	8.48	+1.20
		20-40	5.23	6.56	+1.33
	0.5 dose	0-20	5.69	6.59	+0.90
		20-40	4.54	5.24	+0.70
	full dose	0-20	6.51	7.12	+0.61
		20-40	3.38	4.85	+1.47
full dose	0	0-20	7.91	8.75	+0.84
		20-40	7.22	7.98	+0.78
	0.5 dose	0-20	7.59	8.12	+0.53
		20-40	5.15	7.33	+2.18
	full dose	0-20	6.24	7.88	+1.64
		20-40	5.19	6.98	+1.71

The indicator of the value of hydrolytic acidity indicates the degree of saturation of the soil absorbing complex with hydrogen cations. The higher it was, the smaller the capacity of cation exchange and the weaker the metabolic processes were; in this case, the agrochemical and agrophysical indicators of soil fertility were significantly reduced (Pepo 2021; Gutorova et al. 2021). As the analysis of the materials in Table 2 shows, there was a pronounced heterogeneity of the initial state of soil fertility of the experimental field concerning acid-base characteristics. After three years of intensive cultivation of crops, this soil characteristic did not show significant differentiation.

We have recorded a trend of a slight decrease in the indicator under consideration with the mixed use of organic and mineral fertilizers in the upper layer of the soil and a moderately negative trend (up to 0.06 points) under similar conditions on the mineral fertilizer system. The nitrification ability of the soil belongs to the biological categories of soil fertility, as it characterizes the potential ability of the studied soil to transform available nitrogen compounds from its total reserves, which are part of the nutrient complex of the soil, by the activity of soil biota. The higher the nitrification capacity of the soil, the higher its potential fertility. Naturally, this indicator will grow with an increase in the dose of organic fertilizers (Futa et al. 2021; Peng et al. 2021).

Table 3 shows data on the nitrification capacity of the soil in the experimental field of experimental crop rotations for the period of the study. The change in nitrification capacity indicators by soil layers and experimental variants varies from 3.37 to 7.90 mg/kg of mineral nitrogen (N-NO 3). The explanation of this fact should be sought in the variety of quantitative and qualitative composition of the microflora of soil biota, which the reference soils of Russia and the whole world possess, namely, typical chernozems (Gorban et al. 2020). In this regard, we analyzed soil samples from each experimental plot to record the dynamics of changes in the nitrification capacity of the soil in time and space.

As the data in Table 3 show, there is an increase in the nitrification capacity of chernozem in all variants of the experiment. This indicator showed an increase of 0.53-2.18 mg/kg of soil, depending on the filling of the variant with a tendency to increase with the biological fertilization system of grain crops. Optimal agrophysical properties of the soil create prerequisites for ensuring favorable conditions for water, air, and temperature regimes for crop growth and development. The most significant indicator of the agrophysical properties of the soil is the density and structural composition of the root layer of the soil. Data on the agrophysical properties of the soil in the experimental field after the completion of the full cycle of vegetation of crops of the experimental crop rotation are presented in Table 4. As the results of our studies of the agrophysical properties of the soil have shown, the obtained parameters of the density and structural coefficient of the arable layer of chernozem are in optimal values with minor deviations depending on the factors studied (Gutorova et al. 2021).

Table 4. Agrophysical properties of the 0-20 cm soil layer Depending on the applied fertilizers

Indicators	Content of experiment variants					
	without fertilizers	0.5 NPK	1NPK	Compost (background)	Background + 0.5 NPK	Background + 1NPK
Soybean						
Density, g/cm^3	1.20	1.21	1.20	1.1	1.15	1.17
Pedality coefficient	2.5	2.6	2.6	3.0	3.2	3.2
Winter wheat						
Density, g/cm^3	1.22	1.20	1.20	1.12	1.18	1.19
Pedality coefficient	2.6	3.3	3.2	3.5	3.6	3.7
Grain corn						
Density, g/cm^3	1.20	1.18	1.18	1.12	1.14	1.14
Pedality coefficient	3.2	3.2	3.3	3.5	3.6	3.5

Thus, the density of the soil on the variant without fertilizers and their use in the field, where the cultivated soybean was in the same values (of 1.21 g/cm3), and the application of organic fertilizer (compost) contributed to the loosening of the soil (1.1 g/cm3), the introduction of mineral fertilizers at a dose of 1 kg and 2 kg/ha in physical weight was accompanied by soil compaction to the value of 1.15-1.17 g/cm3. It should be noted that the optimal indicators of the density of the arable horizon of typical chernozem range from 1.05 to 1.25 g/cm3, which was generally favorable for crop cultivation.

Under winter wheat and grain corn, the density on all fertilization backgrounds maintained the same trends in its values as under the cover of soybeans with a slight increase in friability against the background of organic fertilizers. The soil pedality coefficient by definition was the ratio of agronomically valuable soil aggregated with a diameter of 0.25 to 10 mm to the rest of the dry soil sample taken for analysis from each experimental plot. The higher the pedality coefficient, the better properties the soil has in terms of optimizing air, temperature, water, and nutrient regimes (Gutorova et al. 2021). The data in Table 4 also indicate that the soil structure coefficient increases in the soy-corn-winter wheat series and increases significantly against the background of composting based on poultry manure. The use of this local fertilizer stimulated the formation of agronomically valuable soil aggregates due to the connective effect of the substances that make up its composition.

The productivity of soybeans, as a crop, which we entered into the experiment, was formed mainly under the influence of fertilizers applied. In the variants without the use of fertilizers, its value was about 13 c/ha, which is a rather low value for the Central Black Earth region. This fact was explained by the use of intensive-type varieties in the experiment, as well as by the level of soil fertility of the experimental site belonging to old arable lands with an insufficient value of available forms of macronutrients. It should be noted that under the condition of fertilization, this value increased in proportion to the number of fertilizers and on plots with the use of 11 tons/ha of compost based on poultry manure and a full dose of mineral fertilizers, the yield of soybean grain was already 22.9 c/ha. It should be noted that in the experimental field as a whole, the agriculture standards were kept at a fairly high level. Regarding the structure of the soybean crop, we can note a tendency to increase almost all values as the level of fertilization increases, which is quite understandable, since in this case a larger grain is formed (Pepo 2021; Gutorova et al. 2021).

Under the scheme of the field experiment, we used winter wheat for two backgrounds of application of organic fertilizers (compost based on poultry manure) and three levels of mineral nutrition 0; 40 NPK (half dose) and 80 NPK (full dose). The experiment was two-factor because three levels of providing plants with nutrients from synthetic fertilizers were superimposed with two organic backgrounds, amounting to 0 and 11 t/ha of compost. Observations and records on the experimental field under winter wheat were conducted according to the main indicators of wheat quality productivity: the coefficient of productive tillering capacity; the number of productive stems; the number of grains in the ear; the mass of grains in the ear; the mass of 1,000 grains; the nature of grain; the grain: straw ratio; the plant height. Our study has established that the coefficient of the productive tillering capacity of wheat increases with an increase in the amount of plant nutrition from 2.1 in the control variant without the use of fertilizers, to 2.6 at the half and 3.1 with a full dose of mineral fertilizers. The use of organic matter in a full dose contributed to an improvement in the tillering capacity of wheat by 0.3 points with a Least Significant Difference (LSD) index of 0.2 (Pepo 2021; Gutorova et al. 2021).

The organic mineral fertilizer system contributed to the formation of the extremely high tillering capacity of plants up to 4.1 stems per plant. The number of productive stems per unit area increases with an increase in the level of mineral nutrition of the crop from 272 units on the variant without fertilizers to 371 against the background of organic matter and a full dose of mineral fertilizers. At the same time, it should be noted that the high excess background of plant nutrition in a favorable climatic year contributed to the fact that wheat formed a large vegetative mass, as a result of which, at the end of the earing phase during a heavy downpour with gusty wind, plants were lodging with an estimate of 4-5 points on variants with the combined use of mineral and organic fertilizers in full doses. The negative effect of the lodging of wheat plants was noted in the reduction of the grain mass in the ear, the mass of 1,000 grains, and an increase in the proportion of straw to a ratio of 1:1.5 concerning the grain weight during the sheaf analysis of samples from experimental plots of the organic mineral fertilizer system (Pepo 2021).

The yield of winter wheat grain at the control without fertilizers amounted to 43.4 c/ha, which was explained both by the high fertility of the experimental site as a whole and by the use of highly productive varieties of local breeding in the experiment. However, the cultivation of wheat with the absence or lack of mineral nutrition greatly impoverishes the soil, since, for the formation of this crop, the removal of only assimilated nitrogen reaches over 150 kg/ha. The use of a half dose of NPK increased wheat productivity by 7.9 c/ha compared to the absolute control variant with an LSD in the (LSD 05) factor of 3.5 c/ha. The increase in the dose of mineral fertilizers to N 80 P 80 K 80 was not reflected in the further increase in the yield of winter wheat grain: the increase was 1.5 c/ha and is unreliable, i.e. it cannot be mathematically proven. The use of poultry manure-based compost in full norm contributed to an increase in the yield of winter wheat grain by 5.5 c/ha, which undoubtedly proves the high efficiency of local organic fertilizer. The introduction of an incomplete dose of NPK against the background of organics turned out to be optimal. The yield of winter wheat grain on these plots is noted at its maximum values, namely 56.7 c/ha (Gutorova et al. 2021).

The results of the study on winter wheat give the right to assert that with high effective soil fertility and optimal implementation of all agrotechnical measures (sowing, soil preparation, protection from pests and diseases, selection of varieties), the full dose of mineral fertilizers was excessive, especially against the background of organic fertilizers. To increase the productivity of winter wheat at fertilization levels that meet the biological needs of plants, it was necessary to sow short-stem varieties or use special preparations based on trace elements and biologically active substances that help strengthen internodes and increase grain productivity of winter wheat. Cameral processing of the experimental material obtained experimentally according to the indicators of grain productivity of corn showed that the yield of grain according to the experimental variants increased with an increase in the level of fertilization from 67% on the variant without fertilizers to 80% with the combined use of organic and mineral fertilizers. The mathematically proven reliability of excess grain yield is observed only with significant changes in the nutritional regime of plants. Of considerable scientific and practical interest is the data on the number of ears on a plant, depending on the level of fertilization (Orazaeva et al. 2017; Ippolito et al. 2021).

According to the calculations made, the number of cobs in the control variant was on average 0.85/plant, and with a half dose of NPK it was already 1.2, with a full dose of NPK it equaled 1.3, and under similar conditions, but with organic matter, the number of cobs per plant increased in value to 1.5 units. Studies have also revealed that the number of rows and grains in the cob, the weight of the grain from the cob depend on the level of fertilization of corn. Against the background of organic fertilizers, when applying a full dose of mineral fertilizers, a slight decrease in the mass of grains in the cob and the weight of 1,000 grains was recorded, which indicates the frailty of grain with excessive fertilization of the crop. The optimal ratio of grain and aboveground mass of corn was observed by us on plots with a maximum saturation of fertilizers equaling 1:3, while the lowest ratio was observed in the control variant without their use and equaled 1:2.1. Grain productivity of corn in the control variant was fixed at the level of 50.4 c/ha, which confirms our assumption that the typical chernozem of the experimental field has a high level of natural fertility. Grain corn responded well to the additional introduction of nutrients (Orazaeva et al. 2017; Ippolito et al. 2021).

When using a half dose of NPK, the grain yield increased by 11.3 c/ha compared to the control variant, from the use of a full dose, it increased by another 7.7 c/ha compared to the previous version with an LSD05 of 4.5 c/ha. The use of compost based on chicken manure as an organic fertilizer at a full rate of 14 t/ha increased the yield of corn grain by 11.7 c/ha against the variant without the use of fertilizers. It should be noted that in terms of its fertilizing efficiency, compost in the applied norm turned out to be equivalent to a half dose of mineral fertilizers since both variants under consideration provided equivalent increases in the corn yield. The introduction of a half dose of NPK against the background of the use of organic local fertilizers increased grain yield by 11c/ha. The full dose of mineral fertilizers on the background of organic matter turned out to be somewhat excessive since its introduction did not contribute to a reliable increase in corn productivity (Orazaeva et al. 2017; Ippolito et al. 2021).

CONCLUSION

The findings of the present study confirmed that grain corn has huge potential in successfully solving the problem of providing intensive animal husbandry with high-quality feed. At the current level of development of breeding science, promising corn hybrids have been developed and tested, capable of forming grain productivity over 100 c/ha on the optimal background of mineral nutrition. As an example, we can present the advanced farms of the Belgorod region (such as the Krasnoyaruzhskaya Zernovaya Kompaniya LLC or the BESRK-Belgrankorm company group) that received 120 kg/ha of corn on significant acreage in their fields.

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