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SCIENTIFIC BASES OF THE HUMUS STABILIZATION IN ORDINARY CHERNOZEM IN RUSSIA

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Abstract. The influence of long-term use of mineral and organic fertilizers, crop rotations, plant residues, soil treatment systems on humus content of common chernozems and stabilization of productivity of field crops in the arid conditions of the Middle Volga region is considered on the example of researches in the Samara area. The zone climate of field experiments is characterized as extremely continental. The sum of the active temperatures (above 10°C) is 2,800–3,000°C. The average annual rainfall is 453.8 mm with fluctuations over the years from 187.5 mm to 704.6 mm. In some years, precipitation does not happen within a month or more. Hydrothermal index in May–August is 0.7, the duration of the frost-free period is 149 days. If the humus content in the region is 43.5–45.2 g·kg, then, it is necessary to introduce 6.7–8.0 t·ha of manure per year to maintain the balance of the deficit. The introduction of biological methods for the conservation and reproduction of soil fertility (green fertilizers, perennial grasses, straw as fertilizer) reduces the loss of humus by 0.15–0.24 t·ha. This makes it possible to increase the payback of mineral fertilizers, which must be taken into account when developing fertility reproduction systems for soils. In the variants with minimal and differentiated cultivation of the soil during crop rotation in 30 years of the study, the loss of humus in the 0–30 cm layer decreased by 0.4–7.3 g·kg (43–789 kg) per year with maximum values in the combination of direct seeding of spring crops with deep loosening for a number of crop rotations is 41.4 g·kg, significantly exceeding the control (by 5.4 g·kg). The decrease in soil fertility in the variants with constant plowing and minimal processing contributed to an increase in the conjugation of productivity of crops with humus. Based on the research, in order to preserve the fertility of ordinary chernozem, it is necessary to use green fer-

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tilizer, leguminous perennial grasses. In the regional rotations of crop production, new generation technologies are recommended, the basis of which is differentiated tillage with the use of crushed straw as fertilizer.

Keywords: humus, fertilizers, crop rotation, tillage systems, yield

INTRODUCTION

Chernozem soil is one of the main treasures of Russia. The main indicator of soil fertility is the content of humus. It has in its composition almost all soil nitrogen, the main part of phosphorus and sulfur, a small amount of potassium, calcium, magnesium and other nutrients. The basic morphological features of soils are closely connected with humus: water, air and thermal regimes, physical and physicochemical properties, the content of basic nutrients, biochemical and microbiological indices (Mineev and Rempe 1990, Chichkin 2001).

Reproduction of soil fertility in agriculture is carried out according to Kashtanov with the costs of man-made energy in two ways: material and technological. The first includes the use of mineral and organic fertilizers, chemical and water reclamation, green manure, structural optimization of the arable land use. The second is the improvement of properties and soil regimes due to mechanical treatment (Kashtanov 1983).

In modern agriculture in Russia, due to a sharp decline in the use of organic fertilizers and the use of intensive soil treatments for a long time, trends have been established for the reduction of humus content, which in the arable soil layer varies within a very wide range from 0.005 to 0.09% or from 0.1 up to 2.3 t·ha and more per year (Chub *et al*. 2009, Cherkasov *et al*. 2017, Chichkin 2001).

According to SAS Samarskaya, chernozems with a high humus content (over 8%) have practically disappeared in the Samara region over the past 20 years. The areas of medium-humus soils with a humus content of 6–8% decreased, their share in the structure of arable land decreased from 31.9% to 10.7%. The areas of very weakly humified arable land increased from 1987 to 2010 by 98.7–123.6 thousand hectares. The areas of low-humus arable land increased from 545.6 thousand hectares (19.3%) to 1117.5–1132 thousand hectares (39.4–40.0%). In average, for the period from 1993 to 2010, areas of very weak and weakly humus arable land with humus content from 2 to 4% increased by 600 thousand hectares. The weighted average content of humus in the surveyed areas decreased from 5.40% in 1987 to 4.22% (by 29%) in 2010 (Korchagin *et al*. 2014).

For the stabilization of soil fertility in modern conditions, according to many authors, the crops of perennial and annual grasses should be used, green manure pairs, stubble, leguminous crops (Kashtanov 1983, Chichkin 2001, Blaise 2011). The role of straw from cereals increases in arid conditions (Goryanin *et al*. 2018, Kashtanov 1983, Chichkin 2001).

In addition to these factors, soil treatment has a significant effect on the balance of humus, and under different conditions this element can produce both positive and negative effects on the preservation of soil fertility (Bakirov 2008, Kazakov and Milyutin 2010, Kalichkin 2008, Kulikova 1999, Lykov *et al*. 2006, Cherkasov *et al*. 2015, Chudanov 2006). Many researchers note a decrease in the mineralization of humus and the improvement of individual elements of fertility, with minimal soil cultivation and the no-till production system, compared to traditional technology based on annual plowing (Crovett 2010, Chichkin 2001, Vlasenko *et al*. 2003, Blanco-Canqui and Lal 2008, Blanco-Moure *et al*. 2013, Gregorich *et al*. 2009, Laudicina *et al*. 2012, Martín-Lammerding *et al*. 2013, de Rouw *et al*. 2010, Salvo *et al*. 2010, Soane *et al*. 2012). Other scientists believe that in most cases, a decrease in the intensity of soil cultivation leads to a deterioration in effective fertility (Kalichkin 2008, Cherkasov *et al*. 2015). Moreover, in Russia and around the world, an analysis of the humus content variation in chernozem in ordinary or dry conditions was carried out mainly in short-term experiments.

The aim of the research is to identify the long-term effects of various fertilizer systems, field crop rotations, intensification levels and technological systems for tillage and sowing on humus content and productivity of field crops in the Middle Volga region.

MATERIALS AND METHODS

The research was carried out in the long-term experience of the Samara Research Scientific Institute of Agriculture (1975–2011) on the ordinary chernozem. The land relief of the experiments was plain. The following fertilizer systems were studied in the six-field grain plowed fallow crop rotation (black fallow – winter soft wheat – spring soft wheat – corn – spring soft wheat– spring barley): 1. without fertilizer; 2. manure 10t; 3. $N_{52,5}P_{37,3}K_{22,5}$; 4. manure 10t + $N_{52,5}P_{37,3}K_{22,5}$. The initial content of humus is 43.5–47.1 g·kg of the soil.

Fertilizers were applied on the surface, they were sowed (first decade of September) in the soil by plowing. Soil samples were taken in the third decade of August. The initial humus content was determined before the experience, the analysis was made after 18 years.

In the second experiment (1998–2008), three types of crop rotations were deployed (in time and space) against the background of annual plowing: grain (pure fallow – winter soft wheat – spring soft wheat – spring barley); green-manured (green-manured fallow – spring soft wheat – corn – spring soft wheat); grain-grass (perennial grasses of the first year – perennial grasses of the second year – spring soft wheat – spring barley with under-crops of perennial grasses).

The studies were carried out at four levels of the arable land usage intensity: control (without fertilizers and chemical plant protection products); the minimum required (crushed during harvesting cereals straw for fertilizer, row fertilizer – P_{10-15}, radical side-dressing of winter crops – N_{30-40}); medium, conventional (the doses of fertilizers are calculated considering the compensation of nutrient removal by harvest); intensive (doses of fertilizers for harvest at the level of the arable land bioclimatic potential productivity).

The initial content of humus is 4.49%, hydrolysable nitrogen – 35 mg·kg, active phosphates – 200 mg·kg, exchangeable potassium – 150 mg·kg. Row fertilizer P_{10-15} was applied during sowing (spring crops – third decade of April, winter wheat – third decade of August). Root feeding of winter crops was made with N_{30-40} during seeding (third decade of April).

In the third experiment, since 1975, five ways of the basic soil treatment in rotation were studied (pure fallow – winter soft wheat – millet – spring barley – corn – spring soft wheat – oat): 1. Plowing to a depth of 20–22 cm, for all crops (control); 2. Plowing on 12–14 cm for all crops; 3. Flat-topped cutting on 20–22 cm, for all crops; 4. Flat-topped cutting for 10–12 cm, for all crops; 5. Before 1982 – without autumn tillage, since 1983 – combined one: flat-topped cutting 10–12 cm for fallow, 20–22 cm for barley and oats, plowing for corn, shallow plowing for millet and spring wheat.

During the 2000–2011 period, studies in this area continued in the seven-field crop rotation (pure fallow – winter soft wheat – millet – spring soft wheat – corn (since 2006 – green-manured) – spring soft wheat – spring barley). We studied modern technological systems for tillage and sowing:

1. Control – the traditional system of processing and sowing for all crops of crop rotation (plowing – PN-4-35; spring harrowing – BZSS-1.0; pre-sowing cultivation – KPS-4; sowing – SZ-3.6; compacting – ZKKSh-6);

2. Differentiated 1 – fine mulching soil cultivation for cereals (OPO-4.25), deep tillage for steam field and corn (PCh-4.5), sowing with a universal machine of Russian production – AUP-18.05;

3. Differentiated 2 – direct seeding of grain crops – AUP-18.05, deep tillage for corn – PCh-4.5 (the fallow treatment with universal herbicide fighters);

4. Fine mulching soil cultivation for all crops of crop rotation (OPO-4.25), sowing – AUP-18.05;

5. Differentiated 3 – treatment with disk tools for grain crops and on the fallow (Kühne-770), deep tillage for corn (PCh-4.5), seeding – AUP-18.05.

Fertilizers were applied with SZ-3.6 seeder (first decade of September). Chopped straw and stubble-root residues of harvested crops were used as materials for reproduction of soil fertility.

Before deploying a stationary experiment, the humus content in horizon A (0–37 cm) was 3.9%. The content of active forms of phosphorus > 6 mg·kg and potassium > 12 mg·kg in the soil up to the parent rock in depth. The sum of the absorbed bases is 22.9 mg (equivalents).

The zone climate of the conducted field experiment is characterized as extreme continental. The average monthly temperature of the coldest months (January and February) is -10.5, -10.3ºC, the warmest (July) is +21.3ºC, the average annual air temperature is 5.4°C. The sum of the active temperatures (above 10°C) is 2,800–3,000°C. The average annual precipitation is 453.8 mm with fluctuations in some years from 187.5 mm to 704.6 mm. In certain years, precipitation does not occur for a month or more. Hydrothermal index in May–August is 0.7, duration of frost-free period is 149 days (Goryanin *et al*. 2018).

During the research, the favorable years for growth and development of the studied cultures were 1976, 1978, 1982, 1983, 1985, 1986, 1989, 1990, 1993, 1997, 2003 and 2007. In 2002 and 2005, a spring drought was observed. In 1979, 1981, 1992, 2008, 2009, a spring-summer drought was observed and in 1988, a summer drought of medium intensity was detected. In 1996, a strong spring drought was detected, in 1995 and 1998, there was a very strong spring-summer drought, and in 2010, there was the longest spring-autumn drought in the last 100 years (hydrothermal index for May–July was 0.13). Extremely unfavorable years for the studied cultures were 1980 and 1984. The remaining years were at the level of long-term average annual climate data.

The humus content was determined in accordance with GOST 26.213-84 (determination of organic matter by the method of Tyurin, modification of Central Research Institute of Agrochemical Service of Agriculture). The method is based on the oxidation of organic matter with a solution of potassium bicarbonate in sulfuric acid and the subsequent determination of trivalent chromium, equivalent to the content of organic matter, on a photoelectrocolorimeter. The results of records and observations were processed by the method of dispersion and correlation analysis on a computer (AGROS application ver. 2.09.).

Table 1. Monthly and annual precipitation amounts during the study period (mm)

Year	Month												For a year
	1	2	3	4	5	6	7	8	9	10	11	12	
1975	23.0	19.3	25.4	4.9	10.4	6.5	47.0	41.5	16.8	30.7	17.0	36.3	2788
1976	57.0	12.3	1.5	17.5	53.1	68.1	81.8	56.7	14.6	39.8	21.3	14.5	438.2
1977	8.6	50.1	28.1	18.9	63.0	59.3	24.3	66.8	53.3	56.0	32.3	58.8	519.5
1978	28.4	25.1	23.7	18.0	20.0	134.2	37.7	9.2	105.8	52.3	38.2	39.0	531.6
1979	35.4	62.7	10.4	34.2	0.0	40.7	109.6	11.8	60.1	22.8	23.3	15.1	426.1
1980	35.3	20.8	44.1	74.8	6.4	61.7	4.8	76.6	36.8	29.9	27.6	51.3	470.1
1981	39.4	22.2	46.8	52.5	3.6	5.7	32.9	61.5	41.6	65.5	36.3	37.9	445.8
1982	47.5	11.9	26.9	56.8	7.1	56.4	14.6	21.4	94.5	44.4	22.2	52.1	455.8
1983	42.9	51.7	22.0	16.8	47.4	80.6	90.3	42.5	17.1	25.8	36.5	19.6	493.2
1984	47.3	0.6	4.4	7.8	2.6	116.8	39.7	54.0	10.1	78.1	44.3	14.4	420.1
1985	27.3	43.1	4.7	27.7	8.1	70.0	91.6	38.5	69.7	33.9	47.2	35.2	497.0
1986	59.0	34.3	1.4	8.7	22.3	72.3	15.9	46.4	36.7	66.6	36.8	49.1	449.5
1987	57.3	28.6	2.1	28.1	30.1	48.5	98.7	63.8	106.2	1.8	51.7	37.9	554.8

Year	Month												For a year
	1	2	3	4	5	6	7	8	9	10	11	12	
1988	25.2	5.7	40.9	63.4	58.2	46.6	32.6	54.0	37.6	12.2	51.0	48.4	475.8
1989	40.9	18.6	24.6	27.5	51.1	40.3	79.5	89.7	13.7	68.8	47.6	50.2	552.5
1990	30.2	50.4	35.8	36.3	62.8	101.2	92.1	54.9	64.7	64.5	82.7	27.7	703.3
1991	40.3	48.6	18.5	24.2	30.9	58.0	35.1	29.0	33.1	24.1	22.8	40.1	404.7
1992	50.5	45.2	1.8	48.8	36.5	9.5	31.5	23.9	17.9	38.4	51.8	11.0	366.8
1993	32.8	29.6	25.6	83.4	4.6	70.3	164.8	123.0	93.9	29.2	7.7	39.7	704.6
1994	26.4	13.3	32.2	3.0	32.3	98.7	54.5	68.4	10.9	44.2	30.0	32.0	445.9
1995	54.9	48.5	24.7	9.8	16.1	11.8	42.3	34.3	8.4	16.3	28.5	42.2	337.8
1996	7.2	27.0	14.9	29.1	19.0	74.1	12.8	12.0	44.5	11.3	27.0	16.3	295.2
1997	49.8	22.9	39.9	59.5	122.8	50.6	66.0	2.7	77.1	44.9	29.9	32.6	598.7
1998	21.9	32.2	29.8	48.3	0.8	12.3	20.2	37.3	5.1	41.1	55.3	31.3	335.6
1999	47.4	48.7	31.5	5.5	46.6	61.5	64.3	30.7	45.5	35.6	36.5	57.8	511.6
2000	37.4	29.4	30.6	23.5	47.5	62.8	21.7	39.4	77.1	12.1	11.0	99.9	492.4
2001	47.1	58.4	42.1	6.4	56.6	28.5	0.0	34.8	37.0	62.5	30.0	32.2	435.6
2002	33.7	25.7	34.2	1.7	18.4	56.3	7.6	13.5	39.7	63.3	42.7	23.6	360.4
2003	34.7	13.5	7.1	15.7	45.5	81.9	69.0	47.1	11.0	59.4	11.5	22.2	418.6
2004	21.7	29.4	22.1	26.6	30.3	26.0	99.4	9.5	68.7	72.3	51.8	41.9	499.7
2005	21.8	26.7	38.5	18.3	8.7	64.6	25.7	10.1	4.1	25.1	7.2	38.9	289.7
2006	23.9	29.3	29.1	53.1	49.2	21.5	41.7	76.1	32.8	38.0	44.5	25.0	464.2
2007	69.4	41.6	18.1	67.7	10.3	108.1	97.7	6.7	45.2	7.0	44.4	26.1	541.6
2008	36.2	33.6	32.3	17.7	8.7	33.6	121.3	7.7	44.5	12.1	32.6	7.1	387.4
2009	21.1	8.4	36.8	24.5	20.6	35.4	23.6	83.9	12.6	49.8	16.8	21.9	355.4
2010	38.0	40.5	28.9	8.2	19.2	3.6	4.4	15.8	15.5	39.9	78.9	35.7	318.6
2011	48.8	24.7	44.4	23.6	39.6	71.4	7.5	49.3	179.8	28.8	42.3	33.2	593.4
Average annual*	37.1	29.7	25.4	30.2	29.1	55.2	50.9	42.7	44.8	38.7	34.5	35.5	453.8

* average annual value taken for 1975–2014 (data from Bezenchukskaya agrometeorology station)

Table 2. Average monthly and annual air temperature during the study period (˚C)

Year	Month												For a year
	1	2	3	4	5	6	7	8	9	10	11	12	
1975	-7.6	-11.4	-1.2	13.1	17.9	21.7	22.5	18.2	15.3	3.2	-3.0	-5.9	6.9
1976	-12.0	-19.1	-11.3	7.1	14.2	18.3	16.8	18.3	11.6	-2.5	-3.6	-11.6	2.2
1977	-18.1	-12.3	1.7	8.4	17.2	20.3	21.2	18.7	12.1	2.1	0.6	-11.4	5.0
1978	-8.3	-13.6	-3.1	5.2	13.2	16.1	19.0	18.3	12.3	4.1	-0.6	-15.9	3.9
1979	-14.8	-10.6	-3.6	1.8	18.6	16.3	19.9	19.7	14.3	3.7	-2.3	-3.7	4.9
1980	-14.1	-12.6	-9.7	6.0	15.5	18.5	20.6	15.7	12.5	4.3	-2.2	-3.9	4.2
1981	-8.9	-9.7	-6.5	3.7	13.2	22.0	24.0	21.6	13.4	7.2	-0.3	-4.8	6.2
1982	-9.9	-13.2	-4.8	8.3	14.5	16.2	21.8	19.4	14.4	4.8	-0.8	-3.4	5.6
1983	-5.5	-5.0	-5.4	11.0	14.2	16.6	20.7	18.1	13.0	6.0	-2.0	-5.7	6.3
1984	-9.9	-16.3	-5.6	5.4	18.7	19.0	23.2	17.1	14.6	5.9	-3.4	-14.9	4.5
1985	-11.8	-12.3	-7.6	5.4	15.2	18.3	19.0	20.4	12.3	4.4	-2.3	-7.2	4.5
1986	-10.7	-15.8	-4.9	9.4	12.7	20.0	18.9	19.3	11.7	4.4	-6.2	-11.1	4.0
1987	-18.0	-9.9	-10.1	1.3	16.3	22.1	19.8	17.7	10.7	2.5	-7.1	-10.4	2.9

1988	-12.7	-11.9	-5.6	4.5	14.4	22.0	23.7	20.4	12.7	5.6	-5.8	-10.1	4.7
1989	-9.3	-6.2	-4.3	6.6	14.1	22.7	21.1	18.4	13.5	6.2	-4.1	-6.5	6.0
1990	-10.4	-4.7	1.5	9.1	13.3	17.1	19.7	17.0	11.5	5.5	-1.0	-7.0	6.0
1991	-8.6	-10.9	-5.5	8.9	16.0	21.6	21.2	18.0	12.8	10.0	-2.0	-11.1	5.9
1992	-8.5	-10.0	-5.1	6.1	12.7	18.4	19.3	17.9	14.7	4.2	-2.0	-8.5	4.9
1993	-7.4	-11.9	-5.7	5.0	15.5	17.7	20.5	18.1	9.0	5.0	-10.0	-8.4	4.0
1994	-8.9	-17.8	-7.3	6.9	13.9	17.9	17.8	17.1	15.4	6.9	-1.9	-10.2	4.2
1995	-11.5	-4.1	0.7	13.9	17.4	22.9	21.6	19.3	15.1	8.0	0.0	-10.8	7.6
1996	-16.8	-12.6	-9.9	3.4	18.5	20.5	22.1	18.8	12.8	4.7	0.4	-10.8	4.3
1997	-14.3	-8.8	-2.2	6.6	13.6	22.1	19.7	18.0	12.1	7.1	-3.7	-10.7	5.0
1998	-10.7	-11.8	-3.7	2.7	16.0	23.1	23.6	19.4	13.3	6.7	-7.3	-7.1	5.4
1999	-7.1	-5.0	-7.0	8.8	11.3	19.8	22.5	19.4	12.2	7.5	-6.7	-4.6	5.9
2000	-7.2	-5.6	-3.1	10.3	10.4	19.5	22.3	20.2	12.1	5.8	-3.1	-4.5	6.4
2001	-4.7	-9.5	-1.7	10.1	15.0	17.7	22.8	18.7	13.3	4.9	0.0	-11.8	6.2
2002	-6.7	-1.9	1.9	7.0	11.4	17.3	23.5	17.2	14.4	5.4	-0.3	-18.8	5.9
2003	-9.8	-12.3	-8.5	5.6	15.2	14.9	21.1	20.2	13.0	7.3	-0.2	-3.6	5.2
2004	-8.3	-10.6	-0.0	5.6	15.1	19.5	21.3	20.8	14.9	5.8	0.1	-6.1	6.5
2005	-8.3	-13.2	-7.1	6.6	17.9	19.1	20.6	19.8	14.7	7.3	0.2	-5.7	6.0
2006	-16.5	-13.9	-4.1	7.5	14.6	21.9	19.1	20.3	14.1	6.5	-2.1	-2.5	5.4
2007	-1.4	-12.5	-2.4	6.6	16.7	18.4	20.8	23.0	14.4	6.6	-4.5	-14.1	6.0
2008	-13.1	-8.2	1.6	10.2	15.0	17.9	21.6	21.0	12.4	7.5	2.6	-6.5	6.8
2009	-11.8	-9.6	-3.4	4.9	14.6	22.6	21.6	18.5	15.4	7.5	-0.3	-9.5	5.9
2010	-17.1	-12.4	-5.3	7.3	18.0	23.2	26.8	25.2	15.2	4.0	3.1	-4.9	6.9
2011	-11.4	-18.1	-7.2	7.1	15.8	18.1	24.8	19.8	13.5	6.8	-4.2	-7.3	4.8
Average annual*	-10.6	-11.1	-4.4	7.1	15.3	19.5	21.3	19.3	13.3	5.4	-2.1	-8.2	5.4

* average annual value taken for 1975–2014 (data from Bezenchukskaya agrometeorology station)

RESULTS AND DISCUSSION

Studies on the fertilizer systems have established the possibility of directional regulation of the humus state in the soil. With the agricultural use of arable land, this relatively stable indicator can significantly change in a short period. Compared with the initial content, the amount of humus in the soil in 18 years decreased by 6.1 g·kg, the annual loss was 1.017 t·ha. At the fertilized working plots, a higher level of organic matter has been preserved in all variants of the experiment. When applying 10 tons of manure and $N_{52,5}P_{37,3}K_{22,5}$ annually, the uncompensated losses of humus decreased by 0.4 t·ha. With the mineral fertilizer system, due to additional intake of root and stubble residues in the soil, annual losses of humus decreased by 0.117 t·ha.

Studies have established that without mineral fertilizers, the humus mineralization coefficient of ordinary chernozem is 11.5 g·kg of soil per year from the initial content and the annual humus replacement is 0.490 t·ha. Mineral fertilizers do not have a noticeable effect on the mineralization of humus in the arid conditions of the Middle Volga. Our calculations showed that when the content of humus in the soil is 43.5–45.2 g·kg, it is necessary to introduce 6.7–8.0 t·ha of manure annually to maintain a deficit balance.

However, given the current limited usage of organic fertilizers by Russian agricultural producers, we have studied biological methods of reproduction of soil fertility in the second experiment. Due to the use of biologization means in the green-manured and grain-grass crop rotations, the yield of spring wheat increased from 1.56 t·ha to 1.66 t·ha, barley – from 2.00 to 2.40 t·ha. The most significant increases in yields from fertilizers were obtained in grain fallow crop rotation (0.42–0.44 t·ha for winter wheat, 0.78–0.97 t·ha for barley). In crop rotation with green-manured fallow, fertilizers increased the yield of spring wheat by 0.42–0.51 t·ha (26.5–32.2%).

Located at 1 hectare of the crop rotation area, the use of intensification means increased the yield of products in the grain fallow crop rotation by 0.21–0.52 t·ha of grain units, in green-manured one – by 0.28–0.33 t·ha of grain units, in grain-grass one – by 0.23–0.26 t·ha (Table 3).

Table 3. Productivity of crop rotation, on average for 1999–2008, t·ha of grain units (Experience No. 2)

Crop rotations	Arable land usage intensity levels				LSD_{05}*
	Control (without fertilizers)	Minimally-required	Medium – conventional	Intensive	
Grain fallow (control)	1.94	2.15	2.40	2.46	0.09
Green-manured	2.18	2.44	2.68	2.79	0.06
Grain-grass	2.23	2.41	2.63	2.71	0.11

* Least significant difference at the 5% significance level

Similar results in productivity were obtained with the medium and intensive arable land usage levels – 2.63–2.68 and 2.71–2.79 t·ha, respectively. After passing through three crop rotations, the humus content was determined in soil samples. In the green-manured and grain-grass rotations the introduction of fresh organic substance (stubble-root residues + straw) into the soil over the years of research exceeded the control by 24.6–31.0 t·ha, which allowed to reduce annual humus losses by 0.150–0.240 t·ha.

In the third experiment, observations of the humus content indicate that the technological system with differentiated soil treatment (variant 3), compared with the control, reliably, in most years reduces humus losses in the arable layer of the soil and contributes to the preservation of soil fertility. On average for 2000–2011, using this variant, the humus content in the soil layer of 0–30 cm was 38.8 g·kg of soil, which is 5.4 g·kg (16.2%) higher than the control (Table 4).

Table 4. Humus content in the arable soil layer, g·kg soil (Experience No. 3)

Years	Technological systems of tillage and sowing					LSD_{05}, average
	1	2	3	4	5	
(2000, 2003, 2004, 2007, 2008) Hydrothermal index (May–August) > 0.75	35.1	39.0	40.6	35.5	37.8	4.03
(2001, 2002, 2005, 2006, 2009, 2011) Hydrothermal index (May–August) ≤ 0.70	31.9	35.8	37.2	31.1	32.5	4.60
Average (2000–2011)	33.4	37.5	38.8	33.1	34.9	4.34

Given that the years of research differed significantly in terms of climatic conditions and the yield of previous crops, we determined the dependence of the humus content on the amount of precipitation during the vegetation period. In the analysis, a significant increase in humus, compared to the control, both in wet and dry years during the period May–August was noted on the variant with direct sowing of spring crops and superficial placement of straw and stubble-root residues (variant 3). With a combination of minimal tillage with deep bursting of the soil and mixing of straw and stubble-root residues in the upper soil layer (variant 2), a significant increase in humus, compared with the annual plowing variant, was detected only in years with a wet vegetation period. With constant tillage in the crop rotation (plowing and minimal variants), the highest mineralization of humus in the 0–30 cm layer was detected with the lowest values of humus – 33.1–33.4 g·kg of soil. In layer analysis of humus content, the advantage of technologies with differentiated soil treatments compared to annual plowing is detected only in the 0–30 cm layer.

On average for 2001–2011, a mathematically demonstrable increase in humus in the soil layer of 0–30 cm, compared to the control, was detected in the variant with differentiated treatment 2 in the crop rotation – +5.9 g·kg of soil (17.7%). In the layer of 30–60 cm, there was no significant difference in this element of soil fertility between variants with differentiated soil treatments and control. At the same time, over the years of research, it was revealed that the use of a constant minimum tillage in a crop rotation with mixing of plant residues and stubble-root residues on the soil surface created a more distinct soil differentiation in terms of fertility and significantly lowered the content of humus by 3.2–6.1 g·kg of soil, compared to other tested variants in the layer of 30–60 cm (Fig. 1).

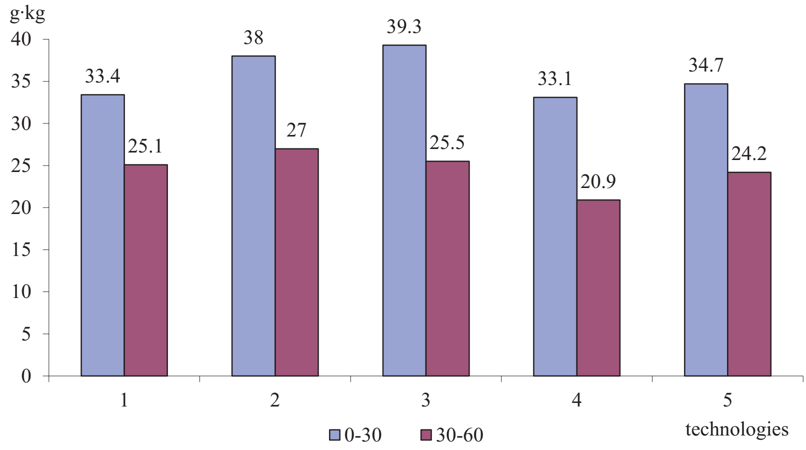

Fig. 1. The layered content of humus in different technological systems of tillage and field crops sowing, on average for 2001–2011 (Experience No. 3)

When comparing the indices with the initial data, it was established that the long-term use of flat-topped and combined tillage in the crop rotation provided a lower mineralization of humus, as compared to control in the arable layer of the soil. For 23 years of research, the content of humus, compared with baseline indicators, decreased by 3.6–6.1 g·kg of soil, which is significantly lower (by 1.8–5.0 g·kg) than the variants with soil tillage. On average for 2003 and 2006, the humus content in the 0–30 cm layer, compared to 1975, using technologies with minimal and differentiated soil treatments, decreased by 4.8–11.7 g·kg (518–1,264 kg per year), which is less (by 0.4–7.3 g·kg) than the loss of humus in comparison with the control (43–789 kg per year). The maximum content of humus was detected in the variant with differentiated treatment 2 (variant 3) – 41.4 g·kg of soil, which significantly exceeds the control (by 15.0%). In other technologies, the content of humus in absolute indices changed insignificantly, compared with the control (Table 5).

Table 5. Humus content, g·kg (Experience No. 3)

Soil layers	Variants					LSD_{05}, average
	1	2	3	4	5	
1975						
0–30	48.1	49.9	47.3	42.6	43.3	4.92
30–60	36.2	35.1	34.5	31.3	29.6	3.37
0–60	42.2	42.5	40.9	37.0	36.4	3.78
2003, 2006						
0–30	36.0	38.2	41.4	34.6	38.5	4.50
30–60	25.1	29.9	24.2	22.2	26.0	3.45
0–60	30.6	34.1	32.8	28.4	32.2	3.85

Soil layers	Variants					LSD_{05}, average
	1	2	3	4	5	
Changes by 1975						
0–30	-12.1	-11.7	-5.9	-8.0	-4.8	-
30–60	-11.1	-5.2	-10.3	-9.1	-3.6	-
0–60	-11.6	-8.4	-8.1	-8.6	-4.2	-

Under the arable layer (30–60 cm), compared with the initial data, the largest loss of humus, as in arable, is detected in the variant with annual plowing -11.1 g·kg. The use of minimal and differentiated treatments in crop rotation reduced the analyzed indicator by 0.8–7.5 g·kg, with maximum values of 0.8–7.5 g·kg (7.8–208.3%), for variants with differentiated soil treatments 1 and 3. In the 0–60 cm layer in the technological systems of the new generation of tillage and sowing, the humus content varied insignificantly in comparison with the control. In this variant the mineralization of humus with minimal soil treatments also decreased by 3.0–7.4 g·kg.

The testing of new technological systems of tillage and sowing, carried out in our studies, showed their high efficiency. In general, over the years of research, in spite of the large number of dry years, a relatively high harvest of winter wheat, millet and barley was obtained, using these systems (Table 6).

Table 6. Yields of field crops using different technological systems of tillage and sowing, t·ha, on average for 2000–2010 (Experience No. 3)

Cultures, indices	Technological systems of tillage and sowing					LSD_{05}
	1	2	3	4	5	
Winter wheat	2.18	2.32	2.08	2.27	2.18	0.24
Millet	1.98	1.99	1.91	2.00	1.97	0.21
Spring wheat	1.33	1.38	1.38	1.35	1.30	0.15
Corn (from 2006 pea + oat), t/ha	2.55	2.65	2.33	2.35	2.64	0.35
Spring wheat	1.35	1.34	1.33	1.31	1.31	0.14
Barley (2003–2007 spring wheat)	1.82	1.79	1.86	1.79	1.74	0.22
Crop yield	1.44	1.47	1.43	1.45	1.42	0.16
Crop rotation productivity, t·ha	1.77	1.82	1.73	1.76	1.76	-

At the same time, in the variants with the highest humus content (2, 3, 5), its connection with the productivity of the crops was insignificant. According to the results of the correlation analysis, an average direct correlation of productivity with soil fertility (r = 0.23–0.25) in the variants with the lowest amount of humus (1, 4) was revealed.

Taking into account equal grain yields in the studied technological systems, winter wheat grain yields ranged from 2.08 to 2.32 t·ha at the average in the crop rotation. One of the reasons for the lower yields in the variants with early and black fallows, treated with discs, was a more loose soil composition (r =

0.45), below optimal indices (1.2–1.3 g·cm^3) for the development of the crop, compared to other variants. In the variant with traditional technology, an average correlation of crop yields to productive moisture reserves was established in the autumn period (r = 0.42–0.50).

The most significant direct correlation of the elements of the crop structure was found between the grain yield of winter wheat and the plant density. With an almost equal number of productive stems on the average during the years of research, applying the studied technologies (327.8–354.0 pcs/m^2), the correlation coefficient was 0.73*–0.78**. When the winter wheat was cultivated in the early fallow, the grain yield was influenced by all elements of the structure, excepting the total and productive bushiness coefficient.

The application of the early sowing period (immediately after the sowing of early grain crops), using the universal seeding machine AUP-18.05, facilitated the production of millet grains of more than 2 tons per hectare on all variants of the experiment from 2003 to 2009. On average, over the years of research, crop yields, depending on the studied technological systems, changed insignificantly and amounted to 1.91–2.00 t·ha.

As for spring wheat, compared with winter wheat and millet, the taken effect of unfavorable weather conditions, intensified in recent decades, compared with the first half of the 20th century, was more strong, which led to a decrease in its productivity to 1.30–1.38 t·ha. At the same time, depending on the technological systems of tillage and sowing, the crop yields changed insignificantly. On the basis of the results of the correlation analysis, one of the reasons for the decline in wheat yields (the predecessor of corn, peas + oats), in the variants with direct sowing and treatment with discs, was an increase in the contamination by perennial weeds during the years with insufficient moisture in the vegetation period (r = -0.63*–0.69*).

As for spring soft wheat, in both crop rotation fields, a more significant correlation between the elements of the structure and the grain yield is revealed, in comparison with the winter wheat.

In contrast to winter crops, with the application of the studied technological systems of tillage and sowing, the maximum significant direct correlation is revealed between the grain yield of spring wheat, the weight of grain from 1 plant and the height of the plant density. With traditional technology, the correlation coefficient between these parameters, depending on the studied predecessors, changed insignificantly and amounted to 0.87**–0.89**. During the cultivation of spring wheat according to the technological systems of the new generation, the correlation coefficient between the grain yield of spring wheat and the grain mass from one plant in the fourth crop rotation field increased to 0.90**–0.96**. The correlation between the grain yield of spring wheat and the height of the plant density changed insignificantly (r = 0.86**–0.91**), compared to traditional technology.

When spring wheat was grown according to the traditional technology of tillage and sowing systems, the correlation between the remaining elements of the structure with yield varied, depending on the preceding crops. So, for spring wheat, running over the millet, the correlation between yield and plant density, productive and general bushiness, the mass of grain in the spike was at a 5% significance level (r = 0.62*–0.73). When cultivating wheat over corn, a direct close correlation was found between the mass of grain from the spike and the yield (0.84**).

In variants with differentiated soil treatments in the crop rotation, according to the analyzed parameters, a close direct link was observed for the preceding millet. The correlation between the yield and the plant density, the number and mass of grain in the spike, productive and general bushiness was 0.72*–0.88**.

When using direct seeding and other modern technologies of tillage and sowing systems in the penultimate crop rotation field, a reliable direct correlation of productivity with the plant density, the number and mass of grain from the spike (r = 0.72*–0.87**) was revealed. The average yield of spring cereals in the final crop rotation field, due to an increase in the yield of spring barley, increased to 1.74–1.86 t·ha. At the same time, the use of modern technologies, in comparison with the control, did not reduce the productivity of crops. In variants with traditional technology, the crop yield depended on the reserves of productive moisture in a meter layer of soil, and in variants with minimal treatments (2, 5), it depended from moisture reserves in the plow layer.

When analyzing six-year data on spring barley (2000–2002, 2008–2010), the correlation between the elements of the crop structure, climatic conditions and grain yield in many indicators was below spring wheat. On all studied technological systems of tillage and sowing, a significant direct correlation of the yield of spring barley with the plant density and the mass of grain from the spike was established. When applying the studied technologies, the maximum significant direct correlation was found between the grain yield of spring barley and the plant density (r = 0.97**–1.00**). The coefficient of correlation between the mass of grain in the spike and yield was 0.94** (traditional technology) and 0.91*–0.97** (technological systems of the new generation).

On average, for 11 years, per 1 ha of crop rotation area, the yield of cereals, depending on the technological systems of tillage and sowing, changed insignificantly and amounted to 1.42–1.47 t·ha. In the studies, the greatest productivity of crop rotation was revealed in the modern technological system with differentiated soil treatment 1 – 1.82 t·ha, which is insignificantly higher by 0.05 t·ha (2.8%) than the control. Decrease in productivity with technologies of constant fine processing and direct sowing of spring cereals, in comparison with the best variant of 0.06–0.09 t·ha or 3.4–5.2% is mainly due to the fall of the corn green mass. Reduction of output in the variant with disc treatment for grain crops is connected with the lowest yield of grain crops.

CONCLUSIONS

Thus, on the basis of the conducted studies it was established:

1. When the humus content in ordinary chernozem is 43.5–45.2 g·kg, it is necessary to introduce manure in amount of 6.7–8.0 t·ha annually to maintain its deficit-free balance.

2. Introduction of crop rotation in green manure crops, leguminous perennial grasses, use of straw as fertilizers reduces losses of humus by 0.15–0.24 t·ha. This makes it possible to increase the payback of fertilizers, which must be taken into account when developing systems for the reproduction of soil fertility.

3. The application of minimal and differentiated soil treatments over 30 years of research contributed to a reduction in humus loss in the 0–30 cm layer, compared to the control by 0.4–7.3 g·kg (43–789 kg per year). The maximum content of humus was revealed in the technological system of soil cultivation with a combination of direct sowing of spring crops and deep bursting for the fifth crop rotation – 41.4 g·kg, which significantly exceeds the control (by 5.4 g·kg). Decreased soil fertility in variants with constant plowing and minimal processing contributed to an increase in the correlation of crop productivity with humus.

4. To preserve the soil fertility of ordinary chernozem in the modern conditions of the region, it is necessary to introduce green-manured crops, leguminous perennial grasses into the crop rotation and straw as fertilizer.

5. The new generation technological complexes are recommended in the grain fallows and grain plowed fallow crop zonal rotations, the basis of which is differentiated soil-free tillage with a direct sowing of spring grains and deep bursting for arable crops, use of crushed straw and stubble-root residues as fertilizers.

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