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The Prospects for Sunflower Production and Improving its Adaptive Potential in the Central Black Earth Region

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ABSTRACT: Sunflower is one of the main oilseed crops in the world and the main one in Russia. Due to the development of erosion on slopes with steepness more than 3°, the cultivation of row crops, including sunflower, is prohibited. The expansion of the crop area in the territories with erosion-hazardous terrain, prevailing in the Central Black Earth Region, is very limited, and in the south-western part of the zone (Belgorod region) it has already been exhausted. The study was aimed at comprehensive assessment of the influence of the main tillage and organic fertilizer methods in the cultivation of sunflower under the relief conditions of the Central Russian Upland on the agrophysical properties of typical black earth and its anti-erosion resistance, crop yield and economic efficiency of crop cultivation. It has been established that the development of landscape farming systems in which erosion processes are stopped is a powerful factor in regulating the water conditions and the bioproduction process, which reduces the difference between the plain conditions and the conditions of the 3 – 5° slope with northern exposure to a non-veracious level. The no-till technology has contributed to increasing erosion stability of the soil on the 3 – 5° slopes especially in combination with organic fertilizers. As a result, the excellent structure (62 – 65 %) and good water stability (57.5 %) of the soil have been formed, moisture loss was reduced by 19 – 26 mm, and soil density was reduced to 1.15 g/cm^3. Application of no-till technology on the slopes with a slight decrease in the yield is compensated for by a high income up to 26.0 thousand rub/ha with the profitability level of 87%. The potential for expanding the sunflower crops through the use of northern slopes with the steepness of 3 – 5° in the Belgorod region is about 20 thousand ha per year.

Keywords: compost, density, economic efficiency, green manure, processing, productivity, structure, sunflower, typical black earth, water resistance.

Abbreviations: CBER, Central Black Earth Region.

I. INTRODUCTION

Sunflower cultivation is highly significant for agricultural production; the demand for this crop has always been and remains stably high. Due to the significant coefficient of sunflower crops erosion hazard and the degree of the yield rate reduction on eroded soil, it is generally adopted not to cultivate it on the slopes that are steeper than 3°. Besides, given the long sunflower return period, the possibilities of increasing its sown areas are quite limited. This problem is especially noticeable in regions of significant spread of soil erosion, the cause of which is the destruction of forests [1] and the high plowing of the territory.

This study was based, on the one hand, on the achievement of landscape farming aimed at preventing the erosion processes and soil preservation in the Central Black Earth Region [2, 3] and on the high efficiency of adaptive landscape farming systems development in the Belgorod region [4, 5], and, on the other hand, on the peculiarities of the slopes with northern exposure that featured the soil fertility not inferior to that of plain landscapes [6, 7]. There are several studies of the effect of separate sunflower cultivation technology elements on its productivity, however, for the most part, they relate to the choice of hybrids, the time of sowing, tillage systems, fertilizers, means of plant protection, etc. [8, 9]. No information is available about the comprehensive effect of the basic tillage methods and organic fertilizers on soil erosion resistance and sunflower productivity in various landscape conditions.

The study was aimed at assessing the prospects of sunflower production in the world and the country, and developing the recommendations for improving its adaptive potential in the sloping terrain of the Central Black Earth Region (CBER) (the Belgorod region).

II. CONDITIONS, MATERIALS AND METHODS

The studies were performed at ZAO Krasnaya Yaruga Grain Company in the Belgorod Region in 2015 – 2018 in a territory with a fully developed landscape farming system. The soil in the plots was typical nonleached black earth (0 – 3°): the humus content was 4.9 % (average), pHsal. was 6.4, and the content of mobile phosphorus and potassium (by Chirikov) was 134 and 234 mg/kg of soil, respectively; typical slightly leached black earth (3 – 5° with northern exposure): the humus content was 4.5 % (average), pHsal. was 6.1, and the content of mobile phosphorus and potassium was 210 and 190 mg/kg of soil, respectively.

The three-factor experiment included the following: factor A (terrain conditions): 1. The 0 – 3° slope (reference), 2. The 3 – 5° slope with northern exposure; factor B (main tillage): 1. Ploughing with PLN-4-35 to a depth of 25 – 27 cm, 2. Deep nonmoldboard tillage with sunflower to a depth of 25 – 27 cm, and 3. No-till; and factor C (organic fertilizers): 1. Without fertilizers, 2. Straw-and-litter compost (20 t/ha), and 3. Green manure (white mustard).

The sown area of the plots was 100 m^2, the accounting area was 50 m^2; the experiment was repeated three times. Straw-and-litter compost is a homogeneous friable brown or dark-brown mass obtained by aerobic biofermentation. Before planting green manure and introducing compost, postharvest stubble ploughing was performed with Amazone-Catros, except for the variant with the no-till technology. Green manure crops were sown with the SZT-3,6 seeder to a depth of 1.5 to 2.0 cm with the seeding rate of 15 kg/ha; in the variant with the no-till technology — with the Amazone-ZA centrifugal spreader. The sunflower was sown with the Massey Ferguson seeder using the seeds of the NK Neoma hybrid produced by the Syngenta Company. The seeding depth was 5 – 6 cm with the seeding rate of 60 thousand seeds per hectare. In the phase of 4 – 6 leaves, the sunflower was treated with the Euro-Lightning herbicide, soluble concentrate (SC) in the norm of 1.0 l/ha with the working fluid consumption of 200 l/ha. The veracity of the difference was assessed by the results of statistical processing with the use of research results using the methods of analysis of variance and correlation analysis in the *MS Excel* and *Statistica* software packages.

The morphometric analysis of the terrain in the Belgorod region was performed based on the GIS modelling methods being widely used in such studies [10-12]: digitalization of the topographic map; processing the vector *.shp file; building a digital model of the terrain (the IDW method) for the steepness and exposure of the slopes; and analyzing the obtained raster files (consolidation and calculation).

III. RESULTS AND DISCUSSION

The trends in sunflower production in the world, the country, the CBER, and the Belgorod region. The vegetable oil obtained from sunflower seeds is of great economic importance: it is used in food, varnish-and-paint, and many other industries. In addition to vegetable oil, processing of sunflower seeds provides other types of products that are well used for feeding animals, including feed additives: meal and cake.

Sunflower production in the world is constantly growing. Over the past 30 years, global oilseed production has increased 2.4 times. By the results of the year 2019, sunflower has moved from the fifth to the third place among the oilseeds, and is only second to soy and rape, its share reaching 9.4 % [13] (Fig. 1).

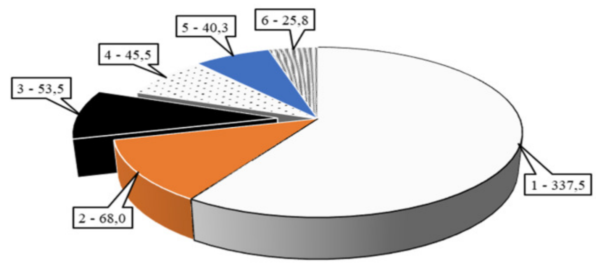


Fig. 1. Oilseed production in the world in 2019: 1. Soy, 2. Rape, 3. Sunflower, 4. Peanut, 5. Cotton, 6. Other.

Russia is one of the main oilseed producers in the world. Given the fact that according to Rosstat, the gross sunflower seed harvest in 2019 in the Russian Federation amounted to 15.1 million tons (Fig. 2), its share in the world's production is 28 %.

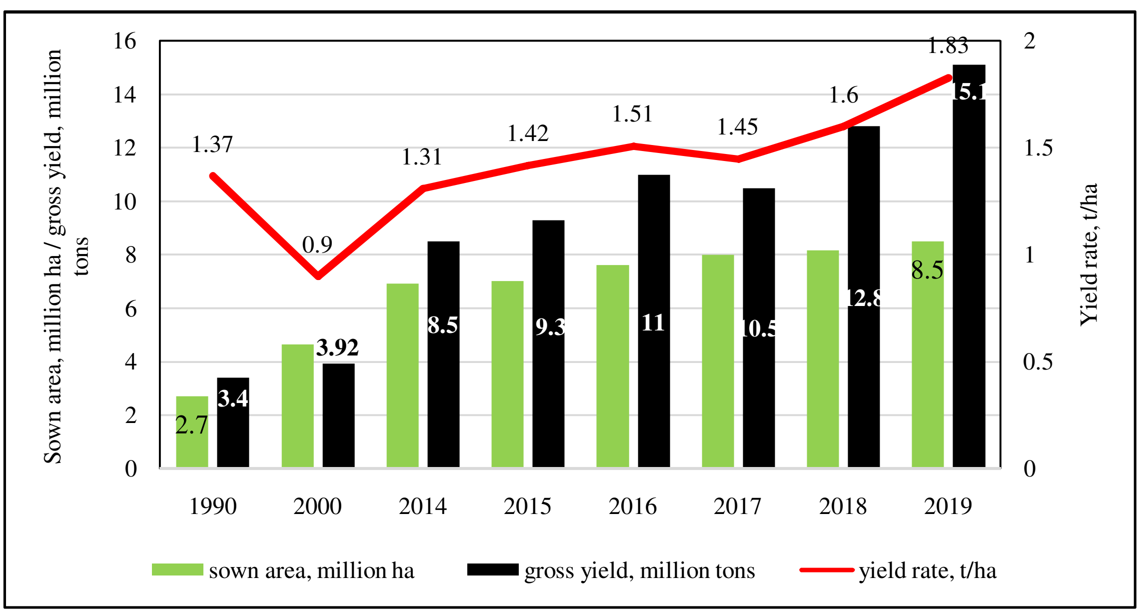


Fig. 2. The dynamics of sunflower production in Russia (the chart has been restored according to the data of Rosstat).

Unlike the global trends, sunflower in Russia is the main oilseed crop; the share of sunflower seed production is 65 %. Since 1990, sunflower production in the country has shown a steady growth of 4.4 times. According to experts, the growth of oilseed production will continue in the future due to the continuing demand for this raw material in the world and the underutilization of the processing capacities (9.1 million tons) in Russia [14].

The CBER is one of the leading producers of this crop in the country. At the end of 2019, its share was 23 % of the gross yield in the farms of all categories [15]. The Voronezh and Tambov regions, the shares of which are 8.3 and 5.8 %, respectively, are in the top 10 regions in terms of the gross yield, while in the Belgorod region, the maximum yield of 3.1 t/ha was obtained (Fig. 3), which was 1.7 times higher than the national average.

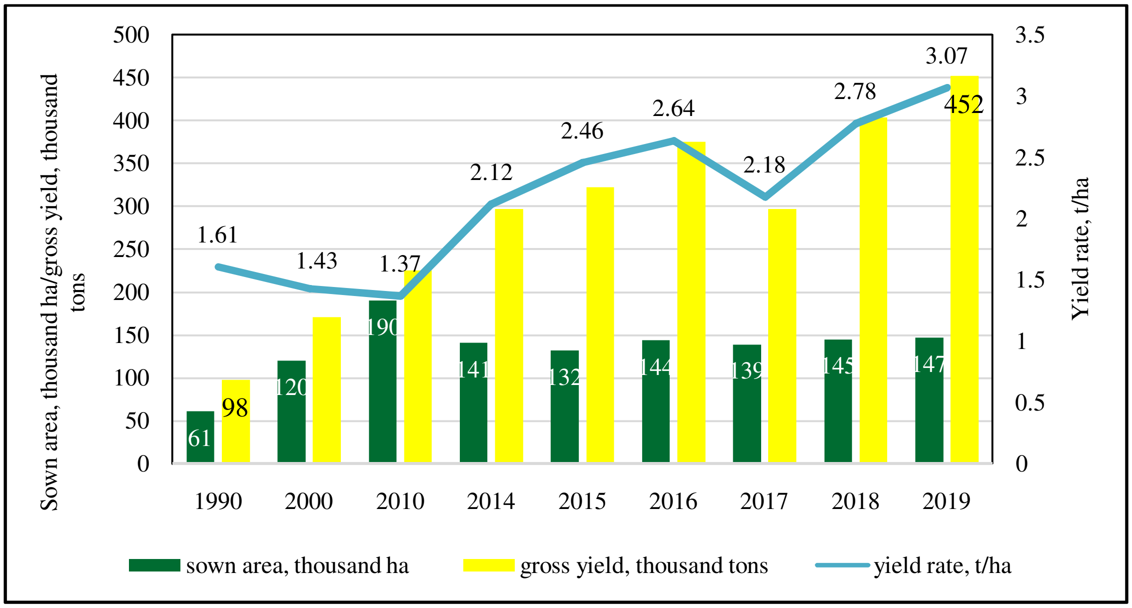


Fig. 3. The dynamics of sunflower production in the Belgorod region (the chart has been restored according to the data of Belgorodstat).

It should be noted that the dynamics of sunflower seeds production in the Belgorod region differ from the national trends. Until 2010, a similar increase had been observed in oilseed production due to the growth of the cultivated areas. In 2010, oilseed production reached its peak of 190 thousand ha, which corresponded to 15.2 % in the structure of sown areas. Since 2014, the sunflower sown area has decreased and stabilized at the level of 145 thousand ha, which does not exceed 10 %. This is not a coincidence. This value has been limited by the Decree No. 9 of the Governor of the Belgorod region dated February 4, 2014. In recent years, the gross yield has been growing solely due to the increased yield rate (r = 0.98*). With the share of 1.7 % of the national sunflower production, its production in the Belgorod region is 3 %.

Improving the technology of cultivation based on choosing highly productive hybrids, optimization of the nutrient and water conditions through the use of efficient soil cultivation systems, fertilizers, plant protection and other elements of the agricultural technology can significantly increase the yield rate, as evidenced by its growth throughout the country, and especially in the Belgorod and other regions of the Central Federal District (the Bryansk, the Voronezh, and other regions). In some regions of the CBER, the sunflower yield rate corresponds to the level of developed countries in Europe, Asia, and America, which is 2.5 – 3.5 t/ha [16].

Since sunflower is a crop with a high export potential that is highly demanded in the domestic market, it is necessary to consider the possibility of increasing the efficiency of its ecologically safe cultivation in the difficult landscape conditions of the CBER, and the Belgorod region in particular. Improving the microclimatic and soil conditions, reducing soil erosion during the development of adaptive landscape farming systems would allow finding an additional source of increasing the efficiency of sunflower cultivation.

Differentiation of the slopes with the steepness of 3 – 5° by their exposure based on *the morphometric analysis of the topography of the arable land in the Belgorod region* would increase the potential of sloped lands, while the adaptivity of the agricultural technologies would contribute to the more rational use of the soil cover and the efficiency of crop cultivation.

As a result of the comprehensive analysis of the morphometric data about the steepness and exposure of the slopes, it was found that the area of the slopes with northern exposure and related slopes with north-western and north-eastern exposure with the steepness of 3 – 5° was 119.2 thousand ha (Table 1), or 7.3 % of the arable land in the Belgorod region.

Table 1: Distribution of the arable land with the steepness of 3 – 5° by the exposure of the slopes.

Slope exposure	NW	N	NE	E	SE	S	SW	W	Total
Area, thousand ha	40.1	53.9	25.2	40.8	37.1	45.3	25.7	38.3	306.4
Share, %	13.1	17.6	8.2	13.3	12.1	14.8	8.4	12.5	100

The agrophysical properties of the typical black earth and water conditions. Erosion resistance of the soil is largely determined by the indicators of its fertility, such as density, structure and water stability, water holding capacity, and water retention capacity. In analyzing the agrophysical properties of typical black earth, a definite pattern is visible: the effect of the studied factors, depending on the period of soil sampling (sunflower sowing or harvesting), is manifested in various soil layers. During sowing, statistically significant differences in soil density, its structure, and water stability were observed in the most important, in terms of erosion, 0 – 10 cm top layer, especially in the spring and summer — the period of melt-water run-off predominating (60 – 70 %) in the total annual amount in the CBER (Table 2). In the period of crop harvesting, on the contrary, a significant difference was observed in the entire 0 – 30 cm ploughed layer.

During sowing, soil density only in the 0 – 30 cm layer was on average veraciously higher by 0.07 – 0.09 g/cm^3 after abandoning main tillage, which confirmed the cardinal difference between the main tillage methods in terms of their effect on soil. In the case of main tillage, soil density was aligned across the studied layers, while in the case of the no-till technology, this value increased with the depth.

Table 2: The agrophysical values of typical black earth fertility (2016 – 2018).

Factor A	Factor B	Factor C	Soil density, g/cm^3				Structure, %				Water stability, %			
			sowing		harvesting		sowing		harvesting		sowing		harvesting	
			0 -10	0-30	0-10	0-30	0-10	0-30	0-10	0-30	0- 10	0-30	0-10	0-30
The 0 – 3° slope (reference)	ploughing	w/o fertilizers	1.15	1.15	1.10	1.13	56.0	58.3	49.6	50.3	50.6	50.3	57.2	54.7
		compost	1.07	1.10	1.08	1.12	65.7	62.6	50.6	48.7	57.9	53.9	53.4	53.7
		green manure	1.05	1.10	1.06	1.14	63.3	61.2	49.4	48.1	52.5	49.1	55.3	54.4
	deep loosening	w/o fertilizers	0.99	1.08	1.08	1.11	59.0	59.2	48.3	50.0	56.4	52.7	59.1	56.9
		compost	1.07	1.11	1.11	1.08	61.7	58.9	49.3	49.8	55.0	52.5	56.9	56.5
		green manure	1.05	1.08	1.18	1.21	63.3	59.3	48.0	48.9	55.1	52.9	57.1	56.6
	no-till	w/o fertilizers	1.13	1.22	1.11	1.16	62.0	58.0	47.0	47.6	59.4	51.1	59.2	58.2
		compost	1.17	1.17	1.18	1.22	50.3	56.1	50.8	50.3	54.2	51.8	54.8	57.7
		green manure	1.18	1.17	1.20	1.27	59.0	59.0	48.0	48.2	46.4	50.0	55.5	57.6
The 3 – 5° slope (with northern exposure)	ploughing	w/o fertilizers	1.11	1.11	1.07	1.13	59.7	56.6	50.9	48.7	53.2	52.4	55.8	56.9
		compost	1.10	1.13	1.14	1.15	56.3	60.3	48.0	47.7	46.8	50.8	55.9	55.7
		green manure	1.08	1.12	1.12	1.18	57.0	56.7	45.0	47.3	49.7	50.0	55.4	54.7
	deep loosening	w/o fertilizers	1.09	1.10	1.09	1.12	62.3	58.1	47.1	48.2	51.4	51.3	57.0	56.5
		compost	1.12	1.12	1.09	1.08	52.7	58.3	45.1	46.6	52.1	49.8	54.6	56.6
		green manure	1.15	1.11	1.15	1.14	57.3	58.1	51.9	48.8	49.4	51.9	57.3	56.0
	no-till	w/o fertilizers	1.18	1.22	1.13	1.22	53.0	55.0	46.9	47.5	50.2	53.4	55.7	57.1
		compost	1.16	1.14	1.13	1.17	61.7	58.0	48.7	45.4	44.3	49.9	57.3	57.2
		green manure	1.22	1.22	1.14	1.20	64.7	59.3	45.7	46.6	41.9	46.2	55.8	56.9
LSD_{05} for the factors with significant influence			B — 0.06; D * — 0.05	B, D — 0.04	-	B, C — 0.05	ABC — 8.9	-	-	A — 1.4	A — 3.7, D — 4.5	-	-	B — 1.7
Note: D — conditions of the year														

The mathematical processing of the data did not reveal any significant effect of either organic fertilizers or the difference in terrain conditions on soil density. It may be noted as a trend that the use of organic fertilizers before ploughing decreased soil density by 0.05 – 0.10 g/cm^3 in the plain, while their use before deep loosening increased the value by 0.03 – 0.08 g/cm^3 in the 0 – 10 cm layer. In using the no-till technology, soil density increased in the 0 – 10 cm layer on the plain and decreased by 0.05 g/cm^3 in the 0 – 30 cm layer. On the 3 – 5° slopes, the effect of organic fertilizers varied: unlike green manure, compost contributed to decreasing the compacting effect of the no-till technology to the optimum value of 1.15 g/cm^3. However, it should be noted that with the use of the no-till technology only, soil density exceeded the favorable value for sunflower cultivation.

During the harvesting period, as already noted, no influence of these factors on the density in the 10 cm layer was found. This could be due to two interrow treatments.

In the 0 – 30 cm layer, the soil compaction that had formed during the sowing period persisted after refusal to use main tillage. Besides, during this period, the effect of organic fertilizers was statistically significant: the use of green manure resulted in soil compaction after the use of the resource-saving techniques in the plain, and after ploughing on the slopes. This emphasizes the importance of proper combination of soil protection and remediation techniques in specific landscape conditions.

This is especially exhibited in analyzing the soil structure. During the sowing season, only the interaction of the terrain factors, tillage, and fertilizers had a statistically significant effect on the studied parameter in the 0 – 10 cm layer that was the most susceptible to erosion. In the plain (0 – 3°), the use of organic fertilizers for primary tillage regardless of the method used (nonmoldboard or mouldboard tillage) contributed to improving the soil structure. In introducing compost before ploughing, the increase in this value by 9.7 % was mathematically proven. On the contrary, the use of organic fertilizers with the no-till technology resulted in a deterioration in the structure; when compost was used, it was statistically veracious (by 11.7 %).

On the 3 – 5° slopes with northern exposure, the opposite situation was observed. The use of organic fertilizers during main tillage decreased the content of agronomically valuable aggregates. Upon compost introduction before deep loosening, the decrease by 9.6 % was veracious, whereas with the use of the no-till technology, organic fertilizers contributed to increasing the share of the macrostructure: with the use of green manure, it veraciously increased by 11.7 %.

Since the soil structure depends on the conditions formed in the soil profile, including the amount and the degree of organic matter transformation, the activity of soil biota and its enzymatic apparatus [17], and the water, air and thermal conditions, the interaction of the contrasting factors used in the experiment in terms of these parameters resulted in a pronounced difference.

During sunflower harvesting, the content of agronomically valuable aggregates in the 0 – 30 cm soil layer on the plain was higher by 1.7 % than on the slopes. The difference was small, although statistically significant.

In contrast to the soil density and structure, the variability of its water stability veraciously depended only on the terrain conditions: on average, its value in the 0 – 10 cm layer on the plain was higher by 5.4 % than on the 3 – 5° slopes with northern exposure. However, it is noticeable that when deep loosening was used, regardless of the use of organic fertilizers, the variability of this indicator was insignificant, and when fertilizers were used before ploughing or in the no-till technology, the water stability decreased. The combination of ploughing + compost on the 0 – 3° (57.9 %) slopes was only slightly inferior to the best variant in the experiment, which was no-tillage in the same terrain conditions (59.4 %).

In the 0 – 30 cm layer, the difference in water stability of the aggregates reduced to the nonveracious level; however, it was the best on the plain in the case of compost introduction before ploughing, and on the slopes — in the case of using the no-till technology (53 – 54 %).

By the end of the sunflower vegetation period, the positive effect of tillage on soil water stability in the 0 – 30 cm layer increased toward improving energy efficiency. The no-till indicator was the highest and averaged 57.5 %, which was significantly (by 2.5 %) higher than that of ploughing.

The ability of the soil to accumulate moisture and retain it for a long time is also a factor of soil erosion resistance. An analysis of the water balance components showed that moisture loss through evaporation, infiltration into the soil, and runoff in the autumn and spring was the lowest in the case of using green manure with deep loosening and the no-till technology on the plain (112 – 114 mm) (Fig. 4).

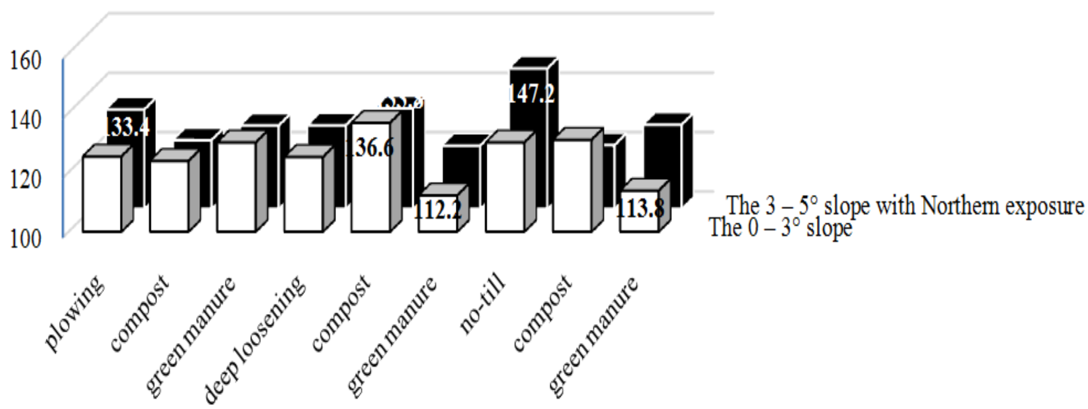


Fig. 4. Moisture loss through evaporation, infiltration into the soil, and runoff in the autumn and spring, mm (2016 – 2018).

The maximum moisture loss occurred on the slope area in the absence of tillage — 147 mm, which was due to the more compacted and levelled soil surface on this agricultural land. The use of organic fertilizers contributed to decreasing the losses by 19 – 26 mm.

Moisture loss was also quite significant in the case of using compost on the background of deep loosening, regardless of the terrain conditions and ploughing on the 3 – 5° slopes — 133 – 137 mm.

It should be emphasized separately that during the period of the research, erosion damage was not detected on any studied agricultural backgrounds, which fact indicated the absence of soil washout. Development of adaptive landscape farming systems was a powerful factor in regulating the water conditions and the uniform distribution of the winter moisture reserves, the share of which on the 3 – 5° slopes with northern exposure was 98 % of that of the plain area.

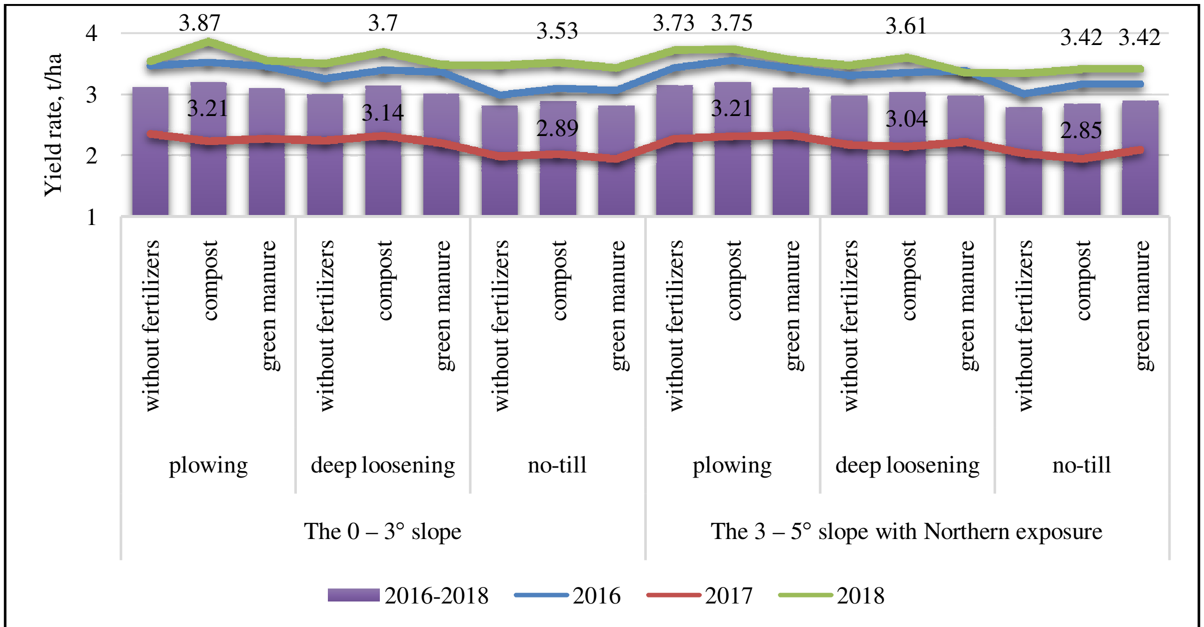
At the same time, the efficiency of the water use depended on the methods of tillage and fertilizers studied in the experiment. Sunflower consumed moisture more economically after ploughing (on average, by 66 and 188 m^3/t less than after non-moldboard tillage and the no-till technology, respectively) and after introducing compost (by 50 m^3/t less than in the case of using green manure).

It is obvious that in the zone of unstable moistening, which the CBER is, moisture supply largely determines the level of crop productivity.

In 2016 and 2018, the most favorable conditions were formed for sunflower crop formation — 3.3 – 3.6 t/ha on average (Fig. 5). The highest yield was obtained in 2018 after introducing compost before ploughing, regardless of the terrain conditions — 3.8 – 3.9 t/ha.

The mathematical processing of the data did not reveal any statistically significant yield rates difference between the conditions of the plain (0 – 3°) and the 3 – 5° slopes with northern exposure over the entire period of the studies.

The choice of the method of primary tillage was of decisive importance for the yield rate, apparently due to the predominant effect of this factor on almost all studied parameters. The no-till technology statistically veraciously decreases the yield rate compared to ploughing (by 11 %) and deep loosening (by 7 %). The sunflower yield rate dependence on the organic fertilizers was determined in the weather-favorable years (2016 and 2018), when it increased after compost introduction by 0.07 – 0.08 t/ha.



LSD$_{05}$ for the factors with significant influence	2016	2017	2018	2016 – 2018
	B, C — 0.05; AC — 0.07; BC — 0.09	B — 0.06; AC — 0.09; BC — 0.10	B, C — 0.15; AC — 0.22; BC — 0.26	B, C, D — 0.06; AC — 0.08; BC — 0.10

Fig. 5. Sunflower yield rate, t/ha: 1. 2016, 2. 2017, 3. 2018, 4. Average for 2016 – 2018.

The effect of the relief conditions on the crop yield rate was manifested only in assessing the interaction of the studied factors: the average yield growth by 0.1 t/ha due to compost introduction was veracious only in the plain conditions. Moreover, compost is only effective with main tillage, regardless of the method. The effectiveness of compost has been confirmed in studies of other authors [18].

Currently, agricultural producers are facing a difficult task: on the one hand, the need to meet the requirements of the market economy, which means highly efficient and economically profitable production, and on the other hand, nonviolation of the ecological balance, mainly, preservation of the cultivated lands and soil as the main and irreplaceable means of agricultural production. Currently, about 80 % of the agricultural land is subjected to medium and strong erosion [19].

The complex slope terrain of the Central Russian Upland has predetermined the high significance of this problem for the traditionally agrarian regions of the CBER with a high degree of the territory ploughness. In this regard, the economic assessment of the soil-protective and environment-improving measures is of considerable interest, especially in relation to row crops with low soil-protective ability, which are still very competitive. This also holds for the sunflower.

The calculation of sunflower cultivation economic efficiency in various landscape conditions depending on the choice of the main tillage method and the use of organic fertilizers showed that their value was determined by the influence of the studied factors both on the sunflower yield rate and the production costs. The difference in the costs was associated with the cost of organic fertilizers (compost and green manure), main tillage (ploughing or deep loosening, and presowing tillage), as well as the cost savings for stubble ploughing in the case of using the no-till technology. For this reason, the difference in the costs reached 42 % between the use of the no-till technology without organic fertilizers and introducing compost before tillage (Table 3).

However, the positive effect of using main tillage and organic fertilizers before ploughing, especially compost, on the sunflower oil seed yield rate significantly reduced the difference in the costs between the above-mentioned contrasting variants to 25 %, while for similar variants with the use of fertilizers, this difference was 7 – 9 %.

Table 3: The economic efficiency of sunflower cultivation in various terrain conditions, depending on the method of main tillage and the use of organic fertilizers (2016 – 2018).

Factor A (Landscape conditions)	Factor B (Main tillage)	Factor C (Organic fertilizers)	Yield rate, t/ha	Product cost, thousand rub/ha	Total costs, thousand rub/ha	Production costs, thousand rub./t	Contingent net income, thousand rub/ha	Profitability level, %
The 0 – 3° slope (reference)	ploughing	without fertilizers	3.12	62.4	37.5	12.0	24.9	66
		compost	3.21	64.2	42.5	13.2	21.7	51
		green manure	3.10	62.0	40.5	13.1	21.5	53
	deep loosening	without fertilizers	3.01	60.2	36.5	12.1	23.7	65
		compost	3.14	62.8	41.5	13.2	21.3	51
		green manure	3.02	60.4	39.5	13.1	20.9	53
	no-till	without fertilizers	2.82	56.4	30.0	10.6	26.4	88
		compost	2.89	57.8	35.0	12.1	22.8	65
		green manure	2.82	56.4	33.0	11.7	23.4	71
The 3 – 5° slope	ploughing	without fertilizers	3.15	63.0	37.5	11.9	25.5	68
		compost	3.21	64.2	42.5	13.2	21.7	51
		green manure	3.11	62.2	40.5	13.0	21.7	54
	deep loosening	without fertilizers	2.99	59.8	36.5	12.2	23.3	64
		compost	3.04	60.8	41.5	13.7	19.3	47
		green manure	2.99	59.8	39.5	13.2	20.3	51
	no-till	without fertilizers	2.80	56.0	30.0	10.7	26.0	87
		compost	2.85	57.0	35.0	12.3	22.0	63
		green manure	2.90	58.0	33.0	11.4	25.0	76

However, on the one hand, cost reduction by rejecting both main tillage and organic fertilizers slightly reduced the sunflower yield rate in these variants due to its high environmental resistance. On the other hand, the landscape farming systems had a favorable effect on the optimization of the water conditions and preservation of typical black earth fertility as a result of erosion prevention. This resulted in achieving the maximum contingent net income of 26.0 – 26.4 thousand rub/ha with the profitability level of 87 – 88 %.
The comparable profit of 25 thousand rub/ha was obtained in the case of ploughing without fertilizers and the use of green manure with the no-till technology, especially on the 3 – 5° slope. The profitability level, in this case, ranged from 66 to 76 %. The use of compost before deep loosening on the slopes provided the lowest income and profitability: 19 thousand rub/ha and 47 %. All other variants, which were main tillage regardless of the method (mouldboard and nonmoldboard tillage), and the use of organic fertilizers, compost, and green manure, took intermediate places.

Taking into account the area of the slopes with northern exposure and the steepness of 3 – 5° determined as a result of the morphometric analysis, the potential for expanding sunflower sowing areas was about 20 thousand ha, and, therefore, the additional annual income in the 2019 prices might amount to 500 million rubles.

IV. CONCLUSION

As a result of the comprehensive assessment of the effect of the main tillage methods and organic fertilization in sunflower cultivation in the landscape conditions of the Central Russian Upland of the CBER on the agrophysical properties of typical black earth and its erosion resistance, productivity, and economic efficiency of crop cultivation, it has been found that in the landscape farming systems, the difference between the plain terrain conditions (0 – 3°) and the conditions of the 3 – 5° slopes with northern exposure for most studied parameters is not statistically veracious.

The effect of the terrain conditions is manifested depending on the main tillage method chosen and the use of organic fertilizers.

The use of organic fertilizers before main tillage in the plain conditions contributes to the formation of its optimal density, excellent structure (62 – 66 %), good water stability (54 %), and efficient water consumption by sunflower crops. The combination of compost + ploughing ensured the highest average yield rates over the three years of the studies (3.2 t/ha) with the maximum of 3.9 t/ha in 2018.

The no-till technology has contributed to increasing the erosion resistance of the soil on the 3 – 5° slopes with northern exposure, especially in combination with organic fertilizers. As a result, the excellent structure (62 – 65 %) and good water stability (58 %) of the soil have formed. Organic fertilizers have also helped reduce moisture losses in the case of using the no-till technology by 19 – 26 mm; compost has helped reduce the compacting action of the no-till technology to the optimal value of 1.15 g/cm^3.

On the plain it is more beneficial to introduce compost before ploughing, while on the slopes, it is more beneficial to use the no-till technology with green manure; with that, a slight decrease in the yield is compensated for by a high income of 26.0 – 26.4 thousand rub/ha with the profitability level of 87 – 88 %. The potential for expanding the sunflower crops through the use of northern slopes with the steepness of 3 – 5° in the Belgorod region is about 20 thousand ha per year. The research results necessitated further study of the most important aspects, including the agrochemical and biological properties of soils, the cultivation of sunflower on the slopes of 3-5° with northern exposure, as well as other cultivated highly profitable crops for the more efficient use of sloping lands in landscape farming systems.

Conflict of Interest. There are no conflicts of interest to declare.

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