The Influence of Landscape Farming Systems on the Fertility of Eroded Residual Carbonate Chernozem

E. Kotlyarova[1], *O.* Kuzmina[1], *N.* Goncharova[1], *A.* Melentiev[1,*], and *E.* Nartova[2]

[1]Belgorod State Agrarian University, 1, Vavilova st., Maysky village, Belgorod district, Belgorod region, Russia
[2]Voronezh state agrarian University, Emperor Peter, Voronezh, Russia

Abstract. The purpose of the work is to study the influence of adaptive landscape farming systems on the fertility indicators of eroded residual carbonate chernozem. The study of carbonate soils is of particular scientific and practical interest, since they are susceptible to easy destruction, accelerated degradation and increased difficulty in restoring fertility; they suffer more from water erosion and deflation. With the integrated use of all elements of adaptive landscape farming systems, primarily including anti-erosion organization of the territory that forms the soil-protective configuration of fields, a system of protective forest plantings, adaptive placement of agricultural crops, a fertilizer system aimed at a deficit-free balance of humus and nutrients, even in extremely difficult soil conditions. -relief conditions of the Krasnogvardeisky test site managed to stop soil erosion losses, which contributed to an increase in their fertility.

1 Introduction

As a result of numerous and long-term studies, not only were qualitative and quantitative parameters established that characterize the intensity of erosion in various natural and climatic conditions, which are extremely diverse in our country, but also methodological approaches and soil protection techniques were developed that help reduce the rate of development, but even prevent soil erosion . However, at the present time this problem remains relevant, and the rate of erosion destruction not only does not decrease, but is increasing. For example, according to expert estimates, in the middle of the last century, the annual loss of arable land in the world amounted to 6-7 million hectares, at the end of the century - 9.3 million hectares, at the beginning of the 21st century, losses of arable land increased to 12 million hectares. This, in turn, leads to irreversible loss of soil in the amount of 75 billion tons, and the total damage from erosion for humanity is estimated at 400 billion dollars per year [2,3,9].

[*] Corresponding author: melentev_07@mail.ru

The study of carbonate soils is of particular scientific and practical interest, since they are susceptible to easy destruction, accelerated degradation and increased difficulty in restoring fertility [7]. Carbonate soils, including typical carbonate, ordinary and residual carbonate chernozems, suffer more from water erosion and deflation. In the world, carbonate soils with different CaCO3 contents are distributed mainly in arid regions, occupying more than 30% of the earth's surface [1,4]. Their area is also significant in the Central Black Earth Region; in the Belgorod region, their share in the structure of arable land reaches 20% [8].

2 Research methodology

In 2004, monitoring studies on the impact of adaptive landscape farming systems on soil fertility were expanded to include the Krasnogvardeysky Test Site model site, located in extremely difficult soil and relief conditions. The territory of the object covers a watershed, slopes of southern and northern exposures, the steepness of which ranges from 1 to 8° or more (in some areas up to 15°), the elevation of the relief reaches 50 m. The soil cover is represented by residual carbonate chernozem of varying degrees of erosion, up to heavily washed away (Fig. 1). In the process of work, research was carried out to study the main indicators of soil fertility (humus content, pH, N, P, K, Ca2+ and Mg2+) in a monitoring system of 42 reference points: 3 in each forest belt (on the edges and in the center) and in each interband space. Humus content is determined according to GOST 26213-91, mobile forms of phosphorus and potassium in neutral and slightly acidic soils according to the Chirikov method modified by TsINAO (GOST 26204-84); mobile forms of phosphorus and potassium in carbonate soils using the Machigin method; easily hydrolyzed nitrogen - according to Kornfield; pH of salt extract using the TsINAO method according to GOST 26483-85; the sum of absorbed bases - according to the Kappen method (GOST 27821-88).

The geographic position of the reference points is recorded by a GPS navigator. Soil samples were taken from different relief elements, including the watershed, upper, middle and lower parts of the slope. To study fertility indicators, soil samples were selected from the arable (0-20 cm) and subarable (20-40 cm) layers. The studies were repeated in 2009, 2014 and 2023. A comparative analysis of fertility indicators was carried out against the data of a large-scale survey of soils in this territory in 1985.

a


b


Fig. 1. Model object “Krasnogvardeisky test site”: a) satellite image of the object, b) soil cover - residual carbonate chernozem of varying degrees of erosion

3 Research results

Unwashed residual carbonate chernozems are characterized by a humus content in the upper layer of 6.3%, slightly washed away - 5.8, moderately washed away - 2.4 and strongly washed away - 2.2% [8]. This is consistent with our data from a study of soil samples taken on a watershed in a forest belt planted in 1947 and on a pasture on the northern slope, which contain 5.7 and 5.4% humus, respectively. Taking this into account, it is possible to estimate the level of organic matter loss in the soils of the southern and northern slopes of the "Krasnogvardeisky test site", the soils of which, according to the materials of the 1985 agrochemical survey, contained 2.38 and 3.70% humus, respectively (Table 1). Thus, the soils of the polar slopes lost 34-57% or more before the development of adaptive landscape farming systems began. Indeed, due to the extreme hydrothermal regime, the southern slopes are more susceptible to erosion processes, which is confirmed by a significantly lower content of organic matter (1.5 times) and is consistent with the results of similar studies [5,10].

Table 1. Dynamics of humus content (%) in the arable soil layer

relief element	Field	Years				
		1985	2004	2009	2014	2023
Southern slope HCP = 0,34	1	2,30	3,85	3,97	3,53	3,57
	2	2,30	3,13	3,64	3,23	3,17
	3	2,40	2,77	3,19	3,35	2,96
	4	2,50	2,95	2,87	3,56	3,28
	X*	2,38	3,18	3,42	3,42	3,25
	V, %	-	14,9	14,2	4,7	7,7
Northern slope HCP = 0,29	5	3,70	3,54	3,13	3,89	3,48
	6	3,70	3,52	3,44	3,53	3,53
	X	3,70	3,53	3,29	3,71	3,51
	V, %	-	0,4	6,7	6,7	0,9
water carrier HCP = 0,32	X	2,73	3,29	3,37	3,52	3,37
	V, %	-	12,4	11,7	6,3	7,2

*- X - arithmetical mean, V, % - the coefficient of variation

In subsequent periods of monitoring, the differences in the dynamics of humus content in the soils of the polar slopes change noticeably. On the southern slope there is an accumulation of organic matter, the content of which increased by an average of 0.8% (abs.) by 2004, and by an additional 0.24% (abs.) by 2009. Moreover, the increase in humus already in the first period was statistically significant (NSR05 = 0.34). The next 20 years are characterized by stabilization of the humus status of soils. Obviously, the decisive role in this was played by the anti-erosion organization of the territory, secured by a system of water-regulating forest strips, and the introduction of soil-protective crop rotation, which is most suitable on slopes steeper than 5°.

The soils of the northern slope continued to lose organic matter, despite the initially more favorable soil and relief conditions. By 2009, losses reached significant values - -0.41% (absolute), apparently due to the fact that grain-fallow crop rotation was used in this territory, and this was with a slope steepness of more than 3°. Subsequently, with the introduction of grain crop rotation (soybeans - winter wheat), which corresponded to the landscape conditions of the northern slope, it was possible to break the negative trend. Research in 2014 established an increase in humus and its stabilization to date.

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The unidirectional nature of the processes occurring in the soil is evidenced by a gradual decrease in the coefficients of variation both on the southern and northern slopes, and throughout the catchment area as a whole. The values of the coefficients of variation currently do not exceed 10%, which indicates the evenness of the indicator and emphasizes the positive vector of its change.

The fact that in the soils of the Krasnogvardeisky test site the processes of humus accumulation and its stabilization are not accidental, but natural, is evidenced by the positive dynamics of humus content in the subsoil layer. In contrast to the noted features of changes in the indicator in the arable layer of the polar slopes, in the subarable soil layer of both southern and northern exposures during the entire period of monitoring studies (20 years), a steady increase in organic matter was noted, which in 2014 was conclusively confirmed by mathematical processing (Fig. 2). Multidirectional changes in the indicator in the arable (-) and subarable (+) layers in 2023 rather indicate differences between them in seasonal fluctuations, which are more dynamic in the arable layer due to the high intensity of the impact of natural and anthropogenic factors on it. The greater stability of the subsoil layer against the background of the processes occurring in it confirms the importance of landscape farming systems in preserving and increasing soil fertility.

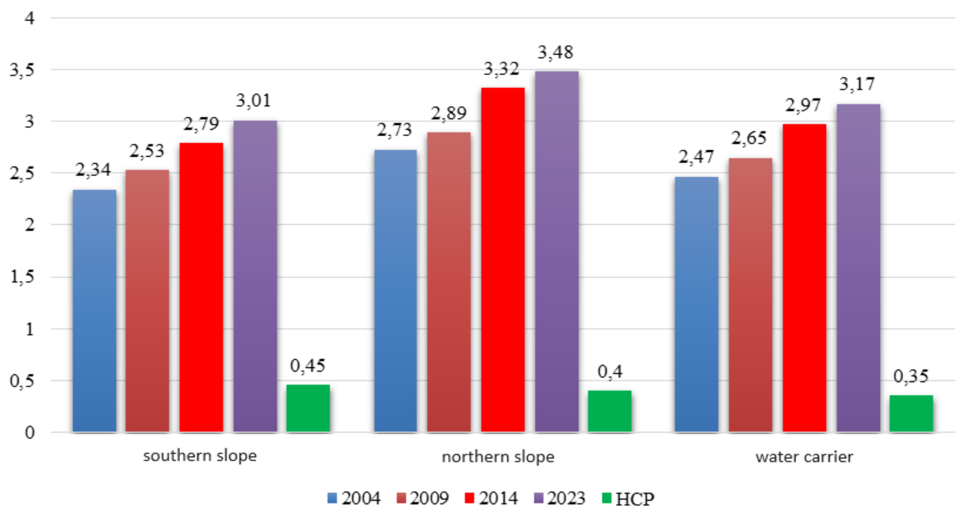

Fig. 2. Dynamics of humus content in the subsoil layer, %

Analysis of soil fertility indicators under forest belts in the agricultural landscape is important from the point of view of comparing the rate of their change in comparison with the space between the belts, since soil formation factors change their nature, at least this concerns vegetation and anthropogenic factors. In contrast to the inter-strip space (crop rotation fields) with predominantly annual agricultural crops growing, part of the phytomass of which is alienated annually, with the accompanying weed components of the agrocenosis and periodic tillage of the soil under forest belts, there is no mechanical impact on the soil covered with perennial woody and herbaceous vegetation. Obviously, this is what is responsible for the significant differences in the humus content already in 2004. If on average in the interstrip space of the Krasnogvardeisky test site the value of the indicator was 3.29%, then in the soils under forest belts it was 4.10%. In subsequent years, the indicator stabilizes at the achieved level.

As noted earlier [6], due to an increase in humus reserves in soils and, in general, their cultivation at the “Turnip Log” model object, there was a shift in the reaction of the soil solution towards neutral values, the most favorable for the growth and development of most agricultural crops. Despite the fact that the humus content in the soils of the Krasnogvardeisky test site is much lower compared to the soils of the Turnip Log site, nevertheless, in this case, the accumulation of humus in the soil had a positive effect on the reaction of its environment. Residual carbonate chernozems are characterized by an "alkaline reaction from the surface" (Krupennikov, 1979). Indeed, according to the 1985 agrochemical survey, the soils of the southern and northern slopes had a pronounced alkaline pH_{sol} reaction. = 7.55-7.68. Subsequently, a shift in pH_{sol} values occurred. towards neutral and close to them values. 20 years after the start of the development of landscape farming systems, a statistically significant decrease in pH_{sol} was noted. by 1.12 units in the arable layer and by 0.57 in the subarable layer (Fig. 3).

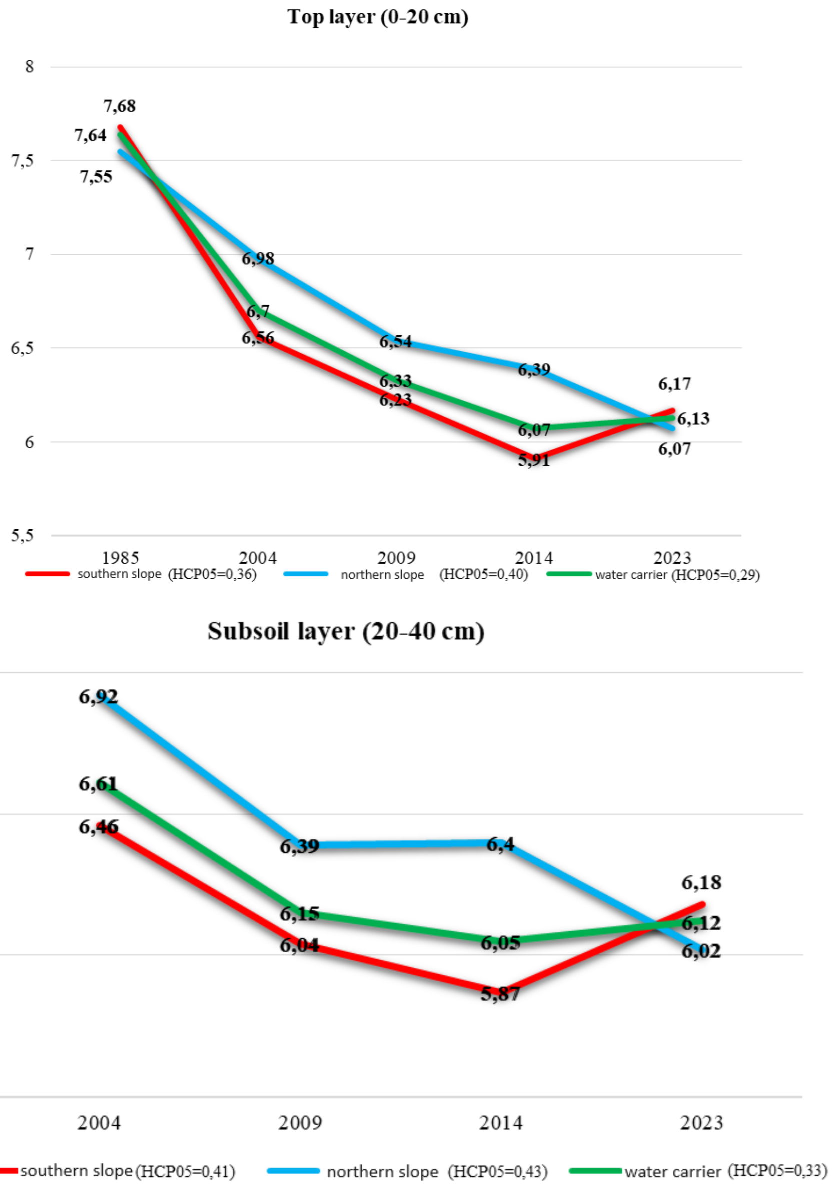

Fig. 3. Change in $pH_{sol.}$ according to soil survey rounds at the Krasnogvardeisky test site

The rates of change in the environmental reaction in the soils of the polar slopes were different (they were higher on the southern slopes), however, by now, attention has been drawn to the leveling of the values regardless of the slope exposure, which is reflected in the behavior of their diagrams. Obviously, this is directly related to the “leveling effect” of the humus status of soils on the polar slopes. If in 1985 the differences between the slopes in the humus content in the topsoil were 55%, then in 2023 it was only 8%. Similar changes in direction and rate are observed in the subsurface soil layer.

Based on this V.D. Solovichenko (2005) described residual carbonate chernozem, widespread in the Belgorod region, the amount of Ca2+ and Mg2+ contained in the soils of the “Krasnogvardeisky test site” indicates that the soil cover of the object has lost about 50 cm of the upper most fertile layer. The variability of agronomically valuable calcium and magnesium cations is statistically significant between survey rounds and in the arable layer has the character of a pulsating redistribution between Ca2+ and Mg2+ on the southern slope (Table 2). We can assume that such dynamics are caused by the cyclicity of soil processes. On the northern slope, over the past 14 years, there has been a significant decrease in the content of calcium cation and the total amount of agronomically valuable cations, while an insignificant increase in magnesium content has been noted. Calcium loss is often associated with leaching [10]. Obviously, this could have happened due to better moistening of the northern slopes and redirection of surface runoff into intrasoil flow in the system of forest water-regulating strips. On the other hand, an increase in humus status and, in general, soil fertility will contribute to an increase in the productivity of agricultural crops and, ultimately, to the biological consolidation of agronomically valuable cations in the upper layers of the soil.

Table 2. Content of exchangeable bases in the soils of the Krasnogvardeisky test site, mmol/100 g

relief element	Field no.	Top layer						Subsurface layer					
		Ca^{2+}			Mg^{2+}			Ca^{2+}			Mg^{2+}		
		2009	2014	2023	2009	2014	2023	2009	2014	2023	2009	2014	2023
Southern slope	1	22,4	16,8	21,4	2,8	4,0	1,9	23,0	19,2	22,5	2,3	4,8	1,9
	2	23,6	17,5	25,7	2,5	3,3	1,8	24,4	18,4	26,7	2,4	4,5	1,6
	3	24,9	22,3	21,2	2,3	2,5	2,4	27,1	22,5	21,9	2,7	3,3	2,1
	4	23,8	22,3	22,0	2,2	2,8	2,3	24,6	22,7	22,3	2,7	2,3	2,3
	X	23,7	19,7	22,6	2,5	3,2	2,1	24,8	20,7	23,4	2,5	3,7	2,0
	HCP_{05}	1,9			0,6			2,1			0,6		
Northern slope	5	24,7	22,5	21,2	1,8	1,1	2,3	25,4	22,6	22,8	2,1	1,0	2,3
	6	23,6	22,7	21,5	2,1	3,7	2,6	26,2	24,2	20,5	2,5	3,6	2,7
	X	24,2	22,6	21,3	1,9	2,4	2,4	25,8	23,4	21,7	2,3	2,3	2,5
	HCP_{05}	2,2			$F_{fact} < F_{theory}$			2,4			$F_{fact} < F_{theory}$		
object	X	23,8	20,7	22,2	2,3	2,9	2,2	25,1	21,6	22,8	2,5	3,3	2,1
	HCP_{05}	1,5			0,6			1,6			0,7		

The arable soil layer of the Krasnogvardeisky landfill is characterized by a low content of easily hydrolyzed nitrogen, due to the high degree of soil erosion of the site. The change in its content over the past 20 years occurs within this security class (Table 3). A positive fact is the transition in the content of easily hydrolyzed nitrogen in the soil to a higher supply class, starting in 2009.

Table 3. Changes in the content of easily hydrolyzed soil nitrogen depending on position in relief, mg/kg

relief element	Field no.	Top layer				Subsurface layer			
		2004	2009	2014	2023	2004	2009	2014	2023
Southern slope	1	138,7	146,4	126,9	130,7	110,1	112,9	107,3	126,0
	2	123,1	133,9	115,7	116,7	75,6	120,4	98,9	109,7
	3	112,8	124,1	108,3	109,7	83,1	98,0	104,5	112,0
	4	119,6	130,2	114,8	128,3	93,3	118,1	96,1	109,7
	average	123,5	133,7	116,4	121,3	90,5	112,4	101,7	114,3
	HCP_{05}	8,9				10,3			
Northern slope	5	132,8	142,3	114,3	128,3	90,3	123,2	103,6	121,3
	6	127,2	137,7	114,8	130,7	96,6	121,3	98,9	133,0
	average	130,0	140,0	114,6	129,5	93,5	122,3	101,3	127,2
	HCP_{05}	5,0				6,3			
water carrier	average	125,7	135,8	115,8	124,1	91,5	115,7	101,6	118,6
	HCP_{05}	8,0				9,4			

Initially (1985), the soils of the Krasnogvardeysky test site were provided with an average level of content of mobile forms of phosphorus (Table 4), since it is known that “on washed away soils, as a result of erosion and plowing of lower horizons with a lower content of total phosphorus, there is a decrease in mobile phosphates" [5].

Already the first rounds of the monitoring survey showed a significant increase in the content of the element in the arable and, apparently, in the subarable layers of both the southern slope by 87.8 and the northern - by 88.6 mg/kg. This contributed to the transition of the soil of the site to two classes higher, which corresponds to a high content of available phosphorus. By 2023, there is a significant decrease in P2O5 in the arable layer, accompanied by a transition to the class of increased soil availability. In the subsoil layer, the decrease is statistically insignificant, although on the southern slope the supply of the element has become average.

Table 4. Dynamics of the content of mobile phosphorus in the soil in the relief conditions of the Krasnogvardeysky test site, mg/kg

relief element	Field no.	Top layer					Subsurface layer			
		1985	2004	2009	2014	2023	2004	2009	2014	2023
Southern slope	1	46,9	121,8	121,3	90,3	84,0	68,2	95,0	81,3	65,7
	2	47,1	102,1	154,0	83,7	112,7	60,0	128,3	71,7	72,3
	3	33,0	126,2	127,3	108,0	52,0	99,0	95,3	98,0	44,7
	4	125,0	176,7	200,7	224,3	168,0	147,7	181,3	159,0	133,3
	average	63,0	131,7	150,8	126,6	104,2	93,7	125,0	102,5	79,0
	HCP_{05}	38,2					$F_{fact.} < F_{theory.}$			
Northern slope	5	97,2	195,5	209,1	180,0	150,0	150,7	161,1	162,3	126,0
	6	96,8	175,3	159,3	126,0	118,7	142,3	120,3	107,5	110,3
	average	97,0	185,4	184,2	153,0	134,3	146,5	140,7	134,9	118,2
	HCP_{05}	48,3					$F_{fact.} < F_{theory.}$			
water carrier	average	74,3	149,6	162,0	135,4	114,2	111,3	130,2	113,3	92,1
	HCP_{05}	31,5					$F_{fact.} < F_{theory.}$			

Recently, there has been a tendency to reduce the content of mobile forms of phosphorus and potassium in the soil. This may be a consequence of the fact that in production, high productivity of agricultural crops is achieved due to an increase in the amount of applied mineral nitrogen, while the consumption of phosphorus and potassium occurs due to soil reserves. Obviously, this is associated with increased mineralization of soil organic matter.

It should be noted that the content of available potassium in the soils of the Krasnogvardeysky test site is at a high and very high level, which has been characteristic of the soils since 1985. It can be assumed that such a high level of supply of the element is a consequence of the chemical composition of the parent rock (Table 5).

Table 5. Changes in the content of mobile exchangeable potassium in the soil in the relief conditions of the Krasnogvardeisky test site, mg/kg

relief element	Field no.	Top layer					Subsurface layer			
		1985	2004	2009	2014	2023	2004	2009	2014	2023
Southern slope	1	140,8	65,2	126,3	83,7	125,1	44,0	105,0	70,7	95,0
	2	141,2	61,3	151,7	81,7	133,7	55,1	112,3	68,7	95,7
	3	145,0	150,3	247,7	170,0	157,0	110,3	171,7	160,7	124,0
	4	210,0	205,3	260,7	235,0	235,7	143,7	205,0	163,3	201,3
	average	159,3	120,6	196,6	142,6	162,9	88,3	148,5	115,8	129,1
	HCP_{05}	$F_{fact.} < F_{theory.}$					$F_{fact.} < F_{theory.}$			
Northern slope	5	207,1	241,8	258,3	230,3	262,3	145,3	154,4	201,7	194,3
	6	206,9	136,2	205,3	94,0	131,3	100,3	160,7	88,0	116,0
	average	207,0	189,0	231,8	162,2	196,8	122,8	157,5	144,8	155,2
	HCP_{05}	$F_{fact.} < F_{theory.}$					$F_{fact.} < F_{theory.}$			
water carrier	average	175,2	143,4	208,3	149,1	174,2	99,8	151,5	125,5	137,8
	HCP_{05}	$F_{fact.} < F_{theory.}$					$F_{fact.} < F_{theory.}$			

4 Conclusion

With the integrated use of all elements of adaptive landscape farming systems, primarily including anti-erosion organization of the territory that forms the soil-protective configuration of fields, a system of protective forest plantings, adaptive placement of agricultural crops, a fertilizer system aimed at a deficit-free balance of humus and nutrients, even in extremely difficult soil conditions. -relief conditions of the Krasnogvardeisky test site managed to stop soil erosion losses, which contributed to an increase in their fertility. Despite the short period in terms of the natural rates of the soil-forming process, a statistically significant increase in the humus status of soils was established. The content of organic matter in the arable layer increased by 0.64% (abs.) on average for the site, by 0.87% (abs.) in the soils of the southern slope. In the subsoil layer, the increase ranged from 0.67 to 0.75% (absolute) depending on the relief element. The humus content in the soils of forest belts is on average slightly higher than in the space between the belts. This is caused by higher (2.5 times) rates of humus accumulation in them in the first period after the development of landscape farming systems. The accumulation of humus contributed to optimizing the reaction of the soil environment. Shift of pH_{sol} values. from the area of alkaline reaction, characteristic of washed away carbonate soils, to the area of neutral and close to neutral values, significantly at the 5% significance level. The transition to a higher level of provision with mobile forms of nitrogen, phosphorus and potassium testifies to the increase in the general cultivation of soils at the Krasnogvardeisky test site.

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