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# Intensity and Direction of Dynamics of Soil Fertility Indicators in Landscape Farming

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**Abstract**. The purpose of the work is to study the dynamics of soil fertility indicators after the development of adaptive landscape farming systems in the most eroded region of the Belgorod region since 1981. Based on 40 years of research at the model object "Turnip Log", it is shown that the direction and intensity of the soil-forming process is changing. Four stages are distinguished: at the first - until 1993 - the decrease in humus content and alkalization of the soil environment, characteristic of washed away carbonate soils, continues; at the second stage, the rate of humus loss drops 10 times; the third ten-year period is characterized by a significant increase in organic matter and its stabilization subsequently, which accompanied by a transition in $pH_{sol.}$ to the area of neutral values. The dynamics of mobile forms of macroelements and agronomically valuable cations Ca2+ and Mg2+ indicate the cultivation of soils in general. At the same time, it is emphasized that there are no universal elements in the agricultural system; Along with the creation of an ecological framework of protective plantings, it is necessary to comply with the principles of adaptive placement of agricultural crops and a deficit-free balance of humus and nutrients in crop rotations.

## 1 Introduction

The impressive achievements of our country in the production of agricultural products in recent years, the growth of export potential and the increase in its significance on the world stage are accompanied by ongoing processes of soil degradation [3,4,8], which indicates a high price for success and lays a mine under the well-being of future generations. The approved Strategy for the Development of the Agro-Industrial and Fishery Complexes of the Russian Federation for the period until 2030 [7] indicates as risks and, therefore, priority areas "Restoring and increasing the fertility of agricultural lands, ... protecting and preserving agricultural lands from water and wind erosion and desertification "

All these tasks and targets can be achieved through the full-scale development of adaptive landscape farming systems (ALS). This is evidenced by the experience of the Belgorod region [6]. The impetus for large-scale work throughout the region was the

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effectiveness of landscape farming systems in the Krasnogvardeisky district, the development of which took place under the leadership of Academician of the Russian Academy of Agricultural Sciences O. G. Kotlyarova, starting in 1981 [2].

The active development of adaptive landscape farming systems in the Krasnogvardeysky district was not accidental, since this area was once the most eroded in the Belgord region: 73% of eroded lands. The rate of erosion was classified as catastrophic with a loss of 1 cm of fertile soil per year, and very often there was a complete loss of soil cover and the emergence of chalky underlying rocks. Without preventing erosion processes, all resources aimed at increasing soil fertility did not achieve the goal, did not work to increase the efficiency of crop production, moreover, their washout led to environmental pollution, primarily water sources, their shallowing and eutrophication, which worsened the water balance territories and moisture supply of agrocenoses ultimately. Was it possible to achieve the goal of soil conservation - the main irreplaceable means of agricultural production and the basis of the country's food security - in the harsh conditions of the most eroded region of the most eroded region of the Central Black Earth Region? Of course, assessing the comparative effectiveness of the effects of erosion (loss of 1 cm/year) and soil formation (gain of 1 cm/300-1000 years) calls into question optimistic expectations, however, a relatively long period of observation makes not only a unique and significant scientific contribution, but also confirmation of the prevention of erosion losses is the evidence base for the need for large-scale development of adaptive landscape farming systems and an incentive for decision-making at the state level.

The purpose of the study is to evaluate the results of five rounds of soil monitoring survey of the model object “Turnip Log” in an area with a fully developed adaptive landscape farming system.

## 2 Research methodology

The research was carried out at the “Repny Log” model object, where 11 reference points were established in 1993 (Fig. 1). Soil correction and description of the morphological features of full-profile sections indicate the distribution of typical carbonate chernozems and typical chernozems of varying degrees of erosion on the site. The territory of the object covers a slope of southern exposure with a steepness of 1 to 4 degrees. Soil samples were examined for the content of humus, mobile forms of nitrogen, phosphorus and potassium, agronomically valuable bases (calcium and magnesium) and pHsol. The dynamics of fertility indicators were assessed in the arable (0-20 cm) and subarable (20-40 cm) soil layers, where major changes occur.

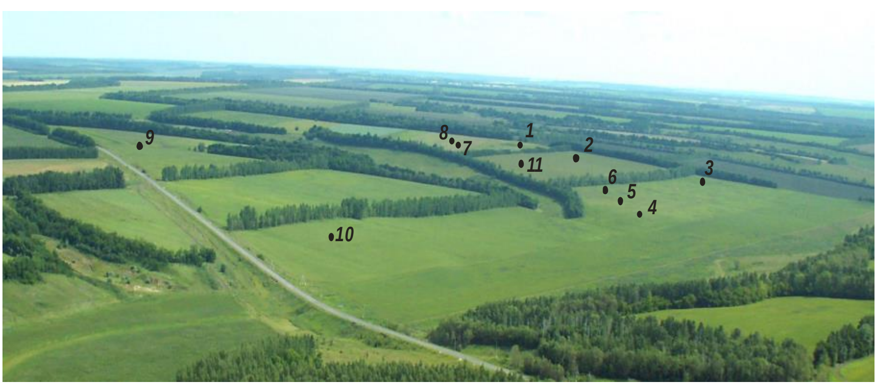


**Fig. 1.** Scheme of placement of reference points along the research route of the model object “Turnip Log”. 1-11 – reference points

Subsequently, similar studies were conducted in 2004, 2009, 2013. and 2023. Thus, studies of the soils of this object cover a thirty-year period, which makes it possible to assess the influence of landscape farming systems on the dynamics of fertility indicators in real production conditions. Initially, this was the land use area of the Lenin collective farm, later Elite LLC, currently the lands of two farms: IP Head of Peasant Farm Demyanov V.F. and JSC AIC "Biryuchensky". It is obvious that the scale of farms leaves its mark on production efficiency. It is all the more interesting to trace the direction and intensity of soil processes regardless of technological equipment.

## 3 Research results

According to the materials of a large-scale agrochemical survey of soils in the territory of the Turnip Log site, the humus content in 1986 was 5.2%. During the first two decades, the decrease in humus content continued, but over time its rate decreased 10 times - from 0.1% (abs.)/year to 0.01% (abs.)/year (Table 1). Next decade from 2004 to 2013 characterized by an increase in the indicator by an average of 0.04% (absolute)/year. Despite the fact that statistical processing of the data did not reveal significant changes for the entire study period, nevertheless, the coefficient of variation, which decreased with each round of the survey from 13.53% in 1993 to 4.99% in 2013, indicates that that the trend towards a positive direction of the soil-forming process is not accidental. That is, the results of research on this model object indicate that already in the initial period after the development of adaptive landscape farming systems, it was possible to sharply slow down the loss of humus in the soil, and subsequently prevent it, obviously as a result of the cessation of erosion processes.

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

| | Years | | | | |
|---|---|---|---|---|---|
| Cuts | 1993 | 2004 | 2009 | 2013 | 2023 |
| 1 | 3,62 | 3,78 | 4,73 | 4,33 | 4,37 |
| 2 | 3,75 | 3,81 | 4,95 | 5 | 5,41 |
| 3 | 4,39 | 4,45 | 3,93 | 4,75 | 5,15 |
| 4 | 4,4 | 4,49 | 4,35 | 4,45 | 3,38 |
| 5 | 3,79 | 4,5 | 4,53 | 4,66 | 5,3 |
| 6 | 4,32 | 4,35 | 4,38 | 4,85 | 5,04 |
| 7 | 4,97 | 4,67 | 4,45 | 4,89 | 5,15 |
| 8 | 4,77 | 4,85 | 5,56 | 4,88 | 3,95 |
| 9 | 5,39 | 5,1 | 4,73 | 5,02 | 4,31 |
| 10 | 5,16 | 4,86 | 5,03 | 5,05 | 3,9 |
| 11 | 5,06 | 3,74 | 4,93 | 5,06 | 5,2 |
| X* | 4,51 | 4,42 | 4,69 | 4,81 | 4,65 |
| V, % | 13,53 | 10,53 | 9,23 | 4,99 | 10,32 |
| $HCP_{05}$ | $F_{f.}<F_{t.}$ | | | | |

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

In the subsoil layer, an increase in the humus content was noted already in the first studied period from 1993 to 2004. (Table 2). By 2009, the increase in organic matter content to 4.33% is significant at the 5% significance level, which confirms the non-randomness of the noted positive trend in the change in the indicator in the arable layer. The increase in humus content continued until 2013 (4.47%).

Over the last decade, the humus content in the arable soil layer decreased by 0.16% (abs.), in the subarable layer - by 0.23% (abs.). Despite the fact that this decrease is statistically unreliable, it is nevertheless necessary to establish the reason for its exclusion in the future.

First of all, it was noticed that soil-protective crop rotations with perennial grasses, which were previously introduced on the surveyed fields, were replaced by grain-row crop rotations, and despite the inadmissibility of cultivating row crops on slopes with a steepness of more than 3°, corn and sunflower crops predominated in the year of soil sampling. Obviously, the decrease in humus in soils could be caused, among other things, by high mineralization characteristic of row crops.

**Table 2**. Dynamics of humus content (%) in the subsoil layer

| | Years | | | | |
|---|---|---|---|---|---|
| Cuts | 1993 | 2004 | 2009 | 2013 | 2023 |
| 1 | 3,04 | 3,4 | 3,77 | 4,23 | 3,95 |
| 2 | 2,31 | 3,21 | 4,38 | 4,84 | 5,09 |
| 3 | 3,33 | 4,01 | 3,86 | 4,24 | 3,33 |
| 4 | 3,69 | 3,88 | 4,86 | 4,31 | 4,11 |
| 5 | 3,74 | 4,01 | 4,18 | 4,46 | 3,69 |
| 6 | 3,93 | 3,62 | 4,15 | 4,64 | 4,32 |
| 7 | 3,89 | 4,26 | 4,12 | 4,55 | 4,84 |
| 8 | 3,25 | 4,41 | 5,08 | 4,6 | 3,85 |
| 9 | 5,25 | 4,81 | 3,68 | 4,29 | 3,8 |
| 10 | 4,57 | 4,58 | 4,92 | 4,22 | 4,11 |
| 11 | 3,88 | 2,74 | 4,71 | 4,77 | 5,51 |
| X | 3,72 | 3,90 | 4,33 | 4,47 | 4,24 |
| V, % | 20,82 | 15,91 | 11,28 | 5,15 | 10,14 |
| $HCP_{05}$ | 0,50 | | | | |

Analysis of the dynamics of humus content at individual reference points revealed differences in the direction of soil processes depending on their location along relief elements. Noteworthy is the pronounced differentiation into two groups in the last round of the survey. The group with an increase in humus in the soil includes samples taken from points characterized by a close location to forest belts - 2, 3, 5, 6, 7 and 11. On the contrary, when moving away from forest belts, regardless of whether the soil was selected on the flat or slope part samples there was a decrease in the indicator (4, 8, 9, 10). Time will tell whether this is a stable trend or a seasonal fluctuation. In any case, this once again emphasizes that there are no universal elements in the agricultural system; Along with the creation of an ecological framework of protective plantings, it is necessary to observe the principles of adaptive placement of agricultural crops and a deficit-free humus balance in crop rotations.

The most favorable reaction for the growth and development of most agricultural crops is a neutral or slightly acidic reaction of the soil solution. The research area, as well as the southeastern and eastern regions of the Belgorod region in general, is characterized by increased alkalinity of the environment due to Cretaceous soil-forming rocks, the spread of ordinary and carbonate chernozems and a significant degree of soil erosion.

Our previous studies showed that improving the humus status of soils helps optimize the reaction of its environment. Significant decrease in pHsol value. = 7.57 with a pronounced alkaline reaction in 1993 to the area of neutral values in 2004 (pHsol. = 6.82) (NSR05 = 0.41) and also significant stabilization in the subsequent period from 2009 to 2023. – pHsol. = 6.31-6.39 (similar changes are observed in the subarable layer with slightly higher pHsol values at HCP05 = 0.46) emphasizes the positive direction of the processes occurring in the arable and subarable soil layers (Fig. 2). This is confirmed by a strong negative relationship between these indicators (r = -0.73) in the arable layer and a close (-0.94*) statistically significant relationship in the subarable layer, which is reflected in the mirror behavior of the diagrams of the dynamics of the reaction of the environment and the humus content of the model soils object "Repny Log".

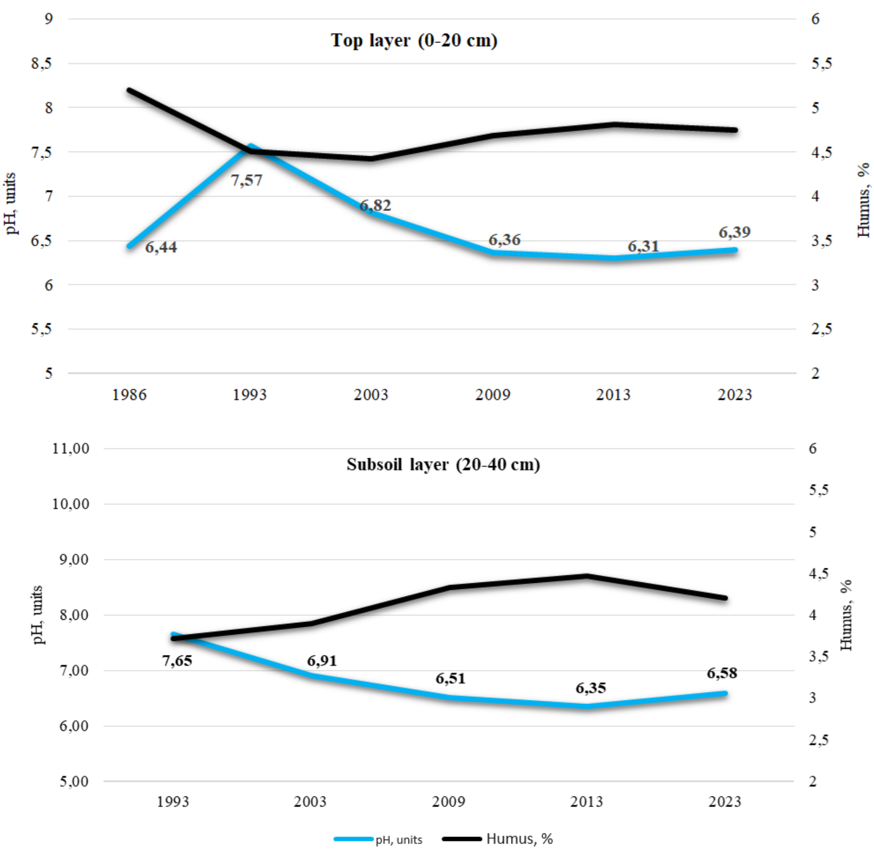


**Fig. 2.** Dynamics of humus and $pH_{sol}$ content. arable and subarable soil layers of the model object "Turnip Log"

When studying the agronomically valuable bases Ca2+ and Mg2+, which contribute to humus accumulation and the formation of a water-resistant soil structure, it is necessary to keep in mind a number of provisions established by scientists in similar studies. First of all, it is believed that the most favorable ratio between Ca2+ and Mg2+ should be at least 5, otherwise, with an increase in the proportion of magnesium at the expense of calcium in the PPC, an increase in alkalinity and salinity of soils is observed [1]. At the same time, a decrease in the content of calcium cations and an increase in magnesium cations is observed with humidization of the water regime [9]. It has also been established that in arable chernozems, compared to virgin soils, the ratio of calcium to magnesium increases from 5 to 6-7 and higher [5].

Indeed, analysis of the ratio of agronomically valuable cations indicates the highly dynamic processes occurring in the soil, including in the soil-absorbing complex. It is noteworthy that the sharp reduction in the ratio between Ca2+ and Mg2+ from 10.4 in 2003 to 5.5 in 2009 is timed to coincide with the period of maximum accumulation of humus in the soil and a decrease in $pH_{sol}$. (Table 3). This, in turn, may indicate the positive impact of the system of forest strips in regulating the water regime, primarily reducing runoff (and soil loss) and moisture losses. Moreover, the observed decrease in calcium (from 27 in 2003 to 23.7 mEq/100 g of soil in 2009) may be a consequence of its removal from the harvest of perennial leguminous grasses, which are known to be calcium-loving crops. A harvest was formed, a significant part of which was used to replenish the soil with organic matter.

**Table 3**. Change in the content of exchangeable cations, mEq/100 g of soil

| Section no. | 2003 | | 2009 | | 2013 | | 2023 | |
|---|---|---|---|---|---|---|---|---|
| | $Ca^{2+}$ | $Mg^{2+}$ | $Ca^{2+}$ | $Mg^{2+}$ | $Ca^{2+}$ | $Mg^{2+}$ | $Ca^{2+}$ | $Mg^{2+}$ |
| Top layer (0-20 cm) | | | | | | | | |
| 1 | 22,3 | 2,3 | 17,5 | 5 | 25,8 | 2,3 | 27,5 | 3,47 |
| 2 | 29,3 | 4 | 22,5 | 4,5 | 22,8 | 3 | 25 | 3,41 |
| 3 | 29 | 2,6 | 25,5 | 3,3 | 29,3 | 2,5 | 25,5 | 3,55 |
| 4 | 21,8 | 2,5 | 23,3 | 4,6 | 27 | 2,3 | 28,5 | 2,72 |
| 5 | 29,3 | 1,8 | 25,3 | 3,9 | 28 | 2,5 | 27,3 | 2,82 |
| 6 | 30,5 | 1,3 | 25,8 | 4,6 | 27,5 | 2,8 | 25,3 | 3,1 |
| 7 | 26,8 | 3,5 | 26,3 | 3,3 | 25,3 | 1,5 | 28,3 | 2,62 |
| 8 | 26,5 | 2,3 | 24,6 | 4,6 | 24,3 | 2,8 | 24 | 3,3 |
| 9 | 29,5 | 2,8 | 26 | 5,3 | 27,8 | 2,5 | 19 | 3,96 |
| 10 | 28,3 | 2,8 | 24,3 | 3,9 | 28,3 | 2,3 | 27,5 | 2,34 |
| 11 | 23,5 | 3,3 | 19 | 4,6 | 21,5 | 3,8 | 26,8 | 3,58 |
| X | 27 | 2,6 | 23,7 | 4,3 | 26,1 | 2,5 | 25,9 | 3,2 |
| V, % | 11,5 | 29,7 | 12,4 | 15 | 9,6 | 24 | 28,2 | 0,1 |
| $HCP_{05}$ | $F_{f.} < F_{t.}$ | 0,54 | | | | | | |
| Subsoil layer (20-40 cm) | | | | | | | | |
| 1 | 21,3 | 1,8 | 15,9 | 5,8 | 25,5 | 2,0 | 27,8 | 3,2 |
| 2 | 26,8 | 2,8 | 23,4 | 4,9 | 22 | 3,0 | 25 | 3,5 |
| 3 | 21,8 | 1,8 | 24,4 | 3,5 | 28,8 | 1,8 | 27,5 | 2,9 |
| 4 | 28,0 | 2,8 | 24,5 | 4,4 | 26,8 | 2,0 | 27,8 | 2,3 |
| 5 | 28,8 | 3,0 | 25 | 4,3 | 27,0 | 2,3 | 27,5 | 3,0 |
| 6 | 29,8 | 1,0 | 27 | 4,8 | 26,8 | 1,5 | 25,3 | 2,8 |
| 7 | 24,5 | 2,8 | 26,6 | 3,6 | 24,8 | 1,0 | 28,0 | 2,8 |
| 8 | 26,8 | 2,8 | 25,3 | 4,5 | 24,0 | 1,5 | 24,9 | 2,5 |
| 9 | 29,3 | 2,6 | 24,8 | 4,0 | 26,5 | 1,8 | 18,8 | 3,9 |
| 10 | 26,5 | 2,3 | 22,8 | 3,5 | 25,5 | 1,5 | 28,3 | 2,2 |
| 11 | 23,8 | 4 | 19,9 | 5,6 | 21,0 | 3,5 | 27,8 | 3,5 |
| X | 26,1 | 2,5 | 23,6 | 4,4 | 25,3 | 2 | 26,2 | 3,0 |
| V, % | 11,2 | 31,6 | 13,5 | 17,8 | 9,1 | 35,0 | 29,4 | 0,1 |
| HCP | $F_{f.} < F_{t.}$ | 0,62 | | | | | | |

Subsequently, there was a restoration of the calcium content and, in general, the amount of Ca2+ and Mg2+ during the period of the so-called stabilization of soil fertility indicators. The ratios between agronomically valuable cations increased to 8.2-10.4 in the topsoil layer and 8.8-12.7 in the subsoil layer. It should be noted that the described dynamics of the calcium cation content is statistically insignificant for either the arable or subarable layers, while changes in the magnesium content in the PPC are statistically significant when moving to each round of the survey. Noteworthy is the difference in the variability of these indicators across reference points. During the period from 2003 to 2013. the coefficient of variation of the calcium cation was 9-13%, and Mg2+ – 15-35%. The last round of the survey (2023) is characterized by an increase in Ca2+ variability to 28-29%, while the Mg2+ content is equalized across reference points in the arable and subarable layers (V = 0.1%). It can be assumed that the data from the last round of the survey indicate a qualitative transformation of soil processes, the results of which can be observed subsequently.

Indirectly, the cultivation of the soils of the model object “Turnip Log” under the influence of adaptive landscape farming systems can be indicated by a significant increase in the content of easily hydrolyzed nitrogen in the soil over the entire thirty-year observation period by 32% in the 0-20 cm layer and by 60% in the 20-40 cm layer (Fig. 3). In the topsoil layer, all changes in the element occurred within the limits of its low availability in the soil, while in the subsurface layer the availability class moved from very low to low.

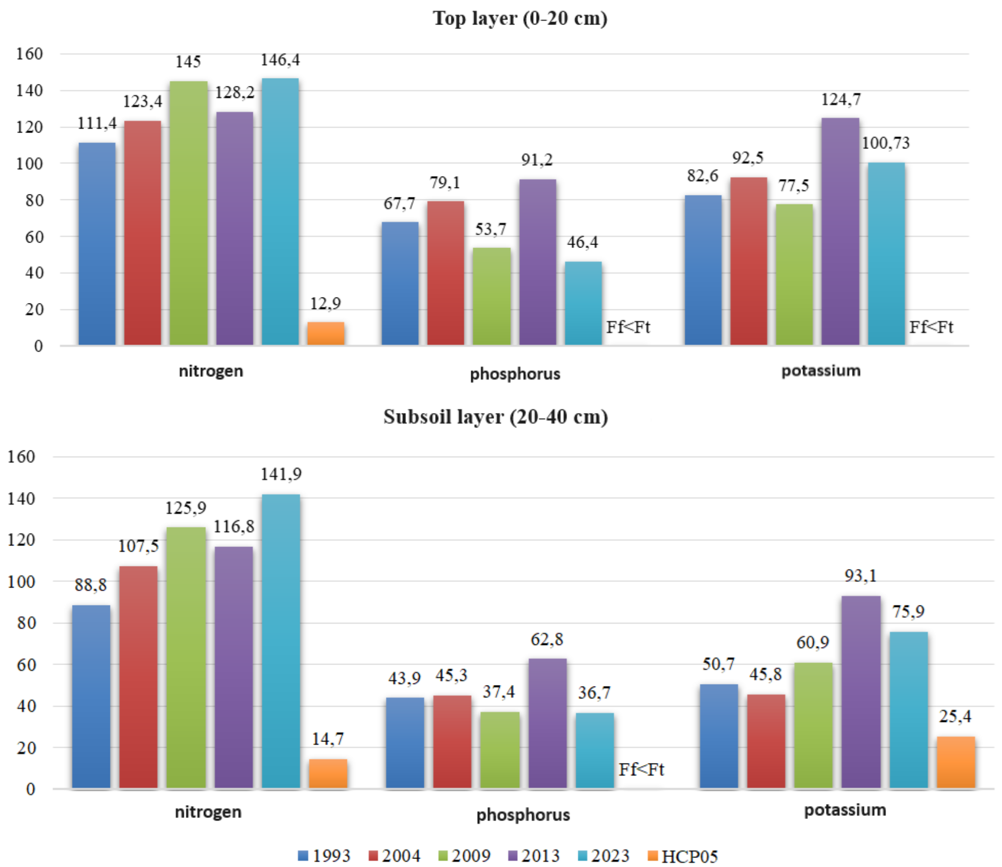


**Fig. 3.** Dynamics of the content of mobile forms of macroelements in soils, mg/kg

Despite the fact that all changes in the content of available phosphorus are not significant at the 5% significance level, nevertheless, the data obtained indicate that in the previous rounds from 1993 to 2013. the soils of the object in the 0-20 cm layer were provided with the element to an average degree, while at present the class of their provision has decreased by gradation. The subsoil layer, compared to the arable layer, was characterized by a predominantly low content of available phosphorus, which reached an average level by 2013. However, to date there has been a rather sharp decrease in its content. A similar trend is observed for mobile potassium. The change in its content in the soil by 2013 was characterized by a transition to a higher supply class: in the arable layer - to “high” (125 mg/kg of soil), in the subarable layer - to “increased” (93 mg/kg of soil), and in the layer 20 -40 cm element growth was significant. In 2023, there is a decrease in its content, although not significantly, but to a lower security group.

It can be assumed that the increase in the content of mobile nitrogen in the soil against the background of a decrease in the mobile forms of phosphorus and potassium occurs as a result of the emerging imbalance between nutritional elements in currently practiced fertilizer systems, when a significant increase in crop yields is achieved by using increased doses of nitrogen fertilizers, and the removal phosphorus and potassium are compensated by potential soil fertility. Obviously, this is also associated with a slight decrease in the humus content in the last round of agrochemical examination of the soils of the model object.

## 4 Conclusion

Despite the seemingly insignificant period (30 years) in terms of the pace of the soil-forming process, studies of the influence of adaptive landscape farming systems on soil fertility at the model site “Turnip Log” in the Krasnogvardeisky district of the Belgorod region have conclusively confirmed their effectiveness. Positive changes in almost all indicators of soil fertility have been established. In the arable (0-20 cm) soil layer, a gradual reduction in the rate of humus loss was replaced by its subsequent growth and stabilization; in the subarable layer (20-40 cm), an increase in the content of organic matter in the soil by 0.52% (absolute) was statistically significant. Improving the humus status of soils contributed to optimizing the reaction of the soil solution environment. There was a significant decrease in $pH_{sol}$ value. = 7.57-7.65 with a pronounced alkaline reaction, characteristic of washed away carbonate soils, to the area of neutral values, followed by reliable stabilization (pHsol. = 6.31-6.58). The interdependence of the indicators is confirmed by a strong negative relationship (r = -0.73) in the topsoil layer and a close (-0.94*) statistically significant relationship in the subsoil layer. Despite the high variability of more dynamic indicators, including agronomically valuable cations Ca2+ and Mg2+, as well as mobile forms of nitrogen, phosphorus and potassium, they made it possible to identify some features of soil processes and the influence on them of such elements of adaptive landscape farming systems as protective systems forest belts, crop rotations, fertilizers. The positive role of protective plantings in regulating water regime, preventing runoff and soil loss, and increasing humidity has been confirmed. At the same time, it is emphasized that there are no universal elements in the agricultural system; Along with the creation of an ecological framework of protective plantings, it is necessary to comply with the principles of adaptive placement of agricultural crops and a deficit-free balance of humus and nutrients in crop rotations.

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