Effect of long-term organo-mineral fertilizer application on the fertility of eroded soils

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Abstract. The research was carried out in 1986–2019 in a multi-factor stationary experiment located in the Rostov region, Russia. The dynamics of organic matter and basic nutrients has been studied depending on the structure of crop rotation and tillage in conditions of an erosion hazard slope. The use of soil–protecting crop rotations on slope lands with 20% of perennial grasses reduced soil washout by 34.8–42.5%, runoff by 32.7–40.6%. An increase in the share of perennial grasses halved soil washout by 54.3–60.0%, runoff – 76.1–97.6%. The use of soil-protecting tillage along the contour lines and leaving stubble on the surface of the field reduces soil loss by 13.0–23.8%, runoff by 11.7–24.1%. As a result of the extensive technology of cultivation of agricultural crops, due to the removal of nutrients with the crop and erosion processes, the content of organic matter and nutrients in the soil decreases in all the studied crop rotations. Systematic application of fertilizers in high doses contributes to the expanded reproduction of soil fertility. It has been established that the nutrient regime of the soil affects the productivity of both individual crops and the entire crop rotation as a whole.

1. Introduction

The development of erosion processes on the slope affects the indicators of soil fertility. Degradation can be prevented by applying in practice adaptive-landscape farming systems. The main element of landscape agriculture remains soil-protecting crop rotation, taking into account the special role of crop rotation. Another most important element is soil conservation tillage [1]. Recently, scientists have paid much attention to soil fertility recovery and the provision of soil with organic matter. Regular organic fertilization and plant residues to transform to humus and elements of mineral nutrition of plants is one of the most important tasks of modern agriculture [2, 3].

According to the state registration data, the total area of eroded agricultural land reaches 130 million hectares, including arable land – 84.8 million hectares. In the whole country in the composition of eroded agricultural land, medium and highly eroded soils occupy 26%. The annual loss of humus on arable land is 0.62 t/ha, its content in arable soils over the past hundred years has decreased by 30–40% [4, 5]. In the South of Russia, erosion hazard slopes with a steepness of up to 3.5–4.0° occupy more than 20% of arable land. The share of eroded and deflated soils continues to grow steadily. Over the past 20 years, their growth rates have been in the range of 6–7% every 5 years. As a result of soil erosion and deflation, the shortfall on arable land reaches 36%, on forage lands – up to 47% [4, 6].
To prevent erosion processes, special soil-protecting crop rotations have been developed that can reliably protect the soil from water erosion [7, 8].

The solution to the problem is seen in imparting certain soil-protecting properties to field crop rotations, which becomes possible in landscape farming conditions with the contour-landscape organization of the territory of erosion hazard slopes. At the same time the strip close to the contours of the terrain, the placement of crop rotation crops, the horizontal direction of tillage, sowing, all types of maintenance work and other technological operations are assumed [9–11].

An important indicator of soil fertility, which determines the productivity of crops, is the humus content. The task of modern agriculture is to ecologize crop rotations, using a biological system for regulating the regime of organic matter in the soil. The scientifically grounded organization of the territory of erosion hazard slopes, using anti-erosion tillage, contributes to an increase in moisture supply and productivity of crops and crop rotations in general [12–13].

The soils of the Rostov oblast as a whole have sufficient reserves of nutrients, but they are few in a form accessible to plants. Diminishing of soil fertility occurs due to the loss of humus, the main nutrients (nitrogen, phosphorus, potassium), and essential micronutrients. In the south of the Rostov oblast, erosion processes cover 60–70% of the agricultural lands. Average annual soil losses due to the joint manifestation of water erosion and deflation are estimated at about 15 t/ha. It can be expected that the total loss of soil fertility from eroded and deflated agricultural lands will be approximately 750–800 million tons, which contain 32 million tons of humus, 4.8 million tons of gross phosphorus, 60 million tons of potassium, 8.8 million tons of total nitrogen [4].

Based on the foregoing, the aim of the research was to study the role of crop rotations located on erosion hazard slopes in regulating soil fertility and increasing crop productivity.

To achieve the set goals, the following tasks were solved:

– to assess the loss of soil fertility under the influence of erosion processes in crop rotations of various structures;
– to assess the dynamics of the content and reproduction of soil organic matter when applying different doses of fertilizers in crop rotations of various designs;
– to study the dynamics of phosphorus and potash regimes at different levels of nutrition and crop rotations of various structures located on an erosion-dangerous slope;
– to identify the effect of systematic fertilization on the productivity of crop rotations of various designs, located on an erosion hazard slope.

2. Method of research

In our research carried out in 1986–2019 in a multi-factor stationary experiment located on a slope with a steepness of up to 3.5–4° of the Bolshoi Log clough, Aksaysky district of Rostov oblast. The soil of the test plot is Haplic Calcic Chernozem (Loamic), on the slope of the southeastern exposure with a steepness of up to 3.5–4.0°, erosion processes are weak. The initial content of humus in the soil is 3.83%, total nitrogen 0.14–0.16%, labile phosphates – 15.7–18.2 mg, exchangeable potassium 282–337 mg/kg of soil.

In the test, three crop rotations were studied with a crop structure: "A" – clean fallow 20%, perennial grasses 0% (fallow, winter wheat, winter wheat, sunflower); "B" – clean fallow 0%, perennial grasses 20% (peas, winter wheat, sunflower, barley, perennial grasses); "C" – clean fallow 0%, perennial grasses 40% (corn for silage, winter wheat, barley, perennial grasses, perennial grasses). An organo–mineral fertilizer system was used: an average level of fertilizer application – 5 tons of farmyard manure (FYM) together with mineral N₄₆P₃₀K₁₀ kg a.s. and an increased level of fertilizer application – 8 tons (FYM) together with mineral fertilizers N₄₆P₃₀K₁₀ kg a.s. per 1 hectare of crop rotation area. A variant of the test with natural fertility, an extensive level of fertilization, served as a control. We have investigated two systems of chisel tillage (soil–protecting) and moldboard tillage, taken as the control option.
Phosphorus and potassium were determined by the method proposed by Machigin, soil organic matter – according to Tyurin [14]. Determination of soil washout and erosion was carried out by measuring the volume of vodoroin [15]. Mathematical processing of the obtained results was carried out by the analysis-of-variance method (GenStat Release 8.1) using the Excel program [16, 17].

3. Result and discussion

3.1. Erosion processes on the slopes
On a slope with a steepness of 3.5–4.0°, erosion processes were studied for a 33 year period. With the onset of abundant snowmelt, surface runoff of meltwater of varying intensity is observed. The most intense runoff of meltwater was noted in a crop rotation containing a 20% field of clean fallow (14.3–16.3 mm). In crop rotations from 20% and 40% of perennial grasses, the runoff decreased from 8.5–10.9 mm to 6.0–7.9 mm. Perennial grasses play a soil-protecting role, preventing the flow of melt and storm water. The introduction of 20% of perennial grasses into the crop rotation reduces the runoff by 32.7–40.6%, in comparison with the crop rotation, which has clean fallow in the structure of sown areas. An increase in perennial grasses up to 40% reduces runoff by 76.1–97.6% (table 1).

Table 1. Soil runoff and washout depending on crop rotation structure and tillage method.

| Crop rotation | Tillage method | Runoff, mm | Washout, t/ha |
|---------------|----------------|------------|---------------|
| A             | Chisel         | 14.3±1.5   | 4.0±0.6       |
|               | Moldboard      | 16.2±1.7   | 4.6±0.6       |
| B             | Chisel         | 8.5±1.0    | 2.3±0.3       |
|               | Moldboard      | 10.9±1.4   | 3.0±0.4       |
| C             | Chisel         | 6.0±0.8    | 1.6±0.2       |
|               | Moldboard      | 7.9±1.2    | 2.1±0.3       |

The use of various tillage methods had different effects on the snowmelt runoff. The smallest runoff was noted for the chisel tillage option. In the crop rotation with 20% of clean fallow, the meltwater runoff was 11.7%. With an increase in the share of perennial grasses in the structure of crop rotation, the water runoff in the case of chisel tillage was less by 22.0–24.1%. Plant residues in the case of non-moldboard tillage – chisel, retard the flows of meltwater formed during intensive snowmelt. Moisture is better absorbed into the soil. Moldboard tillage is carried out with stubble turnover, and plant residues are embedded in the soil. The soil surface has a ridged structure. However, the ridges to a certain limit retard the flow of meltwater. On moldboard tillage, the soil is looser, compared to chisel, and more susceptible to washout. Roots and plant debris hold the soil surface together, thereby preventing runoff. In the case of moldboard tillage, plant residues are embedded deep into the underlying layers, and loose soil remains on the surface. With intense snow melting, water does not have time to soak into the frozen soil and flows down the slope, taking with it the fertile topsoil.

The greatest soil washout was observed in the case of moldboard tillage in a crop rotation with 20% clean fallow (4.6 t/ha). In the crop rotation with 20% of perennial grasses, soil erosion was less by 34.8–42.5%. The doubling of the percentage of perennial grasses in the structure of the sown areas of the crop rotation allowed reducing soil washout by 54.3–60.0%.

The use of chisel tillage reduced soil washout by 13.0% in a crop rotation with 20% clean fallow, by 23.3% in a crop rotation with 20% of perennial grasses, and by 23.8% in a crop rotation with 40% of perennial grasses.

The use of chisel tillage in crop rotations with a field of perennial grasses doubled in area, acquires soil-protecting properties. A field of perennial grasses, having plant residues on its surface throughout the year, prevents the development of melt and storm water runoff and soil erosion. Soil, not sown in winter with either perennial grasses or winter wheat, is most susceptible to erosion processes. One of the ways to prevent runoff processes is to apply conservation tillage along the contour lines. Chisel
tillage, performed without seam turnover, leaves plant residues on the surface of the field, which prevent the development of water runoff and soil washout.

3.2. Dynamics of humus content in soil on erosion hazard slopes

As a result of erosion processes, organic matter is lost along with water runoff and soil washout. When the experimental field was laid in 1986, the soil layer of 0–30 cm contained 3.8–3.83% humus. On the variants of the test without fertilizing for six rotations in all the studied crop rotations, a decrease in the percentage of humus in the soil was noted. In the crop rotation with a 20% field of clean fallow, the loss of humus was the highest and amounted to (−0.27%). In the crop rotation from 20% and 40% of perennial grasses, the loss of humus decreased to (−0.15%) and (−0.08%), respectively. The application of organic fertilizers at a dose of 5 tons of FYM and N<sub>46</sub>P<sub>24</sub>K<sub>30</sub> led to a slight increase in the humus content in the soil from 0.05% to 0.12%. An increase in the fertilizer application dose by one and a half times (8 t FYM and N<sub>84</sub>P<sub>30</sub>K<sub>48</sub>) was accompanied by an increase in soil organic matter content from 0.10% in the crop rotation from 20% pure fallow to 0.26–0.31% in crop rotations with a different proportion of perennial grasses (figure 1).

![Figure 1](image.png)

**Figure 1.** Changes in the humus content in the soil layer 0–30 cm depending on the level of fertilization: 1 – Control plot without fertilizers; 2 – 5 t FYM+N<sub>46</sub>P<sub>24</sub>K<sub>30</sub>; 3 – 8 t FYM+N<sub>84</sub>P<sub>30</sub>K<sub>48</sub> and the structure of crop rotation: "A" – clean fallow 20%, perennial grasses 0% (fallow, winter wheat, winter wheat, sunflower); "B" – clean fallow 0%, perennial grasses 20% (peas, winter wheat, sunflower, barley, perennial grasses); "C" – clean fallow 0%, perennial grasses 40% (corn for silage, winter wheat, barley, perennial grasses, perennial grasses).

Above were listed the soil-protecting properties of perennial grasses, preventing the development of erosion processes. They are also able to fix atmospheric nitrogen and participate in the accumulation of soil organic matter [18]. Perennial grasses, in addition to fixing nitrogen, leave a large amount of plant residues on the field. In the process of decomposition of root and stubble residues, soil organic matter is formed. The introduction of organo-mineral fertilizers in medium doses compensates for the removal of nutrients from the soil with the harvest and losses with washout, the fertility remains at the initial level. In crop rotations with perennial grasses, during six rotations at an increased level of mineral nutrition, the amount of soil organic matter increased by 6.6–8.2 relative percent. There was no significant increase in the crop rotation with 20% clean fallow. In this rotation, the greatest soil erosion was noted. Also, an intensive process of organic matter mineralization takes place in the fallow land. All these processes, as well as the consumption of nutrients for the creation of agricultural products, lead to the loss of soil organic matter.
3.3. **Dynamics of the content of labile phosphorus and exchangeable potassium in soil on erosion hazard slopes**

As a result of systematic observation of the dynamics of labile phosphorus and exchangeable potassium in the soil during six rotations of crop rotations, a trend similar to changes in the content of soil organic matter was noted. The initial content of labile phosphorus in the soil was 16.8–18.8 mg/kg, exchangeable potassium 347.0–393.0 mg/kg. As a result of the extensive technology of cultivation of agricultural crops, the content of exchangeable phosphorus decreased by 17.2–25.5%, and exchangeable potassium – 22.4–32.0%. Systematic application of fertilizers at medium doses affected the increase in exchangeable phosphorus by 81.1–106.9%, and an increase in the dose by one and a half times increased its content by 170.0–206.8%, with lower values in the crop rotation from 20% of clean fallow (table 2).

**Table 2.** Change in the content of labile phosphorus and exchangeable potassium in the soil layer 0–30 cm, depending on the level of fertilization and the structure of crop rotation.

| Period of comparison | Level of fertilization | Crop rotation |
|---------------------|-----------------------|---------------|
|                     | “A”                   | “B”           | “C”           |
| 1986                | 17.3±0.6              | 16.8±0.6      | 18.8±0.6      |
| 2019                | 14.3±0.8              | 13.6±0.9      | 14.0±1.1      |
| 2019                | 31.3±1.5              | 34.8±2.2      | 34.4±1.2      |
| 2                   | 46.7±2.0              | 51.6±4.3      | 51.1±4.0      |
| 1986                | 377.0±13              | 393.0±13      | 347.0±13      |
| 2019                | 256.3±28              | 271.9±7.0     | 269.4±6.3     |
| 1                   | 362.2±29              | 362.3±27      | 374.8±30      |
| 2                   | 387.8±29              | 403.4±30      | 402.0±33      |

The content of exchangeable potassium in the soil in crop rotations with 20% clean fallow (crop rotation A) and 20% of perennial grasses (crop rotation B) as a result of the use of an organic mineral fertilizer system in medium doses decreased slightly (by 3.9–7.8%), an increase in the fertilizer dose by one and a half times there was a tendency for a slight increase in K₂O (2.6–2.9%). In the crop rotation with 40% of perennial grasses, with the application of fertilizers in medium and high doses, the content of exchangeable potassium in the soil increased by 8.0–15.8%. An insignificant increase or decrease in the content of nutrients in the soil within the experimental error, with the introduction of average doses of fertilizers, can be considered as the preservation of soil fertility at the initial level. The introduction of organo-mineral fertilizers in high doses leads to an expanded soil fertility.

3.4. **The productivity of crop rotations of various structures, depending on the tillage method the level of fertilization**

The level of soil fertility affects the productivity of crop rotation. Table 3 shows the productivity of crop rotations of various structures. The lowest productivity was in the crop rotation with low fertility on the variant of the experience of the extensive fertilization system (crop rotation A) and was 2.73–2.78 t/ha, grain units. In crop rotations with different proportions of perennial grasses (crop rotations B and C) in the structure of sown areas, productivity increased by 7.9–9.9% compared to crop rotation "A". Application of average doses of fertilizers (average level of fertility) led to an increase in the productivity of crop rotation "A" by 25.7–27.1%; crop rotation "B" – 20.1–21.1%; crop rotation "C" – 20.6–22.0%. An increase in the dose of fertilization by one and a half times in crop rotations of various structures led to an increase in productivity in crop rotation "A" by 41.3–41.8%; in crop rotation "B" by 32.9–34.1%; in the "C" crop rotation by 35.0–36.8% (table 3).

Tillage did not have a significant effect on the productivity of crop rotations. There was a slight increase in productivity on the option of moldboard tillage by 0.04–0.1 t/ha, grain units. This difference is not reliable, since the experimental error was 0.11–0.15 t/ha, grain units.
Table 3. The productivity of crop rotations of various structures, depending on the tillage method and the level of fertilization, t/ha, grain units.

| Crop rotations | Amount of fertilizers’ application |
|----------------|-----------------------------------|
|                | Control plot without fertilizers | 5 t FYM + N<sub>46</sub>P<sub>24</sub>K<sub>30</sub> | 8 t FYM + N<sub>84</sub>P<sub>30</sub>K<sub>48</sub> |
| A Chisel       | 2.73±0.11                        | 3.47±0.10                        | 3.87±0.12                        |
| Moldboard      | 2.78±0.11                        | 3.49±0.12                        | 3.92±0.14                        |
| B Chisel       | 2.95±0.13                        | 3.57±0.13                        | 3.95±0.13                        |
| Moldboard      | 3.03±0.15                        | 3.64±0.14                        | 4.03±0.14                        |
| C Chisel       | 2.95±0.14                        | 3.59±0.13                        | 4.03±0.14                        |
| Moldboard      | 3.05±0.15                        | 3.68±0.14                        | 4.12±0.15                        |

Significant increases in crop productivity were obtained with the introduction of average doses of fertilizers 0.6–0.7 t/ha, grain units (m = 0.1–0.14). Crop rotation with 20% of clean fallow has the highest soil loss during washout (4.6 t/ha). With an extensive system of growing agricultural crops, the loss of humus was (~0.27%), the content of labile phosphorus decreased by 17.2%, exchangeable potassium – by 32.0%, compared to the initial content. Application of fertilizers in medium doses made it possible to obtain 0.7 t/ha of additional production. In crop rotations with 20% and 40% of perennial grasses in the structure of sown areas, soil erosion was less than in crop rotation "A"; losses of soil organic matter and mobile forms of phosphorus and potassium were also lower. Soil fertility in these rotations was better than in the rotation with 20% net fallow and higher productivity (by 7.9–9.9%). Therefore, when applying fertilizers in medium doses, the increase was slightly less than 0.6 t/ha, grain units, than in the "A" crop rotation.

To obtain higher crop yields, it is necessary to increase soil fertility by applying increased doses of fertilizers. An increase in the fertilizer application dose by one and a half times did not lead to an increase in crop yield by the same amount (1.0–1.1 t/ha, grain units). Less losses of organic matter and mineral nutrients were noted in the crop rotation with 40% of perennial grasses, therefore, this crop rotation has the highest fertility. The level of fertility can be evaluated by the productivity of arable land, which in the "B" crop rotation is greater than in other crop rotations (4.03–4.12 t/ha, grain units).

4. Conclusion

The use of soil-protecting crop rotations on slope lands with 20% of perennial grasses reduced soil washout by 34.8–42.5%, runoff by 32.7–40.6%. An increase in the share of perennial grasses halved soil washout by 54.3–60.0%, runoff – 76.1–97.6%. The use of soil-protecting tillage along the contour lines and leaving stubble on the surface of the field reduces soil loss by 13.0–23.8%, runoff by 11.7–24.1%. As a result of the extensive technology of cultivation of agricultural crops, due to the removal of nutrients with the crop and erosion processes, the content of organic matter and nutrients in the soil decreases in all the studied crop rotations. The application of fertilizers in medium doses (5 tons of FYM and N<sub>46</sub>P<sub>24</sub>K<sub>30</sub>) per 1 hectare of the crop rotation area maintains the humus content and the amount of labile phosphorus and potassium at the initial level. Systematic application of fertilizers in high doses (8 tons of FYM and N<sub>84</sub>P<sub>30</sub>K<sub>48</sub>) contributes to the expanded reproduction of soil fertility. Under the conditions of an erosion hazard slope, the humus content in ordinary carbonate chernozem increases by 8.1%, labile phosphorus – by 206.8%, exchangeable potassium – 15.8% in a crop rotation with 40% of perennial grasses. The nutrient regime of the soil also affects the productivity of both individual crops and the entire crop rotation as a whole. At the average level of fertility, the productivity of crop rotations increases by 20.1–27.1%. The expanded level of fertility increases productivity by 32.9–41.8% and allows you to get 4.03–4.12 t/ha, grain units of agricultural products.
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