Balance of humus and nutrients in the meadow-chernozem soil of the rice ecosystem

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Abstract. The purpose of the study is to determine the influence of mineral and organomineral fertilizer systems on the balance of humus and nutrients in meadow-chernozem soil of the rice ecosystem. The field test was conducted at the Maryano-Cheburgolsky irrigation massif of the Kuban-type rice irrigation system, which studied the effect of mineral fertilizers and their combination with manure slurry introduced in different periods (autumn and spring) and in different ways (with and without the nitrification inhibitor Entec FL). It was established that the optimization of mineral nutrition of plants is accompanied by an increase in rice yield by 2.32–2.78 t/ha and an increase in the removal of nutrients from the soil with harvest. The deficit-free balance of humus and food elements in meadow-chernozem soil under rice is ensured by using an organomineral fertilizer system with slurry application rate of 30 t/ha and $N_{120}P_{80}K_{60}$ mineral fertilizers. The combined action of mineral and organic fertilizers reduces the loss of humus from the soil by 2.9–3.0 t/ha and returns nitrogen 51.4–61.4 kg/ha (35.1–46.8%), phosphorus – 48.6–55.6 kg/ha (72.1–92.1%), potassium – 20.8–31.4 kg/ha (21.4–52.0%) taken with rice crop.

1 Introduction

Rice agrocenosis is a complex multi-component agroecological system. The formation of soil fertility, its productivity and the level of harvest of the reclamation rice crop are inextricably linked with the content of organic matter [1, 2]. The prevailing restoration processes during the period of soil flooding are accompanied by its intensive destruction. If there are few fresh plant residues or organic fertilizers are not added to them, then these processes are accompanied by mineralization of humus [1, 3–5]. The decrease in humus is also associated with the processes of migration of organic matter along the soil profile. During the growing season of rice from soil with filtration and discharge waters, humus losses amount to 0.5% of water-soluble organic substances in terms of carbon, or 17.8 g kg^{-1} [6].

Organic fertilizers are an important factor in increasing soil fertility and productivity. Their introduction is accompanied by an increase in the proportion of humic acids and reserves of total and hydrolyzable nitrogen in organic matter. At the same time, organic fertilizers increase the nitrogen content in the soil not only due to the compounds of this element, but also due to fixation from the air. At the same time, under the influence of organic fertilizers, microbiological activity increases, as a result, the solubility and availability of nutrients, namely calcium, iron, aluminum phosphates, for plants increases [1, 3, 4, 7, 8].

The purpose of the study is to determine the impact of the use of mineral and organomineral fertilizer systems for rice on the balance of humus and nutrients in meadow-chernozem soil.

2 Materials and methods

The field test was conducted on the Maryano-Cheburgolsky irrigation massif of the Kuban-type rice irrigation system with the insertion of slurry into the soil both separately and with the addition of the Entec FL nitrification inhibitor. The latter is an ammonium nitrogen inhibitor DMPP (3.4-dimethylpyrazole phosphate), which slows down the nitrification process, thereby stabilizing the ammonium form of nitrogen in the soil. The slurry used in the test is characterized by 0.2–0.3% nitrogen, 0.4–0.5% potassium and 0.1% phosphorus. The main nitrogenous substances of slurry are urea, urinary and hypuric acids, which, under the influence of urobacteria, form ammonium carbonate, which easily decomposes into carbon dioxide, ammonia and water.

Slurry was embedded in the soil in autumn and spring at the rate of 30 t/ha. The Entec FL nitrification inhibitor was added to the slurry tank by thoroughly mixing the resulting solution. Mineral fertilizers were introduced within the $N_{120}P_{80}K_{60}$ limit on all test options, with the exception of control. The experiment was conducted according to the following scheme:

1. Control (no fertilizer).

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2. Rice cultivation technology ($N_{120}P_{80}K_{60}$).
3. Slurry, 30 t/ha (autumn).
4. Slurry, 30 t/ha + Entec FL nitrification inhibitor (autumn).
5. Slurry, 30 t/ha (spring).
6. Slurry, 30 t/ha + Entec FL nitrification inhibitor (spring).

The field test is based on meadow-chernozem clay soil (corresponding to Gleyic Chernozem in WRB [9]), in which the total humus content is 3.3% with the ratio C_{gc}:C_{fk}=1.94, total nitrogen – 0.214%, pH_{H2O} – 6.6 units [3].

The balance of the food elements was calculated on the basis of nitrogen, phosphorus and potassium removal by the main and by-product of the crop unit (consumption item) and the amount of nutrients supplied to the soil with organic and mineral fertilizers (receipt item). The difference between the receipts and expenditures was used to determine the nutrition balance in the meadow- chernozem soil under the rice crop. The removal of nutrients from the soil by the rice crop was calculated from the content of nitrogen, phosphorus and potassium in the main and by-products and yield data [10].

The balance of humus is characterized by a difference between its consumption or mineralization during the cultivation of crops and neoplasm in the soil due to the humification of crop and root residues, as well as introduced organic fertilizers. This method makes it possible to forecast changes in the humus content and determine the need for organic fertilizers that prevent reduction (deficit-free balance) or create conditions for its accumulation (positive balance) in the soil [11].

Humus mineralization was calculated on the basis of soil nitrogen balance. The consumption of humus from meadow-chernozem soil was considered according to the removal of nitrogen by rice plants. It is believed that 50% of the nitrogen carried by plants is of soil origin. At the same time, plants consume 50% of nitrogen from mineral fertilizers and 50% – from soil. When using organic fertilizers, nitrogen plants take 50% from mineral fertilizers, 25% from organic fertilizers and 25% from soil. The removal of 50 kg of soil nitrogen by plants (at 5% nitrogen in humus) is equal to the loss of 1 ton of humus [11, 12].

The mineralization of humus depends on the cultivated agricultural crop, the grain size distribution of the soil and the intensity of its cultivation [12, 13]. Therefore, the value of nitrogen yield was corrected by correction factors for humus mineralization depending on the grain size distribution and soil cultivation intensity.

The accumulation of humus (the incoming part of the humus balance) in the soil is due to root and crop residues and introduced organic fertilizers. To determine the amount of newly formed humus from plant residues, the crop yield of rice, the number of crop and root residues and the coefficient of their humification were taken into account, and 75 kg of humus was formed out of 1 ton of manure [10, 11].

3 Results and discussion

The crop fertilizer system shall ensure the maximum possible yields, preservation and reproduction of soil fertility. Its development requires a deficit-free balance of elements of nutrition and humus.

The yield data showed that the increase in the rice grain yield from the application of mineral and organic fertilizers was 2.32–2.78 t/ha (HCP_{05}=1.82 t/ha). The increase in yield was considerably influenced by the incorporation of slurry into the soil, which exceeded the mineral system of fertilizer application by 4.4–6.3%. The inclusion of a nitrification inhibitor in manure increased the productivity of rice agrocenosis. At the same time, the greatest increase in the rice crop was achieved during autumn seeding of slurry modified with a nitrification inhibitor in the soil, exceeding the control and mineral background $N_{120}P_{80}K_{60}$ by 2.78 and 0.46 t/ha, respectively. The greatest efficiency of slurry with the addition of Entec FL inhibitor was achieved during autumn seeding in the soil compared to spring (Fig. 1).

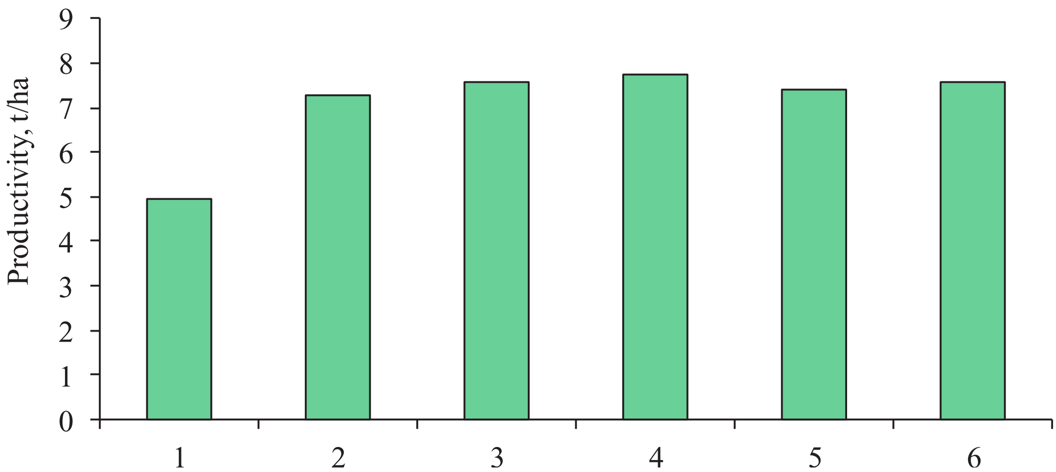

Fig. 1. Rice yield under different rice fertilizer systems: 1–6 – test options are outlined in Section 2.

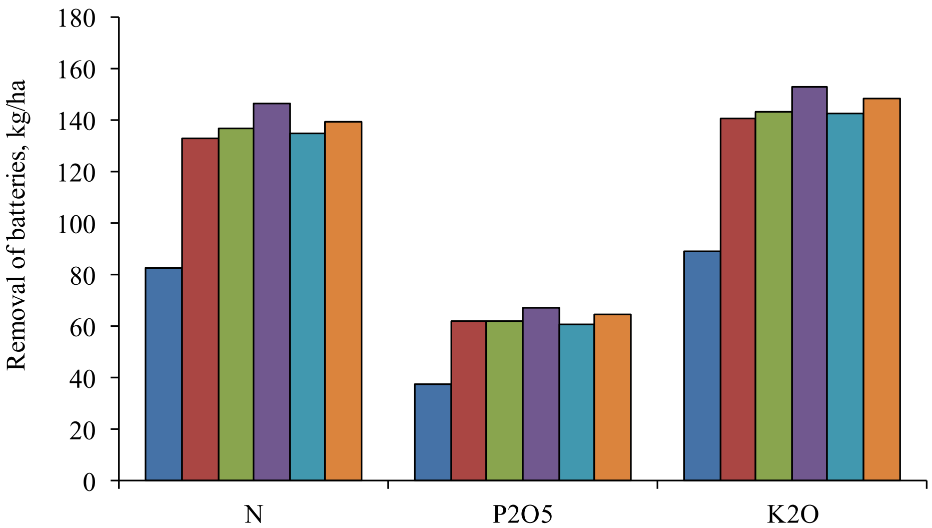

Fig. 2. Removal of food elements from the soil with rice crop

The optimization of mineral nutrition influenced the increase in the economic removal of nutrients from meadow-chernozem soil with the harvest of the main and by-product rice. Rice growing without the use of fertilizers contributed to a small economic removal of nitrogen, phosphorus and potassium from the rice crop. With the use of mineral fertilizers, $N_{120}P_{80}K_{60}$ nitrogen removal increased by 49.8 kg/ha (60.0%), phosphorus – 24.3 kg/ha (64.6%), potassium – 51.7 kg/ha (57.9%). The organic mineral system of rice fertilizer increased the total nitrogen yield with a yield of 51.9–63.6 kg/ha (62.6–76.7%), phosphorus – 22.8–29.8 kg/ha (60.6–79.2%) and potassium – 53.3–63.9 kg/ha (59.7–71.6%). At the same time, the maximum commercial removal of nutrients from the soil with the harvest was noted when the slurry modified with the nitrification inhibitor Entec FL was introduced from autumn.

The balance characterizes the comparison of the items of entry of nutrition elements and humus into the soil with their consumption for the formation of crops and losses from the soil. Balance calculation provides an idea of what is happening to deplete or enrich the soil with nutrients and humus under a developed fertilizer system. When growing rice without fertilizers, a negative balance of nitrogen (–83.0 kg/ha), phosphorus (–37.6 kg/ha) and potassium (–89.3 kg/ha) was added. When applying mineral fertilizers, the $N_{120}P_{80}K_{60}$ loss of nitrogen from the soil decreased by 6.5 times, but the balance remained negative at its intensity of 90.4%. The mineral fertilizer system positively affected the balance of phosphorus (+18.1 kg/ha), the intensity of which was 129.2%, and contributed to a noticeable decrease in potassium losses from the soil. However, the application of potassium fertilizers at the rate of 60 kg of active ingredient per hectare (K_{60}) was insufficient for a deficient potassium balance – the recovery of removal from the soil by application did not exceed 42.5% (Table 1).

Table 1. Balance of food elements in the soil under various rice fertilizer systems

Option[a]	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Potassium (kg/ha)
1	–83.0	–37.6	–89.3
2	–12.8	+18.1	–81.0
3	+61.4	+54.1	+30.7
4	+51.4	+48.6	+20.8
5	+63.1	+55.6	+31.4
6	+58.4	+51.5	+25.2

[a]Test options are outlined in Section 2.

The organic mineral system for the use of fertilizer for rice contributed to the full recovery of the removal of nutrients from the meadow-chernozem soil. Depending on the time and method of slurry application (with and without Entec FL inhibitor), the nitrogen balance intensity ranged from 135.1–146.8%, phosphorus – 172.1–192.1%, potassium – 113.6–122.0%. At the same time, the compensation for the removal of nutrition elements from the soil was almost the same regardless of the term for organic fertilizers. Hence, the positive balance of nutrients in meadow-chernozem soil under rice is formed when using an organomineral fertilizer system with a slurry application rate of 30 t/ha and $N_{120}P_{80}K_{60}$ mineral fertilizers. Under this system, 51.4–61.4 kg/ha (35.1–46.8%), phosphorus – 48.6–55.6 kg/ha (72.1–92.1%), potassium – 20.8–31.4 kg/ha (21.4–52.0%), carried out with rice crop, returned to nitrogen soil.

The humus balance in the meadow-chernozem soil under rice was calculated based on the nitrogen balance (Table 2). In the soil of rice agrocenosis, without applying fertilizers, there was a large shortage of humus, which was 405 kg/ha/year. This is caused by an increase in the mineralization of humus in the soil, the size of which reached 1,593 kg/ha. The use of mineral fertilizers reduced the deficit of humus, while the intensity of the balance increased by 62.4% relative to control (137.0% versus 74.6%). The improvement of humus balance in the meadow-chernozem soil under rice under the influence of the mineral fertilizer system is caused by an increase in the supply of the non-commercial part of the crop into the soil, i.e., root and crop residues of plants.

Table 2. Balance of humus in soil under various rice fertilization systems

Option[a]	Humus mineralization (kg/ha/year)	Newly-formed humus (kg/ha/year)	Humus balance (kg/ha/year, +/–)
1	1593	1188	–405
2	1274	1745	+470
3	656	4072	+3416
4	703	4105	+3402
5	648	4031	+3383
6	670	4067	+3397

[a]Test options are outlined in Section 2.

The organic mineral system of rice fertilizer contributed to a significantly lower mineralization of humus and an increase in its neoplasm in the soil due to the introduction of slurry and the accumulation of root residues [3]. Regardless of the term and method of adding the slurry (with and without the Entec FL inhibitor), the humus balance increased 7-fold. The amount of newly-formed humus in the soil under rice reached 4,031–4,105 kg/ha per year, and the loss of humus relative to the control and mineral fertilizer system decreased by 3.0 and 2.9 t/ha, respectively. To the greatest extent, the components of the humus balance were influenced by the autumn embedding of slurry in the soil, modified with a nitrification inhibitor. It follows that the organomineral system for the use of a fertilizer for rice culture with a slurry application rate of 30 t/ha and mineral fertilizers $N_{120}P_{80}K_{60}$ provided a deficit-free balance of humus in the meadow-chernozem soil.

4 Conclusion

Mineral and organomineral systems of fertilizer application increase the productivity of rice agrocenoses (grain yield increase 2.32–2.78 t/ha). The optimization of mineral nutrition of plants is accompanied by an increase in the commercial removal of nitrogen, phosphorus and potassium from the meadow-chernozem soil with the main and by-products of rice. The deficient balance of humus and nutrients in the soil is ensured by the use of an organomineral fertilizer system with a slurry application rate of 30 t/ha and $N_{120}P_{80}K_{60}$ mineral fertilizers. The combined application of mineral and organic fertilizers reduces the loss of humus from the soil by 2.9–3.0 t/ha and returns nitrogen 51.4–61.4 kg/ha (35.1–46.8%), phosphorus – 48.6-55.6 kg/ha (72.1–92.1%), potassium – 20.8–31.4 kg/ha (21.4–52.0%) removed with rice crop.

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