Influence of fertilizer system on the dynamics of nitrogen content and balance on newly developed lands

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Abstract. Under the conditions of the North-West region, the influence of fertilizer systems and precursors on the dynamics of the accumulation of easily hydrolysable nitrogen and the balance of its total content during the development of unproductive sod-podzolic soils of light granulometric composition was studied. For an eight-year research period, the mineral fertilizer system in the cultivation of barley at the planned yield (40 kg/ha) does not compensate for the loss of easily hydrolysable nitrogen. The organo-mineral system (40 t/ha of organic fertilizers or 100 m3/ha of liquid wastewater from livestock complexes) contributes to an increase in the content of easily hydrolysable nitrogen in the arable soil layer by 2.5 ... 5.1 and 2.1 ... 5.2 mg/kg of soil, compared to control. Stabilization of the balance of the total nitrogen content occurs with an annual application of 6.9 ... 7.2 t/ha of solid fraction of manure or 35 ... 37 m3/ha of liquid effluents and expanded reproduction of soil fertility is ensured with the incorporation of 9.7 ... 11.0 t/ha solid fraction or 49 ... 52 m3/ha of liquid waste. The most intensive accumulation of easily hydrolysable nitrogen is observed when using spring rape as a precursor, on the background of which the highest yield of barley was also obtained.

1. Introduction

Reproduction of soil fertility is one of the most important tasks, the solution of which will significantly improve the economic, social and environmental situation in the country. In the past three decades, due to a sharp decline in the livestock population, many farms have switched to deeper grain specialization, which has led to a significant change in the structure of sown areas. At the same time, significant areas of tilled and leguminous crops were removed from field crop rotations, which caused a decrease in soil fertility, which is accompanied by an increasing negative balance of nutrients, acidification of land and deterioration of the phytosanitary state of agro phytocenoses [1,2]. During this period, the use of nitrogen fertilizers decreased by 5.3 times, which caused a negative balance of this most important nutrient. The annual nitrogen deficit for various sources reached 19 ... 37 kg/ha, which led to the depletion of soils not only in mineral nitrogen, but also in humus [3,4].

For the reproduction of soil fertility, it is necessary to effectively use all fertilizing resources, including both traditional and new types of organic, mineral and microbiological fertilizers, as well as chemical ameliorants.

Of all the elements of mineral nutrition of plants, nitrogen has the greatest effect on the production process of agrobiocenosis and is one of the most difficult for agrochemical diagnostics [5]. Difficulties in assessing the availability of field crops with this element are associated with the rapid mineralization of soil nitrogen, its binding by soil microorganisms, as well as movement along a vertical profile under
the influence of precipitation, which leads to irreversible losses of nitrates outside the root layer and contamination of groundwater. In addition, the seasonal dynamics of nitrogenous compounds in the same field changes significantly during the growing season depending on temperature conditions and other multidirectional factors; therefore, constant annual attention should be paid to the state of the nitrogen regime of unproductive lands.

The purpose of the research was to study the influence of fertilizer systems and precursors on the dynamics of the content and balance of nitrogen in low-productive lands when they are involved in agricultural circulation in the Upper Volga region.

2. Materials and methods

The experiments were carried out in the Rzhevsky district of the Tver region (LLC Ruchevskoe-1) in 2012-2019. The land plot on which the research was carried out was not used in the period from 1994 to 2010. In 2011, work was carried out to clear it of weeds and trees and shrubs; in 2012, leveling crops of vetch-oats were sown with their incorporation into the soil as green manure; in 2013, the cultivation of agricultural crops began.

The soil of the experimental site is sod-podzolic light loamy, the thickness of the arable layer is 16-18 cm. The content of humus in the soil (2012) is 1.69-1.83%; P2O5 106-109 mg/kg; K2O 90-100 mg/kg; rNCL 4.7-4.8.

Solid fraction of manure was used as the main fertilizer - 40, 60 and 80 t/ha (content, %: dry matter - 28 ... 32, N - 0.54, P2O5 - 0.26, K2O - 0.61%, pH = 7.8 units) and liquid effluents of a pig-breeding complex - 100 and 120 m3/ha (content, %: dry matter - 3, N - 0.1, P2O5 - 0.03, K2O - 0.28%, pH = 7.3 units). Preliminarily, a solid fraction is separated from the composition of liquid waste using centrifugal pumps, which is mixed with low-lying peat, disinfected and stored in piles. The solid fraction is applied using spreader trailers over the surface of the field and immediately plowed into the soil as the main fertilizer [6]. Liquid effluents are pumped into lagoons, where they are decontaminated, after which they are applied as the main fertilizer or as top dressing using the technology of hose systems, which allows them to be simultaneously embedded in the soil, which significantly reduces the loss of ammonia nitrogen.

The meteorological conditions in the years of the research differed both in temperature regime and in the amount of precipitation and their distribution over decades and months. However, they were not the limiting reason for the cultivation of the programmed barley yield - 40 kg/ha. The variety Sunshine was used for sowing [7]. When cultivating barley according to the mineral system, N85P60K60 was added fractionally; in terms of organo-mineral, in addition to the main organic fertilizer, P10 was used for sowing and N60 for top dressing. The area of the accounting plot is 140 m², the sowing plot is 280 m². Variant placement - by the method of randomized repetitions; repetition - 4 times. Agrochemical studies on the dynamics of the content of easily hydrolysable and total nitrogen were carried out according to the generally accepted methods by the employees of the Federal State Budgetary Scientific Institution "Nelidovskaya" Agrochemical Service Station. Experimental options are presented in table 1.

3. Results and discussion

On light-textured soils, the content of easily hydrolysable nitrogen depends to a greater extent on the fertilization system than on its predecessors. In the control variant without fertilization, after eight years, the content of easily hydrolysable nitrogen on average for all studied precursors decreased by 0.5-1.0 mg/kg with a content of 74.3 ... 76.3 mg/kg.

When only mineral fertilizers are applied for the planned yield of barley (40 c/ha), there is also a negative dynamic of a decrease in the content of easily hydrolysable nitrogen relative to the initial state (–0.7 ... –1.0 mg/kg). However, in both cases, the difference was within the experimental error, with HCP60 = 4.4 ... 4.7 mg/kg. Thus, the mineral system of fertilizers does not compensate for the loss of easily hydrolysable nitrogen against the background of the studied previous crops [8]. Nitrogen deficiency for eight years of experiments was approximately the same for all predecessors and in relative terms decreased by 0.9 - 1.3%.
The use of solid fraction of manure at a dose of 40 t/ha provided an increase in the content of easily hydrolysable nitrogen in barley crops for all predecessors relative to the initial value: by 5.1 mg/kg in terms of the background of spring rape, by 4.2 mg/kg in terms of the background of spring cereals and by 2.5 mg/kg on the background of winter cereals, reaching values of 79.9 ... 82.1 mg/kg of soil.

An increase in the dose of the solid fraction of manure applied to 60 t/ha led to an increase in the content of easily hydrolysable nitrogen in the soil, in the eighth year after development - by 3.5 ... 5.8 mg/kg, with the incorporation of 80 t/ha by 3.2 ... 8.0 mg/kg.

The use of liquid effluents from livestock breeding complexes at a dose of 100 m3/ha also ensured a positive trend in the content of easily hydrolysable nitrogen for all predecessors, which after eight years amounted to 2.1 ... 3.6 mg/kg. With an increase in the rate of application of liquid effluents to 120 m3/ha, the difference relative to the initial state increases to 2.6 ... 5.2 mg/kg. However, it should be noted that despite the positive dynamics, the content of easily hydrolysable nitrogen in the experiment with the introduction of organic fertilizers, due to the instability and dynamism of this indicator, reached only the following values: for spring rape - 80.8 ... 84.2 mg/kg; for spring grains - 75.2 ... 81.2 and for winter grains - 79.5 ... 81.7 mg/kg of soil. According to the modern gradation, such an amount of this compound makes it possible to classify the studied lands as a group with low and medium content of easily hydrolysable nitrogen.

Of the previous crops, the greatest accumulation of easily hydrolysable nitrogen during the annual application of organic fertilizers is provided by spring rapeseed - 3.6 ... 8.0 mg/kg. According to the background of spring cereals, the increase is 2.9 ... 4.2 mg/kg, and according to the background of winter cereals, 2.1 ... 5.2 mg/kg.

The calculation of the balance of the total nitrogen content was carried out on the basis of materials from an agrochemical survey of lands [9, 10]. At the same time, the income items of the balance include nitrogen inputs with stubble-root residues, with mineral fertilizers, with solid fraction of manure, with liquid effluents, with seeds, with atmospheric precipitation, as well as nitrogen accumulated by free-living nitrogen-fixing bacteria.

The expense items of the balance include nitrogen removal by crops, weeds, as well as losses due to washout by precipitation and denitrification.

It has been found that the fertilizer system and, to a lesser extent, predecessors have a decisive influence on the nitrogen balance (table 1). So, in the control variant without fertilizing in all years of research and for all predecessors, the balance of this element was negative and amounted to –31.6 ... –35.2 kg/ha with a balance intensity of 37.4 ... 38.8%. Consequently, for the formation of the main and by-products, barley crops without additional fertilization use 61.6 ... 62.6% of soil nitrogen, which ultimately will cause a decrease in natural soil fertility, since the mineralization of humus reserves is not replenished due to stubble-root residues.

Cultivation of spring barley according to the mineral system with the use of calculated doses of nitrogen for the planned yield of 40 c/ha increases the intensity of the balance to 89.2 ... 96.2%, however, when using it, the nitrogen balance for all predecessors remains negative and amounts to -4.7 ... -14.9 kg/ha. It follows from this that the mineral system, although it has a significant effect on reducing nitrogen deficiency, however, without the use of organic fertilizers, the reproduction of soil fertility of unproductive lands is impossible, since the amount of organic residues does not allow to fully bring the ratio of input and output balance items to unity.

During the cultivation of spring barley on an organic-mineral system with the introduction of 40 t/ha of solid fraction of manure, a positive nitrogen balance was noted in the background of all predecessors, which during the years of research was in the range of +15.8 ... +35.0 kg/ha at a balance intensity of 114, 9 ... 132.7%.

An increase in the solid fraction of manure to 60 t/ha provides an increase in the intensity of nitrogen balance up to 138.9 ... 163.9%; when applying 80 t/ha, this figure increases to 157.8 ... 193.8%.

The use of liquid effluents from livestock complexes at a dose of 100 and 120 m3/ha also provides an expanded reproduction of the fertility of unproductive lands, since in both cases a positive nitrogen...
balance was noted (+7.5 ... +52.5 and +11.1 ... +67.5 kg/ha) and high balance intensity (106.8 ... 148.0 and 109.7 ... 158.3%, respectively).

On the basis of the calculations, we have established that to stabilize the state of nitrogen on the cultivated light loamy soddy-podzolic soils, it is necessary to annually apply 6.9 ... 7.2 t/ha of solid fraction of manure or 35 ... 37 m³/ha of liquid waste, and for expanded reproduction, respectively 9.7 ... 11.0 t/ha of manure or 49 ... 52 m³/ha of livestock waste.

Analysis of the data on the yield of barley allows us to conclude that the fertilizer systems provide a significant increase relative to the control variant, while the previous crops did not have a significant effect on its productivity (table 2). The highest grain yield (33.5 c/ha) was obtained on the background of spring rape, after spring and winter cereals it was in the range of 31.6 ... 31.9 c/ha with HCPₐₙ = 1.9 c/ha. The maximum increase in grain yield relative to the control option (+30.7 c/ha or 262%) was provided by the mineral fertilizer system, where fertilizers were applied fractionally: N₅₆P₉₀K₀₀ - as the main fertilizer for pre-sowing cultivation; P₉₀ - for sowing and N₃₀ - for foliar feeding in the earing phase.

Table 1. Nitrogen balance in the cultivation of spring barley using different fertilization systems and predecessors on newly developed lands, kg/ha.

| Experiment options (factor A) | Spring rapeseed | Spring cereals | Winter cereals |
|------------------------------|-----------------|----------------|----------------|
|                              | Predecessors (factor B) |                  |                |
|                              |                 |                 |                |
|                              | Years           | coming          | consumption    | Balance | Balance |% intensity | coming | consumption | balance | Balance |% intensity |
| Control (no fertilizer)      |                 |                 |                |         |         |           |       |             |         |         |            |
| 2012                         | 20.9            | 55.4            | -34.5          | 37.7     | 19.9    | 51.5       | 38.6   | 20.4        | 52.6    | -32.2   | 38.4       |
| 2015                         | 20.5            | 54.7            | -34.2          | 37.5     | 20.0    | 52.3       | 38.2   | 20.1        | 52.3    | -32.2   | 38.4       |
| 2018                         | 21.0            | 56.2            | -35.2          | 37.4     | 20.1    | 52.6       | 38.2   | 20.5        | 53.1    | -32.6   | 38.6       |
| Mineral system:              |                 |                 |                |         |         |           |       |             |         |         |            |
| N₅₆P₉₀K₀₀ +P₉₀ when sowing; |                 |                 |                |         |         |           |       |             |         |         |            |
| N₀₀ when feeding             |                 |                 |                |         |         |           |       |             |         |         |            |
| 2012                         | 122.2           | 131.6           | -9.4           | 92.9     | 120.2   | 124.9      | 96.2   | 121.3       | 126.4   | -5.1    | 96.0       |
| 2015                         | 122.7           | 134.5           | -11.8          | 91.2     | 120.8   | 128.2      | 94.2   | 122.0       | 129.5   | -7.5    | 94.2       |
| 2018                         | 123.5           | 138.4           | -14.9          | 89.2     | 121.1   | 129.5      | 93.5   | 122.7       | 132.9   | -10.2   | 92.3       |
| Manure (t/ha)                |                 |                 |                |         |         |           |       |             |         |         |            |
| 40 t/ha +P₉₀ – when sowing   |                 |                 |                |         |         |           |       |             |         |         |            |
| N₀₀ when feeding             |                 |                 |                |         |         |           |       |             |         |         |            |
| 2012                         | 141.9           | 106.9           | +35.0          | 132.7    | 141.4   | 106.9      | 132.3  | 121.3       | 106.1   | +15.8   | 114.9      |
| 2015                         | 142.3           | 108.7           | +33.6          | 130.9    | 141.7   | 109.0      | 130.0  | 142.2       | 107.4   | +34.8   | 132.4      |
| 2018                         | 143.2           | 112.1           | +31.1          | 127.7    | 142.4   | 110.3      | 129.1  | 142.8       | 109.8   | +33.0   | 130.1      |
| Manure (t/ha)                |                 |                 |                |         |         |           |       |             |         |         |            |
| 60 t/ha +P₉₀ – when sowing   |                 |                 |                |         |         |           |       |             |         |         |            |
| N₀₀ when feeding             |                 |                 |                |         |         |           |       |             |         |         |            |
| 2012                         | 183.5           | 115.0           | +68.5          | 159.6    | 182.5   | 111.6      | +70.9  | 163.5       | 109.8   | +42.7   | 138.9      |
| 2015                         | 184.2           | 117.6           | +66.6          | 156.6    | 182.8   | 113.9      | +68.9  | 160.6       | 111.9   | +71.5   | 163.9      |
| 2018                         | 184.6           | 120.4           | +64.2          | 153.3    | 182.6   | 113.2      | +69.4  | 161.3       | 114.5   | +69.7   | 160.9      |
| Manure (t/ha)                |                 |                 |                |         |         |           |       |             |         |         |            |
| 80 t/ha +P₉₀ – when sowing   |                 |                 |                |         |         |           |       |             |         |         |            |
| N₀₀ when feeding             |                 |                 |                |         |         |           |       |             |         |         |            |
| 2012                         | 225.1           | 122.3           | +102.8         | 184.1    | 222.9   | 115.0      | +107.9 | 193.8       | 116.8   | +67.5   | 157.8      |
| 2015                         | 225.4           | 123.8           | +101.6         | 182.1    | 223.6   | 117.3      | +106.3 | 190.6       | 120.4   | +104.8  | 187.0      |
| 2018                         | 226.1           | 126.9           | +99.2          | 178.2    | 224.1   | 118.9      | +105.2 | 188.5       | 122.0   | +103.4  | 184.8      |
| Liquid effluent               |                 |                 |                |         |         |           |       |             |         |         |            |
| 100 m³/ha +P₉₀ – when sowing |                 |                 |                |         |         |           |       |             |         |         |            |
| 2012                         | 163.5           | 115.0           | +48.5          | 142.5    | 161.8   | 109.3      | +52.5  | 148.5       | 110.3   | +7.5    | 106.8      |
| 2015                         | 164.2           | 117.8           | +46.4          | 139.4    | 162.6   | 111.3      | +51.3  | 146.2       | 112.6   | +51.0   | 145.3      |
| 2018                         | 164.4           | 119.4           | +45.0          | 137.7    | 163.0   | 113.7      | +49.3  | 143.5       | 115.2   | +48.7   | 143.3      |
| Table 2. Yield of barley grain with standard moisture content of 14% (kg/ha) depending on the fertilizer system and predecessors in the development of reclaimed lands retired from circulation. |
|---|
| **Experiment options (factor A)** | **Predecessors (factor B)** | **Spring rapeseed** | **Spring cereals** | **Winter cereals** |
| | | 2013 | 2016 | 2019 average | 2015 | 2016 | 2019 average | 2015 | 2016 | 2019 average |
| Control (no fertilizer) | | 11.3 | 11.6 | 12.2 | 11.7 | 10.4 | 10.7 | 10.8 | 10.8 |
| Mineral system +P<sub>10</sub> when sowing; N<sub>8</sub> when feeding | N<sub>2</sub>P<sub>2</sub>K<sub>2</sub> | 41.2 | 42.3 | 43.8 | 42.4 | 38.6 | 39.9 | 40.4 | 39.2 | 40.4 |
| Manure (tf) 40 t/ha + P<sub>10</sub> – when sowing N<sub>12</sub> – when feeding | 31.7 | 32.4 | 33.7 | 32.6 | 30.6 | 31.2 | 32.4 | 31.4 | 31.9 | 32.8 |
| Manure (tf) 60 t/ha + P<sub>10</sub> – when sowing N<sub>12</sub> – when feeding | 34.8 | 35.8 | 36.9 | 35.8 | 31.5 | 33.4 | 34.1 | 33.0 | 32.8 | 33.6 |
| Manure (tf) 80 t/ha + P<sub>10</sub> – when sowing N<sub>12</sub> – when feeding | 37.6 | 38.2 | 39.4 | 38.4 | 34.8 | 35.7 | 36.3 | 35.0 | 35.6 | 37.5 |
| Liquid effluent 100 t/ha + P<sub>10</sub> – when sowing N<sub>12</sub> – when feeding | 34.8 | 35.9 | 36.5 | 35.7 | 32.6 | 33.4 | 34.3 | 33.4 | 33.0 | 33.9 |
| Liquid effluent 120 t/ha + P<sub>10</sub> – when sowing N<sub>12</sub> – when feeding | 36.5 | 37.7 | 38.8 | 37.7 | 35.1 | 36.0 | 36.2 | 35.8 | 34.6 | 35.7 |
| Average | 32.6 | 33.4 | 34.5 | 33.5 | 30.9 | 31.8 | 32.2 | 31.6 | 31.0 | 31.9 |
| HCP<sub>AB</sub> for factor A | 1.9 | 1.9 | 2.0 | 1.9 |
| HCP<sub>AB</sub> for factor B | 2.0 | 1.9 | 1.9 | 1.9 |
| HCP<sub>AB</sub> for AB interaction | 2.8 | 2.9 | 3.0 | 2.9 |

Thus, although mineral fertilizers are the most effective factor in increasing grain yield, they do not provide a positive balance of the total nitrogen content in the soil, since the amount of stubble-root residues does not allow, after their mineralization, to balance the income and expense items of the balance.

The use of solid fraction of manure at a dose of 40 t/ha increased the yield of barley on average for all predecessors by 20.8 ... 21.2 centners/ha or by 78.6 ... 96.3%, with the introduction of 60 t/ha it increased the yield by 22.4 ... 24.1 centner/ha or by 106.0 ... 112%, at 80 t/ha - 25.0 ... 26.7 centner/ha or 128.2 ... 138.9%. When using liquid effluents of livestock complexes as organic fertilizers at a dose of 100 m<sup>3</sup>/ha, the increase in the yield of barley grain was 22.8 ... 24.0 c/ha or 105.1 ... 115.1% to the control, at 120 m<sup>3</sup>/ha increase in yield reached values of 24.9 ... 26.0 centners/ha or 122.2 ... 137.7%.

Our calculations show that the annual use of the solid fraction of manure and liquid effluents as the main fertilizer is advisable only in the first years of the development of unproductive lands, until their nitrogen regime is completely stabilized, since the energy consumption when introducing the solid fraction relative to the recommended dose of 40 t/ha increases during incorporation 60 t/ha by 13.6%
and amount to 41.0 GJ/ha, and at 80 t/ha - by 27.4% with energy consumption of 46.0 GJ/ha. However, the net energy income when applying high doses of solid fraction of manure as the main fertilizer increases much more slowly and amounts to 10.8% with an application of 60 t/ha and 11.3% with a dose of 80 t/ha. Given the high transportability of the solid fraction of manure, they should be applied to fields remote from the livestock complex, while it is economically feasible to dispose of liquid waste using the technology of hose systems at a distance of no more than 4 km from lagoons.

4. Conclusion
For the formation of the main and by-products without fertilization, barley crops use 61.6 ... 62.6% of soil nitrogen, which will ultimately cause a decrease in the natural fertility of soils, since the mineralization of humus reserves is not replenished due to stubble-root residues.

The mineral system of fertilizers does not compensate for the loss of easily hydrolysable nitrogen against the background of the studied previous crops. Nitrogen deficiency for eight years of experiments was approximately the same for all predecessors and in relative terms decreased by 0.9 - 1.3%. The mineral fertilizer system provided the maximum increase in grain yield relative to the control option (+30.7 c/ha or 262%), however, it does not create a positive balance of the total nitrogen content in the soil, since the amount of stubble-root residues does not allow, after their mineralization, to balance the input and account balance sheet.

During the cultivation of spring barley on the organomineral system with the introduction of 40, 60 and 80 t/ha of manure solid fraction, a positive nitrogen balance was noted against the background of all predecessors, the nitrogen balance intensity was 114.9 ... 132.7%, respectively; 138.9 ... 163.9 and 157.8 ... 193.8%. The use of liquid effluents from livestock complexes at a dose of 100 and 120 m3/ha also provides an expanded reproduction of fertility of unproductive lands, in both cases a positive nitrogen balance and a high balance intensity were noted, respectively 106.8 ... 148.0 and 109.7 ... 158.3% %. Among the precursors studied, the greatest influence on the accumulation of easily hydrolysable nitrogen and the balance of total nitrogen during the application of organic fertilizers is provided by spring rapeseed, against the background of which a significant increase in the content of easily hydrolysable nitrogen was noted relative to the initial value and the yield of barley was obtained, which on average over the years of research was 32.6 ... 38.4 c/ha versus 31.4 ... 35.8 after spring cereals and 32.0 ... 36.6 c/ha after winter cereals.

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