Eco logical and agrochemical bases of the nitrogen regime of typical chernozem depending on agrotechnical methods

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Abstract. In the environment of the southwestern part of the Central Black Earth Region (Central Chernozem) of the Russian Federation, an increase in the content of alkali-hydrolyzable and nitrate nitrogen, as well as an increase in the soil nitrification capacity in typical chernozem, is mainly due to increasing doses of mineral fertilizers, manure aftereffects, the use of perennial grasses in crop rotation as precursors of winter wheat, and for the most part, plowing in the main tillage system. The most noticeable variation in the content of alkali-hydrolysable nitrogen in the soil is 20-50 cm in soil, and soil nitrification capacity in the 0-20 cm layer. Nitrate nitrogen is characterized by the most significant increase in its content in the soil layer 0-20 cm with a combination of mineral fertilizers and manure, especially by plowing. The tendency to increase the nitrate content in the underlying layers is due to the use of an overdose of mineral fertilizer for winter wheat - N₁₂₀P₁₂₀K₁₂₀ + N₆₀ (saturation of 1 ha of the crop rotational area in the grass-growing crop rotation N₆₀P₁₂₀K₁₂₀ and in the grain-growing crop rotation N₁₂₀P₁₂₀K₁₂₀) and due to the aftereffects for the fourth year 40 and 80 t/ha of manure (saturation 8 and 16 t/ha). In the grain grass crop rotation, this is common in all studied soil layers — 0-20, 20-50 and 50-100 cm, and in grain cultivation crop rotation, only the 0-20 and 20-50 cm layers.

Nitrogen is one of the main plant nutrients. It plays an important role in the formation of humus substances [1, 2]. Nitrogen accumulation in soil is a characteristic of soil formation, and the total nitrogen reserves determine its potential fertility [3, 4, 5]. In this regard, the analysis of the content of various forms of nitrogen is necessary both for understanding the processes occurring in the soil, and for developing practical measures aimed at optimizing the nitrogen regime in agro-ecosystems [6, 7, 8].

Studies were conducted in 2012-2014 on the basis of a soil fertility laboratory and monitoring in a stationary field experiment, conducted in 1987 at the Belgorod Research Institute of Agriculture, located in the south-western part of the Central Black Earth region. The soil of the experimental area is a typical chernozem - medium-thick, low-humus, heavy-loamy on loess soil containing, on the experiment plots, 5.1 - 5.6% of humus in the topsoil, 4.8 – 5.7 mg of labile phosphorus to 100 g of soil, 9.2-12.1 mg of exchangeable potassium to 100 g of soil, pH₄.₅ 5.8-6.4 [9, 10].

Studies carried out at the end of the fifth rotation of 5-field crop rotations in 2012-2014 did not reveal a noticeable variation in the content of alkali-hydrolyzable nitrogen in the chernozem typical under the influence of increasing doses of mineral fertilizers N₆₀P₆₀K₆₀ + N₃₀ and N₁₂₀P₁₂₀K₁₂₀ + N₆₀ in the 0-20 cm soil layer in cultivation of winter wheat as in the grain grass cultivating crop rotation (preceding crop...
– esparcet in the second year), and in the grain cultivating crop rotation (preceding crop - peas) in the case when the main tillage was carried out with a plow to a depth of 20-22 cm (table 1).

In the soil layer of 20-50 cm, there is a tendency to increase its content in the grain grass crop rotation (ZTP) from 109 to 115 and 118 mg/kg respectively, and in the grain cultivation crop rotation (ZP) from 121 to 122 and 127 mg/kg. Against the manure aftereffects, the impact of the dose N_{120}P_{120}K_{120} + N_{60} is more occurred. The manure aftereffects in the fourth year at doses of 40 and 80 t/ha (saturation of 1 ha of the crop rotation area, respectively, 8 and 16 tons) occurred only in the soil layer of 20-50 cm without variation depending on its doses.

**Table 1.** Changes in the content of alkaline hydrolyzed nitrogen in the black soil typical under winter wheat at the end of the 5th rotation of crop rotations under the influence of fertilizers, soil treatment methods and types of crop rotations, mg / kg (2012-2014).

| Saturation of 1 ha of crop rotation area manure, t | mineral fertilizers, kg | NPK for winter wheat | Crop rotations | 2014 |
|------------------------------------------------|-------------------------|----------------------|---------------|------|
| 0                                              | NPK*                    | \(N_{60}P_{60}K_{60}+N_{30}\) | 145 109 140 121 |
| 0                                              | 2 NPK                   | \(N_{120}P_{120}K_{120}+N_{60}\) | 136 118 142 127 |
| 8                                              | NPK                     | \(N_{60}P_{60}K_{60}+N_{30}\) | 145 120 140 126 |
| 8                                              | 2 NPK                   | \(N_{120}P_{120}K_{120}+N_{60}\) | 155 128 148 136 |
| 16                                             | NPK                     | \(N_{60}P_{60}K_{60}+N_{30}\) | 141 116 141 127 |
| 16                                             | 2 NPK                   | \(N_{120}P_{120}K_{120}+N_{60}\) | 150 133 146 137 |

| Note: * The dose of NPK: grass-grain (ZTP) crop rotation - \(N_{42}P_{62}K_{62}\), grain (ZP) crop rotation - \(N_{60}P_{62}K_{62}\). |

When conducting minimal tillage, the content of this form of nitrogen without the use of fertilizers is noticeably lower in both soil layers and types of crop rotations than when plowing the soil. Of mineral fertilizers, only the dose of \(N_{60}P_{60}K_{60} + N_{30}\) is effective. Against the manure, an increase in its content was observed depending on increasing doses of mineral fertilizers. Moreover, with the excess content in the ZTP compared with the ZP. The dependence of the alkali-hydrolyzable nitrogen content on the studied methods in the ZTP is described by the regression equation for the soil layer 0-20 cm: \(y = 144.74 - 0.34x_1 + 0.05x_2 + 1.35x_3\) with \(r = 0.6563\), for the layer 20-50 cm: \(y = 100.88 + 0.27x_1 + 0.21x_2 + 1.75x_3\) with \(r = 0.9198\); for salary, respectively: \(y = 130.87 + 0.24x_1 + 0.05x_2 + 1.10x_3\) with \(r = 0.7434\) and \(y = 98.25 + 1.03x_1 + 0.14x_2 + 1.19x_3\) with \(r = 0.9077\), where \(y\) is the content of hydrolyzable nitrogen in
typical chernozem, mg/kg, $x_1$ - depth of the arable layer with the main method of processing, cm, $x_2$ - the dose of cattle manure, t/ha, $x_3$ - the dose of mineral fertilizers in the main application, c/ha (total amount of batteries, active ingredient).

**Table 2.** Change in the nitrification capacity of typical chernozem for winter wheat when the $5^{th}$ rotation of crop rotations is carried out under the influence of fertilizers, soil treatment methods and types of crop rotations, N – NO$_3$ after composting, mg/kg (2012-2014).

| Saturation of 1 ha of crop rotation area | NPK for winter wheat | Crop rotations | soil layers, cm |
|----------------------------------------|----------------------|----------------|----------------|
| manure, t                              |                      |                | 0-20  | 20-50  | 0-20 | 20-50 |
|                                        |                      |                | Tillage |        |      |      |
|                                        |                      |                | 0      |        |      |      |
|                                        |                      |                | NPK*   | 0      | 32.4 | 19.5 | 38.4 | 17.1 |
|                                        |                      |                | N$_{60}$P$_{60}$K$_{60}$+ N$_{30}$ | 46.3 | 27.5 | 52.0 | 33.3 |
|                                        |                      |                | 2 NPK  | 0      | 49.7 | 30.3 | 55.9 | 36.3 |
|                                        |                      |                | N$_{120}$P$_{120}$K$_{120}$+ N$_{60}$ | 43.7 | 28.8 | 43.1 | 26.8 |
|                                        |                      |                | 0      | 50.7   | 31.6 | 42.8 | 26.1 |
|                                        |                      |                | N$_{60}$P$_{60}$K$_{60}$+ N$_{30}$ | 55.9 | 48.3 | 57.3 | 29.9 |
|                                        |                      |                | 2 NPK  | 0      | 45.5 | 34.1 | 41.9 | 23.2 |
|                                        |                      |                | N$_{120}$P$_{120}$K$_{120}$+ N$_{60}$ | 45.4 | 34.2 | 50.3 | 23.7 |
|                                        |                      |                | 8      |        |      |      |      |      |
|                                        |                      |                | NPK    | 0      | 41.1 | 24.5 | 37.3 | 21.5 |
|                                        |                      |                | N$_{60}$P$_{60}$K$_{60}$+ N$_{30}$ | 41.1 | 23.1 | 45.2 | 24.7 |
|                                        |                      |                | 2 NPK  | 0      | 43.4 | 38.4 | 53.3 | 38.9 |
|                                        |                      |                | N$_{120}$P$_{120}$K$_{120}$+ N$_{60}$ | 41.5 | 26.1 | 42.3 | 36.1 |
|                                        |                      |                | 0      | 47.1   | 33.0 | 48.9 | 35.5 |
|                                        |                      |                | N$_{60}$P$_{60}$K$_{60}$+ N$_{30}$ | 57.7 | 45.3 | 51.8 | 34.9 |
|                                        |                      |                | 2 NPK  | 0      | 41.8 | 30.1 | 42.7 | 29.5 |
|                                        |                      |                | N$_{120}$P$_{120}$K$_{120}$+ N$_{60}$ | 50.5 | 41.8 | 43.7 | 35.3 |
|                                        |                      |                | 8      |        |      |      |      |      |
|                                        |                      |                | NPK    | 0      | 47.0 | 42.8 | 51.4 | 35.7 |
|                                        |                      |                | N$_{60}$P$_{60}$K$_{60}$+ N$_{30}$ | 47.0 | 42.8 | 51.4 | 35.7 |
|                                        |                      |                | 16     |        |      |      |      |      |
|                                        |                      |                | N$_{120}$P$_{120}$K$_{120}$+ N$_{60}$ | 47.0 | 42.8 | 51.4 | 35.7 |

Note: * The dose of NPK: grass-grain (ZTP) crop rotation - N$_{42}$P$_{62}$K$_{62}$, grain (ZP) crop rotation - N$_{60}$P$_{60}$K$_{60}$.

The greatest increase in the intensity of the nitrification capacity of chernozem typical for tillage depending on the use of mineral fertilizers was observed when they were applied in a dose of N$_{60}$P$_{60}$K$_{60}$ + N$_{30}$, which is common for both crop rotations and soil layers (table 2). Applying a dose of N$_{120}$P$_{120}$K$_{120}$ + N$_{60}$ against the manure aftereffects, especially 80 t/ha (saturation 16 t/ha), is more preferable in increasing the nitrification capacity of the soil, especially when placing winter wheat over perennial grasses. Only the manure aftereffect caused its strengthening, but without variation due to its different doses.
Table 3. Changes in the content of nitrate nitrogen in the of typical chernozem for winter wheat when the 5th rotation of crop rotations is carried out under the influence of fertilizers, soil treatment methods and types of crop rotations, N – NO₃ after composting, mg/kg (2012-2014).

| Saturation of 1 ha of crop rotation area | NPK for winter wheat | Crop rotations | soil layers, cm | grain | grain-grass |
|----------------------------------------|----------------------|---------------|-----------------|-------|------------|
| manure, t                               | kg                   |               | 0-20           | 20-50 | 50-100     |
| 0                                      | 0                    | NPK*          | N₆₀P₆₀K₆₀+ N₃₀ | 16.3  | 9.8        | 6.2  | 8.5  | 9.7 | 4.2 |
| 2 NPK                                  | N₁₂₀P₁₂₀K₁₂₀+ N₆₀   | 24.5          | 7.4            | 7.6   | 16.1       | 7.0  | 6.4  |
| 8                                      | 0                    | NPK*          | N₆₀P₆₀K₆₀+ N₃₀ | 13.1  | 18.5       | 7.1  | 9.4  | 6.9 | 4.5 |
| 2 NPK                                  | N₁₂₀P₁₂₀K₁₂₀+ N₆₀   | 14.0          | 15.3           | 10.6  | 11.2       | 15.4 | 5.2  |
| 16                                     | 0                    | NPK           | N₆₀P₆₀K₆₀+ N₃₀ | 15.2  | 6.5        | 8.0  | 10.6 | 8.9 | 4.8 |
| 2 NPK                                  | N₁₂₀P₁₂₀K₁₂₀+ N₆₀   | 34.9          | 19.0           | 13.6  | 27.0       | 17.3 | 4.0  |
| Minimal processing                     |                      |               |                 |       |            |      |      |      |      |
| 0                                      | 0                    | NPK           | N₆₀P₆₀K₆₀+ N₃₀ | 8.6   | 17.9       | 3.5  | 11.2 | 11.4 | 5.1 |
| 2 NPK                                  | N₁₂₀P₁₂₀K₁₂₀+ N₆₀   | 11.5          | 9.6            | 4.2   | 11.6       | 7.0  | 7.3  |
| 8                                      | 0                    | NPK           | N₆₀P₆₀K₆₀+ N₃₀ | 8.4   | 9.3        | 4.6  | 9.9  | 6.1  | 5.0 |
| 2 NPK                                  | N₁₂₀P₁₂₀K₁₂₀+ N₆₀   | 29.8          | 19.9           | 6.2   | 15.3       | 12.4 | 6.0  |
| 16                                     | 0                    | NPK           | N₆₀P₆₀K₆₀+ N₃₀ | 8.7   | 5.9        | 5.7  | 7.4  | 7.0  | 5.0 |
| 2 NPK                                  | N₁₂₀P₁₂₀K₁₂₀+ N₆₀   | 14.5          | 15.2           | 8.2   | 15.1       | 19.2 | 4.7  |

Note: * The dose of NPK: grass-grain (ZTP) crop rotation - N₆₀P₆₀K₆₀, grain (ZP) crop rotation - N₆₀P₆₀K₆₀.

For minimal tillage, the effect of mineral fertilizers in the ZTP was occurred only in the soil layer of 20-50 cm when applied in a dose of N₁₂₀P₁₂₀K₁₂₀ + N₆₀, and in the ZP, its increase is accompanied by an increase in doses. Strengthening the nitrification capacity of the soil against the manure aftereffects is most noticeable in both soil layers in the ZTP, where 40 t/ha of manure are applied (saturation 8 t/ha). In ZP, its increase against the manure aftereffects under the influence of doses of mineral fertilizers is less occurred. The dependence of the soil nitrification capacity on agro-technical techniques, expressed in the N – NO₃ content after composting, in the ZTP is described by the regression equation for the soil layer 0-20 cm: y = 31.5 + 0.3x₁ + 0.1x₂ + 1.8x₃ with r = 0.7890, for layer 20 - 50 cm: y = 36.5 + 0.2x₁ + 0.1x₂ + 1.7x₃ with r = 0.6009; in the ZP, respectively: y = 4.2 + 1.0x₁ + 0.1x₂ + 1.5x₃ with r = 0.7855 and y = 14.1 + 0.6x₁ + 0.1x₂ + 1.5x₃ with r = 0.6530, where y is the content of N-NO₃ after composting in
chernozem typical, mg/kg, \( x_1 \) - depth of the treated layer with the main method of treatment, cm, \( x_2 \) - dose of cattle manure, t/ha, \( x_3 \) - dose of mineral fertilizers in the main application, c/ha.

The content of nitrate nitrogen in the soil, as its most mobile form, is one of the most important indicators for providing plants with this fertilizer element. Despite the high mobility of nitrates in the soil, we didn’t practically detect changes in their content under the influence of mineral fertilizers in the soil layer of 20-50 cm and a weak tendency for their growth in the layer of 50-100 cm when using tillage as the main cultivation method in both crop rotations (table 3). In the 0-20 cm layer, an increase in their content was observed under the action of increasing doses of \( N_{30}P_{60}K_{20} + N_{30} \) and \( N_{120}P_{120}K_{120} + N_{60} \) from 6.1 to respectively 16.3 and 24.5 mg/kg in an ZTP and from 7.7 to 8.5 and 16.1 mg/kg in an ZP. A more significant increase - up to 34.9 mg/kg in the ZTP and up to 27.0 mg/kg in the ZP, also common for this soil layer, is due to the addition of \( N_{120}P_{120}K_{120} + N_{60} \) against the aftereffects of 80 t/ha of manure (saturation 16 t/ha). In the underlying layers - 20-50 and 50-100 cm against the manure aftereffects in the ZTP also increased the content of nitrates with increasing doses of mineral fertilizers, and in the ZP - only in the layer of 20-50 cm. The manure aftereffects appeared only in a dose of 80 t/ha and then in the soil layer 0-20 cm.

The increase in nitrate content in terms of minimum tillage from mineral fertilizers is less than in tilling - from 6.7-7.7 to 11.5-11.6 mg/kg in a layer of 0-20 cm when applying \( N_{120}P_{120}K_{120} + N_{60} \) and from 3.5-6.0 to 11.4-17.9 mg/kg in a layer of 20-50 cm when making \( N_{60}P_{60}K_{60} + N_{30} \) in both crop rotations. In the layer of 50-100 cm at a low level of their content, there is a tendency to increase - from 2.8 to 4.2-7.3 mg/kg. Against the manure aftereffect, the impact of mineral fertilizers is practically repeated when they are used without manure. With this method of treatment, the manure aftereffects in combination with \( N_{120}P_{120}K_{120} + N_{60} \) contributed to the most noticeable increase in the nitrate content in the soil layer of 20-50 cm. + 0.44\(x_1\) + 0.04\(x_2\) + 1.63\(x_3\) with \( r = 0.7227 \), for a layer of 20-52 cm: \( y = 7.59 - 0.06\(x_1\) + 0.01\(x_2\) + 1.03\(x_3\) with \( r = 0.6323 \), for a layer of 50-100 cm: \( y = -1.48 + 0.25\(x_1\) + 0.02\(x_2\) + 0.69\(x_3\) with \( r = 0.8874 \); and in the ZPR, respectively: \( y = 3.42 + 0.17\(x_1\) + 0.04\(x_2\) + 1.04\(x_3\) with \( r = 0.7448 \), \( y = 3.03 + 0.06\(x_1\) + 0.04\(x_2\) + 0.95\(x_3\) with \( r = 0.7417 \), \( y = 4.60 - 0.06\(x_1\) + 0.01\(x_2\) + 0.23\(x_3\) with \( r = 0.6323 \), where, \( y \) is the content of nitrate nitrogen in typical chernozem, mg/kg, \( x_1 \) is the depth of the treated layer with the main treatment method, cm, \( x_2 \) is the dose of cattle manure, t/ha, \( x_3 \) is the dose of mineral fertilizers in main application, kg/ha.

Thus, in the southwestern part of the Central Chernozem Region of the Russian Federation, an increase in the content of alkali-hydrolysable and nitrate nitrogen, as well as an increase in soil nitrification capacity in typical chernozem, is mainly due to increasing doses of mineral fertilizers, the manure aftereffects, and the use of perennial grasses in crop rotation as precursors of winter wheat, and using, for the most part, tilling in the main tillage system. The most noticeable variation in the content of alkali-hydrolysable nitrogen in the soil is 20-50 cm in soil, and soil nitrification capacity in the 0-20 cm layer. Nitrate nitrogen is characterized by the most significant increase in its content in the soil layer 0-20 cm with a combination of mineral fertilizers and manure, especially by tilling. The tendency to increase the nitrate content in the underlying layers is due to the use of an overdose of mineral fertilizer for winter wheat - \( N_{120}P_{120}K_{120} + N_{60} \) (saturation of 1 ha of the crop rotational area in the grass-growing crop rotation \( N_{60}P_{124}K_{124} \) and in the grain-growing crop rotation \( N_{120}P_{124}K_{124} \) and due to the aftereffects for the fourth year 40 and 80 t/ha of manure (saturation 8 and 16 t/ha). In the grain grass crop rotation, this is common in all studied soil layers — 0–20, 20–50 and 50–100 cm, and in grain cultivation crop rotation, only the 0–20 and 20–50 cm layers.

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