**The Content of Nutritional Elements in Gray Forest Soil and Spring Wheat Yield in Relation to the Aftereffect of Lime and Mineral Fertilizers in an Alternating Crop Rotation**

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**Abstract.** We present the results of studies of the content of nutrients in gray forest soil and spring wheat grain yields for three years of the fifth rotation (2017–2019) in the alternating crop rotation: corn, barley and clover, clover, wheat, in the conditions of Baikal region. The soil of the experimental site is gray forest heavy loamy. The predecessor was clover green manure, and we did not use any mineral fertilizers. The results of the experiment demonstrated that aftereffects of nitrogen-potassium and complete fertilizer of the 2nd year contributed to an increase in nitrate nitrogen content on the non-limed background by 8–12% and on the background with liming aftereffect – by 13–19%; aftereffect of phosphate fertilizer in double and triple combination on two backgrounds increased the amount of mobile phosphorus by 8–15 and 7–10% respectively. As a result of liming aftereffects, the amount of N-NO₃ and P₂O₅ increased by 18 and 2% on average. The content of mobile potassium in the soil did not depend on aftereffects of mineral fertilizers and liming. On average, during the years of research, aftereffects of mineral fertilizers increased the yield of wheat grain by 0.18–0.35 t/ha (7–13%), aftereffects of liming – by 0.17–0.27 t/ha, and joint use of fertilizers and lime – by 0.20–0.45 t/ha (7–16%). Maximum harvest yield of wheat, 3.34 t/ha, was achieved in the variant with aftereffects of N₃₀P₃₀K₃₀ on the limed background.

1. **Introduction**

In order to address food security around the world and to provide people with locally produced goods, it is important to increase crop yields while maintaining soil fertility [1-5]. The availability of nutrients to plants is one of the key indicators of effective soil fertility [6-7].

One of the significant factors of soil fertility, productivity of arable land, and effectiveness of fertilizers is the acidity of soils. Acid soils are one of the main limiting factors for producing consistently high, environmentally friendly, and biologically full crop yields [8-10]. Chemical reclamation is a technique that significantly improves the nutritional regime of soils. The element ranked second in importance, phosphorus, which, along with other elements of mineral nutrition, is responsible for growth and development of plants, is an important criterion in this case. The accessibility of phosphorus for plants differs: in acid soils it sharply drops due to it binding with free aluminum or being included in ferrous concretions [11]. At present, there is no consensus on the impact of liming on the content of available nutrients [12].
Studies conducted in crop rotation during 2009–2018 have shown the effectiveness of lime and mineral fertilizers on the soil supply of mobile nitrogen and phosphorus [13]. The influence of aftereffects of lime and mineral fertilizers on the nutrient content of grey forest soil has not been studied before.

The goal of this research is to study the aftereffects of lime and mineral fertilizers on the nutrient content of grey forest soil and yields of spring wheat in the crop rotation.

2. Materials and methods

The research was carried out on the experimental field of the Irkutsk RIA in the alternating crop rotation: corn, barley and clover, clover, wheat during 2017–2019. The object of the study was the *Buryatskaya ostistaya* spring wheat variety. Starting characteristics of the soil were: gray forest acid heavy loamy, with humus content of 3.7...4.0%; total nitrogen – 0.25%; pH (exchangeable acidity) – 3.9...4.4; Hr – 10.1...11.9 mg equivalent/100 g of soil, base saturation degree 68.4...72.1%, mobile phosphorus content (by Kirsanov) – 100...120, mobile potassium – 80...100 mg/kg of soil. The scheme of two-factor experiment had the following variants: for liming – no liming, lime by 0.5 hydrolytic acidity (5.7 t/ha); fertilizer – no fertilizer, NP, PK, NK, NPK.

As an ameliorator we have used limestone flour with CaSO₃ content of 85%, which was applied at the rate of 0.5 hydrolytic acidity (5.7 t/ha) under corn (*Katerina SV* hybrid) once every 4 years.

Late spring wheat variety *Buryatskaya ostistaya* was sown on clover green manure, without application of mineral fertilizers, after early-spring harrowing, followed by rolling on May 12–15; seeding rate was 7 million grains per hectare. Sowing was done using the SNP-1.6 sower. Care of crops included post-planting rolling, and if necessary, treatment with herbicides and insecticides. Per-field harvesting was done with the direct combine "Sampo-500." The area of the cultivated field was 122.5 m², the accounting one – 80.5 m². The experiment was repeated four times, the layout of fields is one-row, consequent.

Analytical studies of the soil were conducted in the agrochemical laboratory of the FSBSI "Irkutsk RIA" according to the GOST 26483-85 Soils. Preparation of salt extract and determination of its pH by CINAO method [14]; GOST 26951-86 Soils. Determination of nitrates by ionometric method [15]; GOST R 54650-2011 Soils. Determination of mobile phosphorus and potassium compounds by Kirsanov method modified by CINAO [16].

Statistical processing of the experimental results was carried out using Snedekor applied software package [17].

3. Research results

Meteorological conditions during the years of research differed from the long-term average. According to the weather post of the Irkutsk RIA in Pivovarikha, precipitation during the growing periods of 2017–2019 was less than the long-term average by 68.6 mm (20%), 69.5 mm (20%) and 51.4 mm (15%) respectively. Lack of precipitation was 79% in June of 2017, 47 and 57% in May and June of 2018, and 73% in May of 2019.

By the temperature regime, the growing seasons of 2017–2019 were hot: the average daily air temperature was 15.0, 15.3 and 14.9 °C, with the long-term average being 12.5 °C. Overall, the agroclimatic conditions of 2017–2019 were unfavorable for growth and development of spring wheat.

Systematic use of lime at a dose of 0.5 hydrolytic acidity (5.7 ton/ha) once in the crop rotation contributed to the improvement of agrochemical indicators of grey forest soil [18]. During 18 years, there has been a significant reduction in the degree of acidity on the non-limed background by 0.8 units of pH, and on the limed background – by 1.6 units of pH. We associate this with the positive effect of clover green manure [19], as green manure slightly reduces acidity of soils [20, 21].

The aftereffects of liming of the 3rd year and mineral fertilizer of the 2nd year on the content of nutrients in grey forest soil were studied on spring wheat crops in the fifth rotation of alternating crop rotation (2017–2019). Studies have shown that on average for 3 years, the content of nitrate nitrogen under wheat crops was at the average level. Aftereffect of liming provided a reliable increase in nitrate nitrogen content by an average of 2.2 mg/kg of soil (18%) compared to the non-limed background.
The largest increase in this indicator was observed in the variant with aftereffect of full mineral fertilizer (N₃₀P₃₀K₃₀), by 2.9 mg/kg of soil or by 22%, in the second place was the variant with aftereffect of nitrogen-potassium fertilizer, in the third – with aftereffect of nitrogen-phosphorus fertilizer (table 1).

On the non-limed background, nitrogen-potassium fertilizer aftereffect increased the amount of nitrate nitrogen by 1.0 mg/kg of soil (8%), complex fertilizer aftereffect – by 1.4 mg/kg of soil (12%) and aftereffects of these same variants on limed background ensured an increase of 1.8 mg/kg of soil (13%) and of 2.6 mg/kg of soil (19%) respectively. On both backgrounds, the increase in nitrate nitrogen content was the highest in the variants with the aftereffect of full mineral fertilizer. The aftereffect of nitrogen-phosphorus fertilizer increased the quantity of N₂O₃ by an insignificant amount both on non-limed background and with the aftereffect of liming. The phosphorus-potassium fertilizer did not influence the amount of nitrate nitrogen on both backgrounds.

Table 1. The nitrate nitrogen content in the arable layer of soil on average by sampling period, depending on the aftereffects of lime and mineral fertilizers, mg/kg.

| Aftereffect | Year | 3-year average | Difference |
|-------------|------|----------------|------------|
| Lime | Fertilizer | 2017 | 2018 | 2019 | Average | Lime | Fertilizer |
| No lime | No fertilizer | 16.0 | 12.0 | 7.5 | 11.8 | - | - |
| | N₃₀P₃₀ | 15.8 | 12.3 | 7.9 | 12.0 | - | 0.2 |
| | P₃₀K₃₀ | 13.5 | 12.6 | 7.5 | 11.2 | - | -0.6 |
| | N₃₀K₃₀ | 16.8 | 13.6 | 8.0 | 12.8 | - | 1.0 |
| | N₃₀P₃₀K₃₀ | 15.0 | 15.9 | 8.6 | 13.2 | - | 1.4 |
| Average | 15.4 | 13.3 | 7.9 | 12.2 | - | - |
| Lime | No fertilizer | 16.9 | 14.0 | 9.5 | 13.5 | 1.7 | - |
| | N₃₀P₃₀ | 14.9 | 16.2 | 11.2 | 14.1 | 1.9 | 0.6 |
| | P₃₀K₃₀ | 14.4 | 15.4 | 9.1 | 13.0 | 1.8 | -0.5 |
| | N₃₀K₃₀ | 15.9 | 16.9 | 13.0 | 15.3 | 2.5 | 1.8 |
| | N₃₀P₃₀K₃₀ | 16.0 | 16.8 | 15.5 | 16.1 | 2.9 | 2.6 |
| Average | 15.6 | 15.9 | 11.7 | 14.4 | 2.2 | - |
| Average | No fertilizer | 16.5 | 13.0 | 8.5 | 12.7 | - | - |
| | N₃₀P₃₀ | 15.1 | 14.3 | 9.6 | 13.1 | - | 0.4 |
| | P₃₀K₃₀ | 14.2 | 14.0 | 8.3 | 12.1 | - | -0.6 |
| | N₃₀K₃₀ | 16.4 | 15.3 | 10.5 | 14.0 | - | 1.3 |
| | N₃₀P₃₀K₃₀ | 15.5 | 16.4 | 12.1 | 14.6 | - | 1.9 |
| Average | 15.5 | 14.6 | 9.8 | 13.3 | - | - |

Least Significant Difference: total – 0.3; LSD₀.₀₅ lime – 0.6; LSD₀.₀₅ fertilizer – 0.9

The content of mobile phosphorus in the soil was classified as above average and higher (table 2). Aftereffects of liming on average over 3 years contributed to an increase in the amount of P₂O₅ by 4.6–5.8 mg/kg of soil (4–5%) in the unfertilized variant and in one with aftereffect of N₃₀P₃₀. The aftereffect of phosphorus fertilizers had a more significant impact on this indicator. Thus, aftereffects of phosphorus fertilizers in double and triple combination increased the amount of mobile phosphorus by 8.9–16.1 mg/kg (8–15%) on the non-limed background, and by 8.0–10.8 mg/kg (7–10%) on the background of lime aftereffect. The aftereffect of nitrogen-phosphorus fertilizer on the background of aftereffect of lime did not influence the content of P₂O₅ in the soil.
The availability of mobile potassium in gray forest soil during the years of our research was low, its average was 62.8–76.6 mg/kg (table 3). The content of mobile K$_2$O$_3$ did not depend on the aftereffects of fertilizers and lime.

### Table 2. The content of mobile phosphorus in the arable layer of soil on average by sampling period, depending on the aftereffects of lime and mineral fertilizers, mg/kg.

| Aftereffect | Lime (Factor A) | Fertilizer (Factor B) | Year | 3-year average | Difference |
|-------------|-----------------|-----------------------|------|---------------|------------|
| No lime     | No fertilizer   | 2017                  | 2018 | 2019          |            |
|             |                 | 94.8                  | 106.0| 117.0         | 105.9      |
|             |                 | N$_{99}$P$_{30}$      | 103.0| 115.1         | 126.3      |
|             |                 | P$_{99}$K$_{30}$      | 106.3| 119.1         | 130.0      |
|             |                 | N$_{99}$K$_{30}$      | 103.5| 114.9         | 120.0      |
|             |                 | N$_{99}$P$_{30}$K$_{30}$ | 113.3| 120.5         | 131.2      |
|             | Average         | 104.2                 | 115.1| 124.9         | 114.8      |
| Lime        | No fertilizer   | 95.8                  | 116.3| 122.0         | 111.4      |
|             |                 | N$_{99}$P$_{30}$      | 98.8 | 132.5         | 127.0      |
|             |                 | P$_{99}$K$_{30}$      | 108.0| 125.0         | 124.0      |
|             |                 | N$_{99}$K$_{30}$      | 102.3| 117.5         | 122.3      |
|             |                 | N$_{99}$P$_{30}$K$_{30}$ | 103.3| 129.8         | 133.5      |
|             | Average         | 101.6                 | 124.2| 125.8         | 117.2      |

Least Significant Difference$_{total}$ = 1.9; LSD$_{0.05}$ lime = 3.4; LSD$_{0.05}$ fertilizer = 5.4

### Table 3. The content of mobile potassium in the arable layer of soil on average by sampling period, depending on the aftereffects of lime and mineral fertilizers, mg/kg.

| Aftereffect | Lime (Factor A) | Fertilizer (Factor B) | Year | 3-year average | Difference |
|-------------|-----------------|-----------------------|------|---------------|------------|
| No lime     | No fertilizer   | 2017                  | 2018 | 2019          |            |
|             |                 | 74.8                  | 68.3 | 71.0          | 71.3       |
|             |                 | N$_{99}$P$_{30}$      | 77.0 | 65.3          | 66.8       |
|             |                 | P$_{99}$K$_{30}$      | 78.0 | 69.8          | 64.8       |
|             |                 | N$_{99}$K$_{30}$      | 74.8 | 72.5          | 71.8       |
|             |                 | N$_{99}$P$_{30}$K$_{30}$ | 82.3| 71.0          | 76.5       |
|             | Average         | 77.4                  | 69.4 | 70.2          | 72.3       |
| Lime        | No fertilizer   | 66.8                  | 68.5 | 68.3          | 67.8       |
|             |                 | N$_{99}$P$_{30}$      | 58.0 | 65.5          | 64.8       |
|             |                 | P$_{99}$K$_{30}$      | 63.8 | 73.5          | 76.0       |
|             |                 | N$_{99}$K$_{30}$      | 57.3 | 70.8          | 78.8       |
|             |                 | N$_{99}$P$_{30}$K$_{30}$ | 60.8| 73.3          | 77.3       |
|             | Average         | 61.3                  | 70.3 | 73.0          | 68.2       |
| Average     | No fertilizer   | 70.8                  | 68.4 | 69.6          | 69.6       |
|             |                 | N$_{99}$P$_{30}$      | 67.5 | 65.4          | 65.8       |
|             |                 | P$_{99}$K$_{30}$      | 70.9 | 71.6          | 70.4       |
|             |                 | N$_{99}$K$_{30}$      | 66.0 | 71.6          | 75.3       |
|             |                 | N$_{99}$P$_{30}$K$_{30}$ | 71.5| 72.1          | 76.9       |
|             | Average         | 69.3                  | 69.8 | 71.6          | 70.2       |

Least Significant Difference$_{total}$ = 1.9; LSD$_{0.05}$ lime = 3.5; LSD$_{0.05}$ fertilizer = 5.6
On average for 2017–2019, the yield of spring wheat on the non-limed background depending on the variant of the experiment was 2.72–3.07 t/ha, and on the background with aftereffects of liming – 2.89–3.34 t/ha, and was the highest in the variant with the aftereffect of N$_{30}$P$_{30}$K$_{30}$ (table 4).

Table 4. Yield of spring wheat grain depending on the aftereffects of mineral fertilizers and lime on average for 2017–2019, t/ha.

| Variant          | Yields, t/ha | Increase from the effects of fertilizer | from the aftereffect of liming |
|------------------|--------------|----------------------------------------|-------------------------------|
|                  | non-limed background, aftereffect of liming, 0.5 h.a. | average | non-limed background, aftereffect of liming, 0.5 h.a. | 0.17 |
| No fertilizer    | 2.72         | 2.89                                   | 2.81                          | - |
| N$_{30}$P$_{30}$ | 2.90         | 3.09                                   | 3.00                          | 0.18 |
| P$_{30}$K$_{30}$ | 2.87         | 3.18                                   | 3.03                          | 0.15 |
| N$_{30}$K$_{30}$ | 2.93         | 3.19                                   | 3.06                          | 0.21 |
| N$_{30}$P$_{30}$K$_{30}$ | 3.07 | 3.34 | 3.21 | 0.35 |
| Average          | 2.90         | 3.14                                   | 3.02                          | - |

Least Significant Difference ($0.05$ total) $= 0.04$; LSD$_{0.05}$ lime $= 0.07$; LSD$_{0.05}$ fertilizer $= 0.11$

Aftereffect of mineral fertilizers increased the yield of wheat grain on the non-limed background by 0.18–0.35 t/ha (7–13%), on the background of liming aftereffect – by 0.20–0.45 t/ha (7–16%). The lowest yield was obtained in the variant with aftereffect of phosphorus-potassium fertilizers on the non-limed background and in the variant with the aftereffect of nitrogen-phosphorus fertilizers on the background of liming aftereffect.

Aftereffect of liming contributed to the increase of the grain yield by 0.17–0.27 t/ha (6–10%).

4. Conclusion

In the fifth rotation of the alternating crop rotation under the spring wheat crops, the aftereffects of nitrogen-potassium and complete fertilizer of the 2nd year contributed to an increase in nitrate nitrogen content on the non-limed background by 8–12% and on the background with liming aftereffects – by 13–19%. Aftect of the 3rd year of liming has increased the nitrogen content by 18% on average. Aftereffect of phosphate fertilizer in double and triple combination increased the amount of mobile phosphorus by 8–15 on non-limed background and by 7–10% on the background of liming aftereffects. Aftereffects of liming contributed to an increase in the amount of mobile phosphorus by 4.6–5.8 mg/kg of soil (4–5%) in the unfertilized variant and in one with aftereffect of N$_{30}$P$_{30}$. The aftereffects of mineral fertilizers and liming did not influence content of mobile potassium in the soil. Aftereffects of just mineral fertilizers increased the yield of wheat grain by 0.18–0.35 t/ha (7–13%). Aftereffects of liming, depending on the variant of experiment, facilitated growth of this indicator by 0.17–0.27 t/ha (6–10%). The highest increase in harvest yield of wheat, 0.45 t/ha, was achieved with joint use of complete mineral fertilizer and lime.

5. References

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