Role of soil liming in increasing crop yields in crop rotation

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Abstract. These studies were conducted on the effects of new converter slag fertilizer (complex mineral fertilizer, limestone, soil ameliorant) for land reclamation, provided by the Japanese agricultural chemical manufacturer, containing 37.3% of CaO and 18.0% of MgO, on two types of soil in the Amur Region (Russia). About 85% of arable land has a high acidity (pH$_{KCl}$ ≤ 5.5) in the region. Therefore, the need for the use of land reclamation in the region is high. Studies aimed to establish the effect of various doses of the slag fertilizer on the change in the acidity of brown forest and meadow chernozem-like (Amur prairie) soils, as well as increase the yield of soybean and wheat in crop rotation. The experimental scheme was tested in doses of the limestone from 1 to 4 t/ha on the background of nitrogen-phosphorus fertilizer. The application of studied mineral fertilizer ensured a decrease in soil acidity by 0.05-0.30 (pH$_{KCl}$) units by increasing of exchangeable Ca$^{2+}$ and Mg$^{2+}$ ions in soil exchange complex. The result was an increase in soybean yield by 0.18-0.45 t/ha and an increase in seed quality. Based on the results, fertilizer was recommended in doses of 2 to 4 t/ha, depending on the type of soil.

1. Introduction

Many researchers have proven positive effects of liming on the agrochemical properties of soil, regulation of mineral nutrition, and the yield of crops [1–5]. An agrochemical survey of soils in the Amur Region showed that about 85% of arable land has a high acidity (pH$_{KCl}$ ≤ 5.5), with half being are medium acidic and strongly acidic soils [6]. Therefore, the need for reclamation of acidic soils remains high, which makes it necessary to provide agricultural producers with complex mineral fertilizers.

Soybean is the main crop in the agricultural sector of the Amur Region [7]. Wheat is the most common cereal in the region. Barley, oats, and corn are also cultivated there. Soybean is a reasonably demanding crop, including soil acidity. Therefore, for soybean growth and development, pH$_{KCl}$ of the soil solution from 5.5 to 8.5 is required, high yields are formed at optimal values of 6.5-7.0 [8]. Past studies have noted that liming has a positive effect on the development of the soybean symbiotic apparatus and its functioning during liming after the previous crop [9]. Moreover, the application of limestone provides an additional number of proteolytic, amylolytic, and diazotrophic microorganisms that contribute to the improvement of plants’ nitrogen nutrition [10,11].

Our research aimed to study the effect of different doses of provided complex mineral fertilizer by the Japanese agricultural chemical manufacturer. We studied the change in the acidity of brown forest and meadow chernozem-like soils, an increase in the yield of soybean and wheat in the crop rotation.
2. Materials and methods
The effectiveness of soil mineral fertilizer for changing soil acidity was studied in the southern zone of the Amur Region on the experimental field of the All-Russian Scientific Research Institute of Soybean (meadow chernozem-like soil) and in the central zone of the region on the areas of the Belogorsky district farming (brown forest soil). Research began in 2018 on meadow chernozem-like soil and in 2019 on brown forest soil.

The agrochemical composition of the studied soils was determined before the start of the experiment. The meadow chernozem-like thin soil in combination with medium-thick soil in the arable layer had a slightly acidic reaction, an average value of hydrolytic acidity, and an increased amount of absorbed bases. The content in meadow soil was mineral nitrogen (N-NO₃+N-NH₄) - 17.7, mobile phosphorus (P₂O₅) - 33.0, potassium (K₂O) - 193.7 mg/kg of soil, humus - 4.1%. The brown forest soil had an acid reaction, an increased degree of saturation of the soil absorbing complex with bases, and a low amount of absorbed bases.

The experimental scheme included five options: 1. Control; 2. Control + Magnesium limestone (ML) 1 t/ha; 3. Control + ML 2 t/ha; 4. Control + ML 3 t/ha; 5. Control + ML 4 t/ha. The total area of the plots was 100 m², the registration area was 70 m², and the experiment was repeated four times. All agrotechnical methods for post-harvest and pre-sowing tillage, sowing, treatment, and harvesting of soybean and wheat were carried out at the optimal time recommended for the central and southern areas of the Amur Region. For wheat on brown forest soil, ammonium nitrate was added at a dose of 150 kg/ha (N51), and 100 kg/ha (N34) on meadow chernozem-like. Fertilizer was applied to soybean after barley at a dose of 100 kg/ha (N₁₃P₃₂), to soybean after corn and wheat fertilizer was not applied. Background doses of fertilizers were selected depending on the fundamental characteristics of soil and the needs of wheat and soybean in nutrients.

Converter slag fertilizer provided by the Japanese agricultural chemical manufacturer was used as a limestone ameliorant. Provided limestone is a complex mineral fertilizer in the form of granular powder from gray to black color. Agronomic value of agrochemical is determined by its chemical composition: the content of calcium (CaO) - 37.3%, magnesium (MgO) - 18.0, iron (Fe₂O₃) - 22.3, manganese (MnO) - 2.0, phosphorus (P₂O₅) - 1.5%, as well as neutralizing ability 62.3%.

In soil samples, the content of organic matter was determined by the method based on oxidation with a solution of potassium dichromate in sulfuric acid. Next, trivalent chromium, equivalent to the content of organic matter, was determined on a photocolorimeter. The content of mobile forms of phosphorus and potassium was determined by the method in which a 0.5 M of acetic acid served as an extractant. Phosphorus was determined photometrically, potassium - flame photometrically, mineral nitrogen (N-NO₃+N-NH₄) - according to Kjeldahl. Hydrolytic acidity was determined by the pH-metric method in an extract of a 1 M sodium acetate solution. The pH of the salt extract was determined by the potentiometric method, where the extractant was a 1 M solution of potassium chloride. The main exchange cations were extracted with 1 M NH₄OAc, calcium and magnesium were determined by atomic absorption spectrophotometer [12].

The agrometeorological conditions of the growing season were relatively favorable for the growth of soybean and wheat. High precipitation in July led to short-term flooding of fields, but the high temperature contributed to the rapid evaporation of water and the healthy development of plants.

Statistical processing of the obtained data was carried out by analysis of variance. For each randomized method of placing options in the experiment, a modification of the analysis of variance method was used. A final statistical indicator in the method of analysis of variance is used by LSD, least significant difference [13]. LSD is calculated in absolute (for the yield of crops in tons per 1 ha) and relative (in %) indicators. The significance of the differences between the experimental variants is established using LSD, while only two variants are compared. The analysis showed how much the yield from one experiment is higher than from the control. The difference was established between two tests, comparing their yield. This difference is considered significant, and it is concluded that it is due to the positive influence of the test if the value is greater then control.
3. Results and Discussion

Soil acidity is a soil factor that can be regulated on a large production scale. Thus, in the experiment, it is necessary to know the indicators characterizing the pH of the soil solution. For the Amur Region, this is especially important, since almost all soils have an acid reaction. Previously, researchers studied the effectiveness of liming soil when using calcareous fertilizers under the previous culture [9, 14]. The change in soil acidity is shown by indicators of exchangeable and hydrolytic acidity, which depend on the type of soil the duration of effect of lime fertilizers [15, 16]. In our experiments, the study of the acidic properties of brown forest and meadow chernozem-like soils under the influence of lime showed that there was a significant increase in the pH of the salt extract. An increase of 0.15–0.30 units was noted in medium acid brown forest soil in the first year of operation. As well as an increase of 0.10 units in slightly acidic soils in the second year after the application of the highest dose of magnesium limestone was shown (figure 1).

Changes in acidic properties of brown forest and meadow chernozem-like soils under the influence of lime are represented in figure 1. A significant increase in pH_KCl was noted by 0.15-0.30 units in medium-acid soils in the first year of liming and by 0.10 units in slightly acidic soils in the second year after applying the highest dose of magnesium limestone. Hydrolytic acidity in brown forest soil significantly decreased by 0.54-0.75 mEq/100g of soil, and in meadow chernozem-like soil by 0.22-0.24 mEq/100 g of soil with doses of 3-4 t/ha. The hydrolytic acidity of brown forest soil, even with a minimal dose of magnesium limestone, was less than control after wheat crops. The pH indicator changed insignificantly, by 0.05-0.13 units. On meadow chernozem-like soil, a decrease in acidity was not observed.

![Figure 1](image_url)

**Figure 1.** The effects of various doses of limestone on the acidity and hydrolytic acidity (Hh) of brown forest and meadow chernozem-like soils in the Amur region were obtained.

The acidity of brown forest soil decreased due to the enrichment of the soil absorbing complex with Ca\(^{2+}\) and Mg\(^{2+}\) ions, and therefore the degree of base saturation increased by 4-5% (figure 2). A slight increase in magnesium ions was observed on meadow chernozems-like soil. However, the number of absorbed bases and base saturation rates remained unchanged.
Figure 2. The changes in the number of absorbed bases and base saturation of the soil when using different doses of limestone in the first and second year of application in the Amur Region.

The application of magnesium limestone on a slightly acidic meadow chernozem-like soil after the previous crop of barley increased the soybean yield by 0.18-0.26 t/ha (LSD$_{0.05}$ = 0.17) when applied after corn by 0.35-0.45 t/ha (LSD$_{0.05}$ = 0.32). There is also confirmation of these data from previous researchers on the effect of liming of meadow chernozem-like soil on its productivity in the Amur Region [9]. In all variants of the experiment, the effect of liming of the soil was revealed. However, magnesium limestone had the most significant impact in doses of 2-4 t/ha (table 1). The weight of 1000 soybean seeds increased by 6.0 and 41.1 gram with doses of 1 and 3 t/ha, respectively.

Table 1. Crop yield of crops depending on the dose of limestone on the first and second year of application in the Amur Region, t/ha, 2019 year.

| Experiment trials | First-year application | Second-year application |
|-------------------|------------------------|-------------------------|
|                   | Aryuna wheat | +/- | Umka soybean after wheat | +/- | Aryuna wheat | +/- | Lydia soybean after barley | +/- | Kirossa soybean after corn | +/- |
| 1. Control         | 2.02        | -   | 2.31                      | -   | 1.92        | -   | 2.58                      | -   | 1.35        | -   |
| 2. Control + lime 1 t/ha | 1.87  | -0.15 | 2.41                     | 0.10 | 1.86       | -0.06 | 2.84                     | 0.26 | 1.70        | 0.35 |
| 3. Control + lime 2 t/ha | 2.03  | 0.01  | 2.39                     | 0.08 | 1.96       | 0.04  | 2.81                     | 0.23 | 1.80        | 0.45 |
| 4. Control + lime 3 t/ha | 2.07  | 0.05  | 2.50                     | 0.19 | 2.00       | 0.08  | 2.76                     | 0.18 | 1.63        | 0.28 |
| 5. Control + lime 4 t/ha | 2.08  | 0.06  | 2.52                     | 0.21 | 1.95       | 0.03  | 2.78                     | 0.20 | 1.80        | 0.45 |

The use of magnesium limestone on medium-acid brown forest soil directly under soybean provided an increase in soybean yield by 0.21 t/ha (LSD$_{0.05}$ = 0.20) when using magnesium limestone at a dose of 4 t/ha; in other experimental variants, only a tendency to increase soybean yield was noted. In soybean, the weight of 1000 seeds increased by 6.4-11.3 grams with the application of magnesium limestone in doses of 2-4 t/ha.
Many researchers have studied an increase in the content of mobile phosphorus during the liming of acidic soils and improvement in the nutrition of plants with phosphorus [17,18]. There is evidence of no effect of lime on the content of mobile phosphorus [19]. Studies have also shown that in soils with high liming doses, a decrease in the number of phosphates available to plants occurs [20,21]. Therefore, the sorption or release of phosphates in the soil solution as a result of the application of lime depends on the characteristics of a particular soil, its genesis, cultivation techniques, and other factors. According to Amur researchers, under the application of lime, the content of phosphorus available to plants decreases due to its fixing in the form of tightly bound calcium phosphates, which appears even in the 7th year after liming [22].

In the experiment, the high initial level of mobile phosphorus in brown forest soil during liming provided the necessary amount of element for plant development, which also played a role in increasing soybean yield. At the low initial content of phosphorus forms available to plants and the absence of phosphorus fertilizers for wheat on two types of soil, liming at a dose of 1 t/ha adversely affected the yield of this crop. At doses of 2-4 tons, it gave insignificant increases (0.01-0.08 t/ha).

4. Conclusion
The application of magnesium limestone on a slightly acidic meadow chernozem-like soil under the previous crop of barley increased the soybean yield by 0.18-0.26 t/ha (LSD0.05=0.17). After the application of limestone for corn, the yield was increased by 0.35-0.45 t/ha (LSD0.05=0.32). The greatest effect was obtained when used in doses from 2 to 4 t/ha. The weight of 1000 soybean seeds increased by 41.1 g when applied under the previous culture at a dose of 3 t/ha.

The use of magnesium limestone on medium-acid brown forest soil under soybeans at a dose of 4 t/ha showed an increase in its yield by 0.21 t/ha (LSD0.05=0.20). At the same time, soybean showed a tendency to increase the weight of 1000 seeds by 6.4-1.3 g with limestone in doses from 2 to 4 t/ha. Wheat yield under the application and aftereffect of liming did not change significantly, and the increase was 0.01-0.08 t/ha.

A significant increase in pHKCl by 0.25-0.30 units on medium-acid soils in the first year of application and by 0.10-0.17 units on slightly acidic soils in the second year of the application indicates the effectiveness of complex mineral fertilizers in reducing soil acidity. This is confirmed by the data of hydrolytic acidity, which decreased by 0.54-0.75 mEq/100 g of soil in brown forest soil, and by 0.22-0.24 mEq/100 g of soil in the second year after application, in chernozem-like soil.

The use of magnesium limestone, which contains 37.3% CaO and 18% MgO, had a significant impact on productivity, quality of soybean seeds, and ensured a decrease in soil acidity. We concluded that in order to improve the agrochemical parameters of the soil and increase the soybean yield, it is recommended to add magnesium limestone in doses of 2 to 4 t/ha.

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