Economic efficiency of fertilizer system in field crop rotation of the Trans-Urals

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Abstract. In order to determine the optimal combination of components of a fertilizer system economic and agronomic efficiency of lime, organic and mineral fertilizers in grain and steam crop rotation in the forest steppe of the Trans-Urals was analyzed. The definition of agronomic efficiency showed that the payback of 1 kg of active ingredient (a.i.) of added fertilizers yield gain on average over 3 years made 1.04-1.42 kg, the maximum payback was observed in the option with a dose of N30P30 – 5.33 kg of grain units (g.u.)/kg a.i. The increase in the dose of mineral fertilizers increased the production costs and reduced the payback from 2.12 to 1.49 rubles. Options of mixed organo-mineral fertilizer on the basis of sapropel with lime and mineral fertilizers in the ratio of mass fractions 1:0,1:0,01 and 1:0,1:0,05 are proposed.

1. Introduction

All types of soils, including chernozem, are characterized by spatial heterogeneity of fertility and phytosanitary state of crops, which is caused both by natural factors and the nature of anthropogenic influence. The use of mineral fertilizers without considering this important aspect reduces their efficiency and leads to further increase of soil fertility variability. In some cases, this leads to yield shortfall, in others – to deterioration of product quality and environmental pollution. Therefore, differentiated application of mineral fertilizers taking into account heterogeneity of nutrient content and other soil properties is an important element of modern farming [1-3].

However, such technologies require the assessment of their efficiency in specific soil-climatic and economic conditions, as well as some adjustment of fertilizer application rates since the recommended doses of nutrients (NRC) are based on gross data [4, 5].

In order to solve these and many other problems of agricultural chemical application there is a need for appropriate research, especially through special experiments.

Complex economic and environmental conditions of modern development of the country make it necessary to develop new technologies adapted to modern requirements of land use. The introduction of new farming technologies is not possible without the systematic analysis of factors that directly affect the production of yield. Therefore, it is critical to assess the contribution of soil fertility and fertilizers to the formation of field crop yield [5-12].

In addition to climatic, economic, technological, morphological and genetic properties of soils, the construction of a science-based fertilizer system plays a significant role in creating favorable conditions for maximizing crop productivity.
2. Materials and methods

The study was carried out in 2014-2016 on the experimental field of the Kurgan State Agricultural Academy. Soil of the experimental field – leached slightly humic minor light loamy chernozem, the number of fractions less than 0.01 mm in the arable horizon made 22.4%; humus content – 3.32%; cation exchange capacity – 20.5 mmol/100 g of soil, degree of base saturation – 80.8%, salt extract pH – 5.24; bulk density – 1.15 g/cm$^3$, particle density – 2.61 g/cm$^3$, total porosity – 55.9%, moisture content – 7.0%; content (according to Chirikov) of labile phosphorus – 119 mg/kg, exchange potassium – 148 mg/kg; capacity of humus-accumulated horizons A+AB – 36 cm.

Four-course crop rotation with rotational farming: steam – spring wheat – spring wheat – barley. The field stationary test was carried out in quadruple repetition in time.

The arrangement of option in repetitions was randomized. The repetitions were arranged in four layers. The total area of the plot was 15 m$^2$, accounting – 12 m$^2$ (2 m x 6 m). Sapropel and lime were introduced under pre-planting cultivation with embedding at a depth of 10-12 cm.

The scheme of the experiment represented a matrix of a three-factor complete factorial experiment and included 12 options. Factor A – lime (CaCO$_3$) (0 and 2.0 t/ha to neutralize 1/2 hydrolytic acidity). Factor B – annual introduction of mineral fertilizers (0 and N30P30). Factor C – sapropel (0 and 20 t/ha). Sapropels of Kurgan (No. 1) and Sverdlovsk (No. 2) regions were used in the experiment. Sapropels were characterized by the following indicators: sapropel No. 1 – pH – 7.76; ash content – 29.8%; N – 7.05 %; P$_2$O$_5$ – 0.53 %; K$_2$O – 0.23 %; CaO – 47.8%, sapropel No. 2 – pH – 4.40; ash content – 55.6%; N – 4.11 %; P$_2$O$_5$ – 0.41 %; K$_2$O – 0.40%; CaO – 23.2 %. The chemical ameliorant used in the experiment is represented by limestone flour (CaCO$_3$ – 85%, humidity – 1.2%, non-active particles – 1.5%). The hydrolytic acidity of soil at the time the experiment made 3.81 mmol/100 g of soil. Nitrogen-phosphorus mixed fertilizer – ammonium nitrate (N – 34.6% a.i.) and simple superphosphate (P – 26% a.i.), which was introduced annually before sowing according to the test scheme, were used as mineral fertilizers. Spring wheat of Zhigulevsky variety and barley of Prairie variety were grown with the seeding rate of 5.0 million germinating grains per hectare. The yield was taken into account manually from each plot and after weighing was recalculated by 1 ha at standard humidity and 100% purity.

3. Results and Discussion

Preservation, reproduction and rational use of fertility are important for the whole agricultural complex of Russia since they determine the possibility of reducing costs and obtaining the maximum profit by agricultural producers.

Agronomic efficiency or payback of fertilizers by increasing grain harvest allows estimating the efficiency of used doses and types of fertilizers. Even at optimal doses and ratios of nutrients, the efficiency of fertilizers depends on their specific forms, main and accompanying elements, water content, solubility, grain size composition, physiological and hydrolytic reactions. According to numerous data, the payment of 1 kg a.i. of mineral fertilizers by increasing the main production can make 2.0-6.0 kg of cereals grain units (g.u.) [4].

| Option  | Amount of fertilizers kg a.i./ha | Grain yield gain, kg g.u. | Payback, kg g.u./kg a.i. |
|---------|---------------------------------|--------------------------|-------------------------|
| 1. Without fertilizers (control) | -                              | 200                      | -                       |
| 2. Sapropel 1, 20 t/ha          | 781                            | 340                      | 660                     | 0.44 | 0.85 |
| 3. Sapropel 2, 20 t/ha          | 492                            | 110                      | 460                     | 0.22 | 0.94 |
| 4. N30P30                       | 180                            | 880                      | 960                     | 4.89 | 5.33 |
| 5. N30P30 + sapropel 1, 20 t/ha | 961                            | 1000                     | 1160                    | 1.04 | 1.21 |
| 6. N30P30 + sapropel 2, 20 t/ha | 672                            | 920                      | 970                     | 1.37 | 1.42 |
There is evidence in scientific literature that as the fertilizer rate increases, their yield payback decreases. This trend has also been observed in our studies (Table 1). The annual use of mineral fertilizers in the amount of 60 kg of active ingredient per hectare allowed increasing the productivity of crop rotation by 0.88 tons, where the payback made 4.89 kg g.u./kg a.i. against the background of limestone – 5.33 kg g.u./kg a.i. In other options there was a decrease in payback due to additional use of organic fertilizer 1.04-1.42 kg g.u./kg a.i.

Figure 1 shows the annual production cost of crops and fertilizers. In option without fertilizers, the cost of cultivation of crops amounted to 7520 rubles, with additional use of organic fertilizers (sapropel) it increased to 10093 rubles per 1 ha. The options 11 and 12 with the joint use of ameliorant and fertilizers showed the largest production costs – 12043-12070 rub/ha.

![Figure 1. Production costs for grain crops, rub/ha (Kurgan SAA pilot field, 2014-2016)](image)

Cost payback (Figure 2) on average for three years amounted to 2.12 rubles in the option without fertilizers, 2.07 rubles in the seventh option with ameliorant. The use of mineral fertilizers reduced the payback to 1.93 rubles. At joint use of sapropel, lime and mineral fertilizers, the cost payback in 11 and 12 options made 1.51-1.57 rubles.

Thus, the highest annual economic costs were noted in the options with sapropel, lime and mineral fertilizers. The use of sapropel of the Kurgan region was more cost-effective, compared to sapropel of the Sverdlovsk region – the payback of its introduction was higher by 0.03-0.08 rubles.

Low indicators of crop industry are related to poor attention to the use and development of innovative technologies, a large part of which specializes in highly productive varieties of cereals and legumes, the development of a farming system and intensive technologies for their production, which provides for additional crop yield.

The results of field (productivity of agroecosystem) and laboratory (provision of plants with food elements, soil acidity) studies, as well as economic calculations allow choosing mixed organomineral fertilizers based on sapropel of the Kurgan region as the base of the fertilizer system.

When sapropel is replaced with mineral fertilizers, especially nitrogen fertilizers, the costs increase sharply at different combinations of them up to 11544-12925 rubles per 1 ha (Table 2).
Figure 2. Cost payback for fertilizers in crop rotation field (Kurgan SAA pilot field, 2014-2016)

Table 2. Options for replacing sapropel with mineral fertilizers (Kurgan SAA, 2016)

| Fertilizers | Kg per 1 ha / cost, rub. | Content a.i., % |
|-------------|--------------------------|-----------------|
|             | N | P₂O₅ | K₂O | CaO         |
| Sapropel (Yurgamyshsky area, Kurgan region, in the scheme of experiment 1, at 50 % moisture content) | – | 7.05 | 0.53 | 0.23 | 47.8 |
| Lime        | 20000 | 705 | 53 | 23 | 4780 |
| Nitrogen-phosphate fertilizer | 606 | 90 | 90 | – | – |
| Total included per rotation | 2806 | 795 | 143 | 23 | 6180 |
| Annually at random introduction | – | 265 | 47.8 | 7.7 | 2060 |
| Mineral fertilizers: ammonia nitrate (cost – 13800 rub./t) | 770 / 10626 | 265 | – | – | – |
| carbonyl diamide (alternative, cost – 16050 rub./t) | 576 / 9245 | 265 | – | – | – |
| simple superphosphate (cost – 9600 rub./t) | 183 / 1757 | – | 47.8 | – | – |
| double superphosphate (alternative, cost – 21000 rub./t) | 104 / 2184 | – | 47.8 | – | – |
| potassium chloride (cost – 11350 rub./t) | 12.8 / 145.3 | – | – | 7.7 | – |
| lime (cost – 135 rub./t) | 2943 / 397 | – | – | – | 2060 |
| Options for fertilizer mixing: gross weight of fertilizers, kg /cost, rub. | – | – | – | – |
| 1 ammonia nitrate + simple superphosphate + potassium chloride + lime | 3909 / 12925 |
| 2 carbonyl diamide + simple superphosphate + potassium chloride + lime | 3715 / 11544 |
| 3 carbonyl diamide + double superphosphate + potassium chloride + lime | 3636 / 11941 |
When developing options of fertilizer composition based on a mixture of sapropel and mineral additives, instead of using ammonium nitrate and simple superphosphate (at 30P30) it is proposed to replace it with carbonyl diamide. The introduction of an equivalent dose of carbonyl diamide (n30) in the active substance will reduce economic costs by 93 rub/ha.

In the development of mixed fertilizers two options of combination of fertilizers and lime in ratios 1:0.1:0.01 and 1:0.1:0.05 were considered (Table 3). In the second option of fertilizer composition the proportion of mineral fertilizer is increased. As a result, the amount of nitrogen (from 26.3 to 28.4 kg), phosphorus (from 2.8 to 5.7 kg) increased at a dose of 400 kg/ha and calcium decreased (from 197.3 to 190.8 kg).

| Table 3. Versions of mixed fertilizer composition based on sapropel mixture with mineral additives |
|------------------------------------------------------|-----------------|-----------|-----|-----|
| Indicator Introduction dose per 1 ha N P K Ca kg     |  |  |  |  |
| Option 1. Fertilizer at a dose of 400 kg/ha (with ratio of 1:0,1:0,01) sapropel, 360 kg | 25.4 | 1.9 | 0.8 | 172.1 |
| lime, 36 kg | – | – | – | 25.2 |
| mineral fertilizer, 4 kg | 0.9 | 0.9 | – | – |
| Total | 26.3 | 2.8 | 0.8 | 197.3 |
| Annually during the introduction at a dose of 200 kg/ha | 13.2 | 1.4 | 0.8 | 98.6 |
| Option 2. Fertilizer at a dose of 400 kg/ha (with ratio of 1:0,1:0,05) sapropel, 348 kg | 24.5 | 1.8 | 0.8 | 166.3 |
| lime, 35 kg | – | – | – | 24.5 |
| mineral fertilizer, 17 kg | 3.9 | 3.9 | 0.8 | – |
| Total | 28.4 | 5.7 | 0.8 | 190.8 |
| Annually during the introduction at a dose of 200 kg/ha | 14.2 | 2.9 | 0.4 | 95.4 |

Experimental production of this fertilizer in the form of pallets was organized using a laboratory press. The costs of fertilizer production using the laboratory press TDP-3 amounted to 23.8-24.1 rub/kg.

The calculations made during the production of palletized fertilizers using a production line and a high-speed rotary pellet press showed that the cost of fertilizer decreases in the first option of the composition to 5.32 rub/kg, in the second option with the increase in the share of mineral fertilizer to 5.66 rub/kg.

4. Conclusion

The positive effect obtained in field conditions over 2014-2016 from the combination of three factors allowed performing experimental work on the creation of fertilizers (Patent No. 2667159) from combined organo-mineral mass (sapropel, lime, nitrogen-phosphorus mineral fertilizers in the ratio of weight parts 1:0,1:0,01 and 1:0,1:0,05, the variation coefficient of a mix (uniformity) not less than 80%) in order to increase the efficiency of agroecosystems and to reduce economic costs of crop growing.

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