Influence of long-term use of fertilization systems on the productivity of winter grain crops

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Abstract. In the conditions of the Vyatka-Kama agricultural province, a study was carried out to evaluate the effect of long-term use of various fertilization systems on the productivity of winter grain crops and the fertility of soddy medium podzolic soil in terms of agrochemical indicators. Long-term use of the mineral fertilization system in doses of N69P68K53 on soddy medium podzolic medium loamy soil contributed to an increase in winter grain crops' productivity on average per year in relation to the control without fertilizers – 1.83 tons of grain units/ha. Long-term use of an organic fertilization system against lime background provided an increase in the productivity of winter crops of 0.64 tons of grain units/ha in relation to control. The most effective was the organomineral fertilization system, which contributed to an increase in the productivity of the studied winter crops in long-term use by 2.64 tons of grain units/ha in relation to control. As a result of a long-term field experiment, it was revealed that the productivity of winter grain crops in the Vyatka-Kama agricultural province significantly depends on agroclimatic conditions. A close inverse interrelation of productivity from the sum of active temperatures and average air temperature was revealed. For expanded fertility reproduction of soddy medium podzolic medium loamy soil in the Vyatka-Kama agricultural province of Russia, an organic-mineral fertilizer system should be used against liming background.

1. Introduction.
Soddy podzolic soils are the most widespread in the Vyatka-Kama agricultural province, which are characterized by many unfavorable agrochemical properties. Therefore, the systems of fertilizers' application on such lands play an important role in increasing the productivity of agricultural land and in the reproduction of soil fertility [1-4]. The effect of the systematic fertilizers' application on the productivity of agricultural crops and the fertility of soddy podzolic soils can vary greatly depending on the soil and climatic conditions [5-6]. According to several researchers, organomineral fertilizer systems are recognized as the most rational, contributing to maintaining deficit-free balance of humus and nutrients in crop rotations [1-4].

The results of long-term experiments with mineral and organic fertilizers make it possible not only to establish the efficiency of agrochemical preparations' use, but also to reveal the influence of agroclimatic conditions on the "crops - soil - fertilizers" system [7-10]. Thus, the study of the long-term use effect of various fertilization systems on the agricultural crops' productivity and the fertility of soddy medium-podzolic soils by agrochemical indicators under the conditions of the Vyatka-Kama agricultural province is relevant.
2. Materials and methods

The effectiveness of various fertilizer systems was studied under the conditions of a long-term experiment established in 1979 on the experimental field of the FSBEI HE Izhevsk SAA (Iyulskoe village, Votkinsk region, Udmurt Republic of the Russian Federation) and continues at the present time. According to the soil and climatic zoning, the Udmurt Republic belongs to the Vyatka-Kama agricultural province. The research was carried out in a four-field grain-fallow crop rotation. The experiment included 17 options for various types, combinations and ratios of fertilizers [4]. The full doses of mineral fertilizers were determined considering the crops’ biological characteristics. Organic fertilizers in the form of covering manure were introduced in the crop rotation for row crops, liming for complete hydrolytic acidity was carried out once in two rotations of the crop rotation. The experiment was carried out in four repetitions, the plots’ placement in repetitions was randomized. The soil of the experimental site was soddy medium podzolic medium loamy on red-brown sandy loam. When establishing the experiment, the soil was weakly acidic (pH KCl = 5.20) with an average humus content (1.93%), low content of mobile forms of phosphorus (69 mg/kg) and potassium (91 mg/kg) according to Kirsanov [4].

Winter crops are among the most important for agricultural production in the Non-Black Earth Zone of Russia. Their products are used for food and feed purposes. Many researchers have noted the high responsiveness of winter crops to fertilizers [11-12]. To assess the effect of fertilization systems on the productivity of winter grain crops (winter rye and winter triticale) and soil fertility, 6 options were selected from the complete experimental scheme, including various combinations of mineral fertilizers and manure with a saturation of 10/ha with and without lime. The average annual dose of mineral fertilizers in the cultivation of the studied crops was N69P68K53. The yield of grain and straw of the studied crops obtained in field studies from I to X crop rotations was recalculated in grain units. Soil sampling was carried out at the end of the growing season of the studied crop from the arable layer. Agrochemical analyzes were performed according to the methods recommended for the taiga-forest zone of Russia. Mathematical processing of the results was carried out by correlation-regression and variational methods.

3. Results and discussion

Udmurtia belongs to the moderately cold climatic zone. Agroclimatic resources are sufficient for the cultivation of crops provided for by zonal adaptive landscape farming systems [6]. However, according to the data of long-term experiment, the productivity of winter grain crops in the years of the study varied greatly (Table 1), which was largely determined by the agrometeorological cultivation conditions (Table 2). Winter crops developed in dry conditions in 1988 and 2010. Excessive soil moisture according to the hydrothermal coefficient was observed in 1984, 1985, 1990.

| Option                        | Productivity by years of research | M ± ∆m | V, %  |
|-------------------------------|----------------------------------|--------|-------|
|                               | 1984  | 1985  | 1988  | 1989  | 1990  | 2006  | 2010  | 2014  | 2018  |        |
| No fertilizer (control)       | 1.98  | 2.17  | 1.28  | 1.15  | 2.61  | 1.82  | 1.16  | 2.58  | 2.51  | 1.92 ±0.43 | 29.7 |
| Lime                          | 2.50  | 2.21  | 1.15  | 1.13  | 3.55  | 2.68  | 1.17  | 2.63  | 2.71  | 2.19 ±0.62 | 36.9 |
| Lime + N1P1K1                 | 4.88  | 4.71  | 3.71  | 2.68  | 3.31  | 4.34  | 2.39  | 6.59  | 4.78  | 4.05 ±0.79 | 25.6 |
| N1P1K1                        | 4.28  | 4.47  | 3.12  | 2.99  | 3.33  | 4.12  | 1.72  | 5.21  | 4.51  | 3.75 ±0.76 | 26.5 |
| Lime + manure 40 t/ha + N1P1K1| 4.73  | 4.42  | 3.86  | 2.79  | 3.22  | 4.62  | 2.70  | 6.21  | 4.98  | 4.17 ±0.82 | 25.9 |
Lime + manure 40 t/ha 3.33 3.32 2.00 1.46 2.89 2.86 1.63 2.69 2.84 2.56 ± 0.82 25.6

M ± ∆m: mean and confidence interval, P = 0.05
V, %: weak up to 10%; average 10-20%; strong more than 20%

It was found that the natural fertility level of the soddy medium podzolic medium loamy soil provided the productivity of winter crops with only 1.92 tons of grain units/ha on average over 9 years of research.

Table 2. Agroclimatic conditions of winter rye growing seasons (from May 10 to August 10).

| Agroclimatic indicator | Research year | M ± ∆m | V, % |
|------------------------|---------------|--------|------|
| The sum of active temperatures over 10°C, °C | 1984 | 1577 | 1524 ± 135 | 11.7 |
| Precipitation, mm | 1985 | 1209 | 179 ± 71 | 52.5 |
| Hydrothermal coefficient | 1988 | 1643 | 1.21 ± 0.49 | 53.1 |
| Average air temperature, °C | 1989 | 1691 | 1.00 | 9.2 |
| 1990 | 1349 | | |
| 2006 | 1428 | | |
| 2010 | 1836 | | |
| 2014 | 1531 | | |
| 2018 | 155 | | |

It is known that winter rye and triticale are not demanding on the soil acidity level; therefore, soil liming did not provide a significant increase in the yield of these crops. Against the liming background, the use of organic fertilizer in the crop rotation in the form of covering manure at a dose of 40 t/ha in the after-effect increased the productivity of winter grain crops in comparison with the absolute control by 0.64 t grain units/ha, which was 33.3%.

On average for 9 experimental years, the application of mineral fertilizers in a dose of N69P68K53 made it possible to increase the productivity of winter grain crops by 1.83 tons of grain units/ha. This proves the agronomic efficiency of this technological method in the production of winter rye and triticale grain on soddy podzolic soils. However, the most effective was the organomineral fertilization system against the liming background; in relation to absolute control, the increase in productivity averaged to 2.25 t grain units/ha per year. It should be noted that the coefficients of variation in winter grain crops' productivity amounted to 25.6-36.9% (strong degree of variation), which is explained by the instability of agro-climatic conditions over the years (Table 2).

For the years of research, during the growing periods of winter grain crops' development (from May 10 to August 10), precipitation amounted to from 61 to 401 mm with a change in the sum of active temperatures within 1209-1836 °C. Hydrothermal coefficient varied from 0.33 to 2.54. The fertilization systems' efficiency largely depended on the agro-climatic conditions of the growing seasons. It was found that in arid conditions, higher increases in the yield of winter grain crops from mineral fertilizers are formed against liming background. At the same time, under conditions of sufficient moisture, higher increments from industrial fertilizers were obtained against the background fertilized with covering manure. This pattern is probably related to the microbiological activity of the soils. It is known that the necessary conditions for ammonification and nitrification are both the presence of easily hydrolyzable organic matter in the soil and the necessary conditions for moisture and temperature for these microbiological processes to occur.

Table 3. Relation between the productivity of winter grain crops and agro-climatic indicators (vegetation period - 90 days).

| Option | Sum of active | Precipitation, mm | Hydrothermal | Average air |
|--------|---------------|-------------------|--------------|-------------|
|        |               |                   |              |             |
temperatures, \( r \) \( \eta \) \( r \) \( \eta \) \( r \) \( \eta \) \( r \) \( \eta \\
No fertilizer (c) -0.73 0.79 0.33 0.57 0.44 0.63 -0.79 0.83 \\
Lime -0.71 0.80 0.44 0.61 0.53 0.67 -0.75 0.82 \\
Lime + \( \text{N}_1 \text{P}_1 \text{K}_1 \) -0.53 0.70 0.32 0.34 0.36 0.41 -0.63 0.75 \\
\( \text{N}_1 \text{P}_1 \text{K}_1 \) -0.65 0.82 0.37 0.54 0.43 0.61 -0.74 0.86 \\
Lime + manure 40 t/ha + \( \text{N}_1 \text{P}_1 \text{K}_1 \) -0.40 0.65 0.16 0.18 0.18 0.25 -0.52 0.68 \\
Lime + manure 40 t/ha -0.80 0.82 0.61 0.64 0.72 0.74 -0.84 0.85

Note: \( r \) - the correlation coefficient; \( \eta \) - correlation ratio for the polynomial trend type; \( n = 9 \); \( r (\eta)_{0.05} = 0.67 \)

Correlation-regression analysis (Table 3) revealed a close inverse interrelation between the productivity of winter grain crops with the sum of active temperatures and average air temperature. Moreover, a reliable connection was obtained for options without fertilizers and with systematic liming, that is, when cultivating crops without the use of organic and mineral fertilizers. As a factor that largely determines the productivity level, fertilization systems somewhat weaken the dependence of productivity on agro-climatic indicators.

It is known that the use of fertilizers is an important factor that significantly affects soil fertility, especially with their systematic use [13-15]. In these studies, the fertility level of soddy medium podzolic medium loamy soil under the influence of fertilization systems' use for 40 years has significantly changed in comparison with the initial state (Table 4).

**Table 4.** Changes in the agrochemical properties of soddy podzolic medium loamy soil under the influence of long-term fertilization systems' use (2019).

| Option | Humus, % | pH_{KCl} | Hydrolytic acidity mmol/100 g soil | S | V, % | P_2O_5 | K_2O mg/kg soil |
|--------|----------|----------|----------------------------------|---|---|--------|--------------|
| Before the experiment was established, 1979 | 1.93 | 5.20 | 2.80 | 10.8 | 79 | 69 | 91 |
| No fertilizer (c) | 1.51 | 5.00 | 2.22 | 9.5 | 81 | 72 | 46 |
| Lime | 2.69 | 4.45 | 3.12 | 9.4 | 75 | 168 | 65 |
| Lime + \( \text{N}_1 \text{P}_1 \text{K}_1 \) | 2.32 | 5.81 | 1.48 | 13.2 | 90 | 228 | 66 |
| \( \text{N}_1 \text{P}_1 \text{K}_1 \) | 2.69 | 4.45 | 3.12 | 9.4 | 75 | 168 | 65 |
| Lime + manure 40 t/ha + \( \text{N}_1 \text{P}_1 \text{K}_1 \) | 2.58 | 5.83 | 1.26 | 13.0 | 91 | 214 | 85 |
| Lime + manure 40 t/ha | 2.69 | 5.68 | 1.43 | 11.2 | 89 | 160 | 56 |

The use of soddy medium podzolic medium loamy soil for the cultivation of agricultural crops without the use of fertilizers for 40 years led to a decrease in the humus content by 0.42%. At the same time, soil acidification by 0.20 pH units was revealed. The content of mobile phosphorus did not undergo significant changes; however, agrodepletion was established in terms of mobile potassium content. The use of systematic liming helped to neutralize soil acidity and increase the content of mobile phosphorus due to its transition to a more plant-accessible state. The use of a mineral fertilization system without liming led to a significant soil acidification, although it contributed to an expanded reproduction of fertility in terms of humus and mobile phosphorus content. Against liming background, the use of manure with maintaining the crop rotation saturation of 10 t/ha favorably influenced the main agrochemical indicators of soddy medium podzolic medium loamy soil. However,
organomineral fertilization system against the background of liming is the most effective for increasing the fertility level, which improves all agrochemical characteristics of soils apart from mobile potassium content.

4. Conclusions

1. Long-term use of fertilization systems on soddy medium podzolic medium loamy soil contributed to the increase in the productivity of winter grain crops on average per year in relation to the control without fertilizers: the mineral system in doses N₆₉P₆₈K₅₃ - 1.83 t grain units/ha; organic against lime background - 0.64, and organomineral - 2.64 t grain units/ha.

2. The productivity of winter grain crops in the Vyatka-Kama agricultural province significantly depends on agro-climatic conditions. A close inverse interrelation of productivity from the sum of active temperatures and average air temperature was revealed; the correlation coefficients were -0.71 ... -0.80 and -0.74 ... -0.84, respectively. The use of fertilization systems reduces the interrelation's tightness.

3. For expanded fertility reproduction of soddy medium podzolic medium loamy soil in the Vyatka-Kama agricultural province of Russia, an organic-mineral fertilizer system should be used against liming background.

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