Biological activity influence of soil and nitrates on the yield of soft spring wheat in crop rotation and permanent sowing in Urals southern chernozems

D V Mitrofanov¹, N A Maksyutov¹, V Yu Skorokhodov¹, Yu V Kaftan¹, L V Galaktionova¹,² M P Mordvintsev¹ and T A Tkacheva²

¹ Federal Scientific Center for Biological Systems and Agrotechnologies of the Russian Academy of Sciences, Orenburg, Russia
² Orenburg State University, Orenburg, Russia

E-mail: dvm.80@mail.ru

Abstract. The paper presents a study of the main factors affecting the yield level of soft spring wheat. This research is based on the study of the biological activity of the soil and the content of nitrates in the Urals southern chernozems. This paper is obtained as a result of field and laboratory studies. The purpose of the research work is to establish the influence of each factor individually on the yield of grain crops according to various predecessors and backgrounds of mineral nutrition. For the first time in the experiment, the methodology of the field experiment, decomposition of linen (applications) and the ionometric method are used. Over 18 years, rich experience has been accumulated, and soil fertilizer options have been developed to increase wheat productivity. Studies show that using balanced fertilizer it is possible to increase the yield of wheat after growing millet in this territory to 9.7 centners per 1 ha, the dependence on the influence of the activity of microorganisms is 71.51 %. In other research options, after the application of mineral fertilizers during the growing season, grain yield of 9.4 and 9.0 kg per 1 ha is noted, and the proportion of the effect of nitrate-nitrogen is 33.82 and 24.67 %. The results obtained are of scientific and practical importance in the field of microbiology, chemistry, agriculture, agronomy and agricultural production.

1. Introduction
Grain farming is the basis of food supply for the population of Russia. Wheat occupies a leading position in world agriculture in sown areas and gross harvest of grain. Increasing the production of high-quality spring wheat grain is currently one of the essential tasks of the agro-industrial complex of the Russian Federation.

In solving the problem of increasing wheat grain production, the central place belongs to the study of the ongoing microbiological soil processes and the degree of mobilization of nitrate-nitrogen in the soil [1].

The Pacific Northwest of the United States is a major wheat production area. Long-term studies in this area have established that the presence of water in a semi-arid agroecosystem forms a microbiome in the soil under wheat crops [2].

Crucial to the growth and development of common spring wheat are bacteria associated with the root. Understanding agricultural composition and the role of soil microbiome is important for agricultural methods [3]. The absorption of organic nitrogen by the roots of common wheat is low
compared to inorganic as a result of the activity of soil microorganisms [4]. In another research work, the changes in the fluxes of ammonium and nitrate in thin roots of wheat are studied using the method of a scanning ion-selective electrode. According to the results of the device, the inflows are shown at a distance of 20 and 25 mm from the root tip. In this regard, it was found that $\text{NO}_3^-$ is more sensitive to environmental changes than $\text{NH}_4^+$ [5].

For example, in one field test, it was determined that plants in their ability to absorb nitrogen from the soil solution depending on the morphology of the root system [6]. Besides, studies show that the absorption of nitrate-nitrogen from the soil after flowering of wheat strongly affects the condition of the plant, which leads to an increase in grain yield [7].

Some researchers have found that to reduce wheat grain yield losses caused by water scarcity, fertilizers with a high nitrogen content can be applied to the soil [8]. So, for example, in Mediterranean conditions in the south of Portugal in 2017-2018, with a favourable seasonal distribution of precipitation, with the use of ordinary nitrogen fertilizers, the highest values of crop yield were obtained [9]. For achieving maximum wheat productivity using the minimum amount of nitrogen, complex interdisciplinary cooperation is required, as well as major scientific and practical achievements in soil science, agronomy, and selection related to plant nutrition [10]. Many researchers are studying wheat productivity in various directions [11–15].

Orenburg region is the subject of the Russian Federation, which is the largest producer of a marketable grain of spring wheat among the main grain crops. Raising the yield is a major problem in the field of agronomy. Thus, studies on the influence of the biological activity of soil and nitrates on the yield of soft spring wheat in crop rotation and permanent sowing are currently underway in the Orenburg region.

2. Materials and methods
The study was carried out by the Department of Agriculture and Resource-Saving Technologies of the Federal Scientific Center for Biological Systems and Agricultural Technologies of the Russian Academy of Sciences. Field experiments were laid from 2002 to 2019 on the southern chernozems of the Urals. Research work was carried out on the territory of a long stationary field experiment on crop rotation and permanent crops, laid in 1988.

Nine options for growing spring soft wheat were studied according to various predecessors in crop rotation (seven six-field and one two-field) and permanent sowing: I. Spring soft wheat after hard crop rotation with black steam (control); II. Spring soft wheat after hard in crop rotation with soil-protective steam; III. Spring soft wheat after hard crop rotation with green manure; IV. Spring soft wheat after corn for silage in a grain-crop rotation; V. Spring soft wheat after millet in a grain-steam rotation; VI. Spring soft wheat after sorghum for silage in a grain-crop rotation; VII. Spring soft wheat after peas in a grain-steam rotation; VIII. Spring soft wheat after hard in a non-steam (double-field) crop rotation. IX. Spring soft wheat after soft with its permanent cultivation.

The field experiment methodology was used according to B.A.Dospeshov. Field experiments were studied at the site in four repetitions over eighteen years of research. The plot size of soft spring wheat in crop rotation was 14.4 m per 90 m at $S^2 = 1296$ m$^2$, in permanent sowing – 7.2 m per 90 m at $S^2 = 648$ m$^2$.

Observations were carried out on a fertilized length of 30 m and non-fertilized – 60 m food backgrounds. In the first part of the plot in the autumn, under the primary tillage (ploughing), with the help of a seeder, complex mineral fertilizers (amorphous, nitroammophos, nitrogen phosphate, ammophosphate) were applied at the established norm of 40 kg of nitrogen and phosphorus of the active substance per 1 ha. Mineral fertilizers were not used in the second part of the spring soft wheat plot.

In the experiment, varieties of soft spring wheat were sown (Saratovskaya 42, Orenburg 13, Uchitel) with an optimal norm of 4.5 million units germinating seeds per 1 ha.

On the studied plots of grain, crop yields in crop rotation and permanent sowing were recorded after harvesting with Sampo-500, and Terrion SR2010 selection combines. Bags were manually
weighed on the platform scales, taking into account two food backgrounds with an area of 60, 120 m² and grain bunker weight was determined. The yield was calculated, resulting in relatively 14 % moisture and 100 % grain purity.

Determination of the biological activity of the soil on the plots based on the using of the decomposition method of linen "appliqués." In the second replicate of the experiment, for each nutrition background after sowing soft spring wheat, two samples were set to a depth of 0–20 cm of the soil layer, fabric strips of linen cloth on cut glass surfaces in the form of a rectangular shape. Before harvesting, samples from all crop options were manually dug up. In laboratory conditions, the weight of the paintings was found on electronic scales. The per cent decomposition of flax tissue was calculated; the difference in weight was multiplied by 100 % and divided by the mass before instillation. The activity of aerobic microorganisms (bacteria) decomposing cellulose was determined on each experiment variant. They mainly belonged to the Cytophagaceae family and to the genus Sporocytophaga (forming microcysts) and Cytophaga (non-forming microcysts). As a result, the degree of decomposition of linen expressed as a percentage established their activity in the soil environment.

At the first and third repetition of the study on plots from three wells in a 0-30 cm arable layer of soil, samples were taken using hand-held samplers to determine the amount of nitrate-nitrogen after sowing and harvesting.

Sample preparation for analysis was carried out according to GOST 26951-86 "Soils. Determination of nitrates by the ionometric method." A 20.0 g sample of soil, weighed to an error of not more than 0.1 g, was taken, placed in a conical flask, 50.0 cm³ of the primary extracting solution was poured into it and mixed on a stirrer for three minutes. In the resulting suspension, the concentration of nitrate ions was measured using the MIKON-2 kit, which included the Expert-001 microprocessor ionomer, ELIT-0.21 ion-selective electrode (nitrate), and ESr-10101 reference electrode. The measurement data were expressed in mg of nitrate-nitrogen per kg of the analyzed sample, then the value was divided by 10, and the content was obtained in mg per 100 g of soil.

The obtained data on the yield of spring soft wheat grain, the biological activity of the soil and the content of nitrate-nitrogen in the soil were statistically processed using the multiple regression analysis methods in the Statistica 10.0 computer program (Stat Soft Inc., Tusla, Oklahoma, USA).

3. Results and discussions

As a result of the observations, it was noted that various predecessors of crop rotation, including permanent sowing, and the application of mineral fertilizers affect the change in grain yield of soft spring wheat. This fact is evidenced by the data on biological activity and nitrate nitrogen in the 0–30 cm soil layer.

After the field experiments, the average results for the years 2002–2019 of the study on the activity of cellulose-degrading bacteria under crops of a grain culture for various precursors and nutritional backgrounds were calculated.

The greatest decomposition of flaxseed by soil microorganisms at a depth of 0–20 cm of soil was observed in the seventh variant of the wheat experiment after the previous pea, and the degree of decomposition amounted to 11.2 % against a fertilized background and 10.2 % from non-fertilized (Table 1).

An analysis of the results on the biological activity of the soil showed that the smallest degree of decomposition of flax tissue was observed in the first version after spring durum wheat with fertilizers and amounted to 8.4 %.

In the eighth version of the experiment, on a non-fertilized diet background, a minimal percentage of decomposition was observed after the same precursor. Thus, the level of activity of decomposition by microorganisms in various previous cultures and nutritional backgrounds ranged from 7.8 to 11.2 %.

Nitrate nitrogen was necessary for the growth and development of soft spring wheat. Changes in the content and availability of nitrates in the soil played a crucial role in obtaining crop yields. On two
nutrition backgrounds, after sowing soft spring wheat, the maximum nitrate-nitrogen content was observed in the fourth and ninth experimental variants. These indicators, respectively, amounted to 9.6 mg after corn silage on a fertilized background and 7.7 mg per 100 g of soil after soft wheat on unfertilized soil.

Table 1. Soil biological activity, nitrate-nitrogen content and wheat yield in the study areas (average for 2002–2019)

| No., predecessor     | Decomposition of linen by microorganisms on food backgrounds, % | Determination period and nitrate-nitrogen content in 0–30 cm soil layer | Productivity, centners per 1 ha after and without making N40P40 |    |
|----------------------|------------------------------------------------------------------|---------------------------------------------------------------------|---------------------------------------------------------------|----|
| I. Durum wheat       | 8.4 8.3                                                          | 7.7 7.2                                                             | 5.9 5.2                                                      | 8.9 8.5 |
| II. Durum wheat      | 9.2 8.7                                                          | 6.8 5.7                                                             | 6.4 5.4                                                      | 9.4 8.5 |
| III. Durum wheat     | 10.3 8.3                                                         | 7.3 7.1                                                             | 7.1 5.6                                                      | 9.0 8.1 |
| IV. Silage Corn      | 9.5 9.1                                                          | 9.6 6.2                                                             | 5.8 5.4                                                      | 8.3 7.9 |
| V. Millet            | 9.9 9.0                                                          | 7.8 5.8                                                             | 6.3 5.1                                                      | 9.7 9.0 |
| VI. Sorghum on Silo  | 10.7 9.9                                                         | 6.4 5.6                                                             | 5.1 3.9                                                      | 8.6 7.9 |
| VII. Peas            | 11.2 10.2                                                        | 8.4 6.2                                                             | 6.5 4.7                                                      | 9.8 9.3 |
| VIII. Durum wheat    | 9.5 7.8                                                          | 7.4 6.9                                                             | 5.5 4.7                                                      | 8.5 7.0 |
| IX. Soft wheat, unchanged | 10.0 8.7                                                      | 7.6 7.7                                                             | 5.7 4.9                                                      | 7.9 7.2 |

After harvesting the grain, the highest amount of nitrates was noted in the soil under wheat sowing after hard wheat in the third variant with 7.1 mg fertilizers and without them – 5.6 mg. According to two terms of determination and food backgrounds, the minimum number of them was sown after sorghum for silage. The content of NO$_3^-$ for all precursors varied in the range from 3.9 to 9.6 mg per 100 g of soil.

Long-term data showed that the highest yield of soft spring wheat was observed in crops after peas and millet in grain-crop rotation on a fertilized background of nutrition was 9.8 and 9.7 centners, and on non-fertilized – 9.3 and 9.0 centners per 1 ha. The lowest grain yield was observed for both nutrition backgrounds in constant sowing and amounted, respectively, to 7.9 and 7.2 centners per 1 ha.

The introduction of mineral fertilizers favourably influenced the definite increase in durum wheat yields, which amounted to 1.5 centners per 1 ha. The application of mineral fertilizers led to an increase in the indicator of soil biological activity and productivity.

For establishing the influence of each of the studied factors individually on the yield of soft spring wheat in crop rotation and permanent sowing, statistical processing of the results was carried out using the method of regression analysis.

As a result of mathematical processing of data for 18 years of observations on the experimental options using the apparatus of multiple relationships, it was found that the yield depended mainly on the activity of bacteria in the soil. A strong influence of the biological activity of the soil was noted in the fifth experiment and against a fertilized background was 71.51 % with a regression coefficient of 0.85, determination – 0.71, and on non-fertilized – 68.78 %, 0.94, and 0.68, respectively (Table 2).

The aftereffect of mineral fertilizers led to a minimal influence of the factor in the sixth version of the experiment and amounted to 36.83 %. In the eighth version of the experiment, fertilizers were not applied. The consequence of this was a decrease in the activity of microorganisms under wheat, especially in a non-steam (double-field) crop rotation. In all cases, positive regression and determination coefficients were observed. The second coefficient showed how well the regression was designed. As a result, the level of influence of the soil biological activity on productivity in all experiment variants varied from 17.92 to 71.51 %.

Figure 1 shows the dependence of the yield of soft spring wheat on the influence of the vital activity of cellulose-degrading microorganisms in the 0–20 layer of soil.
Table 2. The effect of soil biological activity on crop productivity based on the calculation of multiple regression at a level of p<0.05 for 18 years of observation

| Option No. | Fertilized Min. nut. background | Coefficients | Determinations | Factor Influence, % | B - Coefficient | R² - Coefficient | Factor Influence, % |
|------------|--------------------------------|--------------|----------------|---------------------|----------------|-----------------|---------------------|
| I. (control) | 0.87 | 0.64 | 64.41 | 0.78 | 0.59 | 59.31 |
| II. | 0.77 | 0.58 | 58.29 | 0.80 | 0.54 | 54.39 |
| III. | 0.53 | 0.41 | 41.85 | 0.87 | 0.52 | 52.18 |
| IV. | 0.83 | 0.54 | 54.24 | 0.70 | 0.43 | 43.80 |
| V. | 0.85 | 0.71 | 71.51 | 0.94 | 0.68 | 68.78 |
| VI. | 0.44 | 0.36 | 36.83 | 0.52 | 0.36 | 36.28 |
| VII. | 0.68 | 0.42 | 42.92 | 0.85 | 0.57 | 57.90 |
| VIII. | 0.42 | 0.40 | 40.14 | 0.35 | 0.17 | 17.92 |
| IX. | 0.44 | 0.38 | 38.73 | 0.57 | 0.32 | 32.34 |

Figure 1. Change in the yield of soft spring wheat after millet in a grain-crop rotation on a fertilized nutrition background, depending on the activity of microorganisms

Table 3. The effect of nitrates on wheat grain yield for three rotations of six-field crop rotation as a result of a regression analysis over 18 years of research

| No., crop rotation | Determination period of nitrate-nitrogen (NO₃⁻) | Significance level | Delta coefficient | Share of Influence, % | P - Criterion | Delta Coefficient | Share of Influence, % |
|--------------------|-----------------------------------------------|-------------------|------------------|----------------------|--------------|------------------|----------------------|
|                    | after sowing after cleaning after applying mineral fertilizers |                      |                  |                      |              |                  |                      |
| I. with black steam | 0.04 | 0.22 | 8.14 | 0.01 | 0.78 | 28.86 |
| II. with soil vapor | 0.24 | 0.01 | 0.38 | 0.01 | 0.99 | 33.82 |
| III. with green steam | 0.01 | 0.69 | 24.67 | 0.04 | 0.31 | 10.93 |
| IV. grain-cultivating | 0.87 | 0.13 | 0.05 | 0.80 | 0.87 | 0.35 |
| V. grain-steam | 0.01 | 0.63 | 23.31 | 0.02 | 0.37 | 13.69 |
| VI. grain-cultivating | 0.03 | 0.53 | 17.60 | 0.04 | 0.47 | 15.60 |
| VII. grain and steam | 0.02 | 0.57 | 20.94 | 0.03 | 0.43 | 16.06 |
| VIII. steam-free | 0.00 | 0.53 | 27.08 | 0.00 | 0.47 | 24.12 |
| IX. permanent sowing | 0.17 | 0.11 | 2.64 | 0.04 | 0.89 | 21.16 |
As a result of processing the data from the first to the fourth version of the experiment, on a non-fertilized nutrition background, there was no significant effect of the factor on the crop. From the fifth to the ninth version of the experiment, the effect of the nitrate content on the crop yield after the application of mineral fertilizers was not established.

In the eighth version with a steam-free crop rotation against an unfertilized background of nutrition, the most significant influence of 27.08 and 24.12% throughout determination of NO$_3^-$ on the yield of the grain of the crop was noted. On other variants of the experiment, mathematical data showed the least significant effect of nitrates on the yield of soft spring wheat.

4. Conclusions
As a result of the aftereffect of mineral fertilizers, the linen was decomposed by aerobic bacteria in the seventh variant of the wheat experiment after the previous pea. Therefore, their activity led to an increase in yield. The statistical processing of the data showed that the maximum activity of soil microorganisms in the fifth experiment with a fertilized nutrition background affected the increase in spring soft wheat yield after millet. In the eighth version of the experiment, bacterial activity attenuation was observed against an unfertilized diet, despite the best influence of NO$_3$ during the growing season, which led to a decrease in the yield of grain crops after spring durum wheat due to the development of root rot. The highest share of the effect of nitrate-nitrogen in the second and third variants of wheat cultivation after the application of mineral fertilizers according to the two determination periods in crop rotation with green manure and soil-protective couples reached the optimum yield level for this zone. In the fourth variant of the study, on a fertilized nutrition background, a small fraction of the effect of nitrate content in the soil after sowing and harvesting was noted, which contributed to a decrease in the yield of wheat grain after corn on silage due to excessive nitrogen accumulation. On the other variants of the experiment, an insignificant influence of factors on the crop yield was noted. In this regard, it is necessary to apply crops in agricultural production after the predecessors of peas, millet and durum wheat in grain-steam, green manure and soil-protective crop rotation using mineral fertilizers.

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Ethical Standards: All applicable international, national, and institutional guidelines have been followed.

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