The effect of nitrate nitrogen on barley yield on chernozem of the southern steppe zone of the Southern Urals

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Abstract. Increasing the yield of barley cultivated in crop rotations and by sowing permanently is a major problem in the steppe zone of the Southern Urals. This requires to study factors affecting an increase in the crop yield. The aim of the study is to identify the effect of nitrate nitrogen, the biological activity of soil and the aftereffect of predecessors on barley productivity at different levels of mineral nutrition. In the experiment, methods such as field, ionometric and decomposition of flax fiber were used. The methods used make it possible to obtain new original results on the factors and experimental options. Over 18 research years, the highest barley yield was observed in millet and pea rotation using fertilizers. It amounted to 1.42 and 1.43 tons per 1 ha. These results were achieved due to the consumption of nitrate nitrogen up to 2.3 mg and accumulation in the amount of 7.7 mg per 100 g of soil with an activity of microorganisms of 8.3 and 8.1 %. The results are of scientific and practical importance in the field of agriculture and crop production.

1. Introduction
In the arid zone of the South Ural steppes of Russia, barley is the main grain crop, which is of great importance in the manufacture of fodder. In Orenburg region, proportion of barley is 20–25 % and, due to its biological characteristics, it is a good component of field crop rotation. In this area, barley is planted in crop rotations with the last crop, with high weed and low soil fertility, but even under such circumstances, it exceeds spring wheat by 0.3–0.4 tons per 1 ha. The use of mineral fertilizers creates favorable conditions for obtaining high barley yields.

The problem of increasing barley yields has been studied by many researchers [1–6]. For the development of barley, the presence of organic matter in soil, decomposed by microorganisms is required. Under the influence of natural factors, a change in biomass and activity of biochemical processes occurs.

Some of the results emphasize the structural diversity of enzymatic systems in soil bacteria and indicate the role of numerous abundant bacterial taxa in the decomposition of cellulose [7]. The models of structural equations showed that available nitrogen is the key factor determining the dynamics of cellulose in soil [8]. The availability of NO$_3$ is important for the Arctic ecosystems when identifying the species composition, and determining nitrogen losses as a result of leaching and denitrification [9, 10].

Under the arid conditions of Orenburg region, the vital activity of various microorganisms plays a special role. During decomposition of organic matter, the relationship with the content of nitrate...
nitrogen increases, and the peak of biological activity is observed in June. Studies are aimed to establish the effect of nitrate nitrogen and biological activity of soil on barley yield for various predecessors on two nutritional backgrounds.

2. Materials and methods
The experiment was conducted in 2002–2019 at the Federal Scientific Center for Biological Systems and Agricultural Technologies of the Russian Academy of Sciences founded in 1988. The object of research is barley cultivated after various predecessors, and soil samples.

   The location of the experimental site is 51.775125 ° N and 55.306547 ° East

   The field research method was applied. Three grain-crop rotations were studied: 1. Rocker black steam – 2. Spring durum wheat – 3. Spring soft wheat – 4. Harvested field (corn for silage, millet, peas) – 5. Spring soft wheat – 6. Barley.

   The following scheme were used: I. Barley after silage corn; II. Barley in after millet; III. Barley after peas; IV. Barley after barley (monosowing).

   Barley is cultivated after various predecessors using mineral fertilizers. The plot size for the option without fertilizers is 3.6 x 60 m (216 m²), 7.2 x 60 m (432 m²) and with fertilizers (using mineral fertilizers at a dose of N40P80K40 a.e) is 3.6 x 30 (108 m²), 7.2 x 30 m (216 m²).

   The following barley varieties were sown: Donetsk 8, Anna, Natalie and Orenburg 11. Harvesting was carried out by a Sampo-500 selection combine. The grain yield was determined using the weight method. The yield was calculated taking into account 14 % moisture and 100 % grain purity.

   To assess the agrochemical and microbiological state of the southern chernozem, the ionometric method and decomposition of linen were used. To establish the nitrate nitrogen content in the arable 0–30 cm soil layer, soil samples were taken during sowing and harvesting. In the laboratory of the Federal Scientific Center, using the ionometric method, the amount of nitrates contained in a 0–30 cm soil layer was determined and converted to mg /100 g soil.

   The biological activity of soil is determined using the method of decomposition of flaxen linen buried in the soil on plots after sowing and excavated before harvesting. In laboratory conditions, the degree of decomposition of flaxseed fibers by microorganisms was established and the weight method was used to find the difference in weight between samples; then, the exact percentage of bacterial activity was calculated. This method allows us to draw conclusions about the bioactivity of cellulose-decomposing microflora by a decrease in the mass of tissue located in the arable layer.

   The data on the barley yield and soil biological activity are statistically processed in Statistica 10.0 (Stat Soft Inc., USA).

3. Results and discussion
As a result of the study, reliable data on the productivity of barley cultivated after various predecessors on two nutritional backgrounds were obtained. During the study period, barley was cultivated in various weather conditions, which confirms the value of the obtained material.

   From 2002 to 2019, the yield value was different. The growth of barley is influenced by many factors that positively or negatively affect its productivity. During the study, the effects of various precursors and mineral fertilizers, as well as biological activity and nitrate nitrogen content (depending on the background of soil nutrition) on productivity were examined.

   In the field experiment, the highest barley yield was obtained in 2017, and the maximum one was obtained in the crop rotation after millet using fertilizers. It amounted to 3.25 tons/ha (Table 1).

   In wet 2003, permanent barley sowing plays a positive role in increasing the yield with the application of mineral fertilizers. It amounted to 3.26 tons/ha compared with other experimental options.

   Under the most severe drought of 2010, the hydrothermal coefficient was 0.15 and the lowest barley yield was formed in all experiment options. In 2010, barley yields ranged from 0.12 tons (using fertilizers and sowing after peas) to 0.32 tons/ha (using fertilizers under monosowing).
Table 1. Barley yield depending on the predecessor and nutrition background by research years, t/ha

| Years | I. corn for silage | II. millet | III. peas | IV. monosowing |
|-------|-------------------|------------|-----------|----------------|
| 2002  | 1.70\(^a\) 2.33\(^b\) | 1.88\(^a\) 2.37\(^b\) | 1.92\(^a\) 2.32\(^b\) | 1.64\(^a\) 1.59\(^b\) |
| 2003  | 1.83 2.25 | 2.10 2.55 | 2.32 2.97 | 2.41 3.26 |
| 2004  | 1.41 1.48 | 1.26 2.12 | 1.83 2.43 | 1.26 0.96 |
| 2005  | 0.52 0.59 | 0.93 1.34 | 0.90 1.20 | 0.80 0.81 |
| 2006  | 0.68 0.40 | 0.87 0.63 | 1.03 0.61 | 2.13 1.64 |
| 2007  | 1.22 1.40 | 1.60 1.93 | 1.59 2.20 | 1.35 1.42 |
| 2008  | 1.69 2.09 | 1.96 2.33 | 1.90 2.23 | 1.38 1.65 |
| 2009  | 1.16 1.30 | 0.96 1.37 | 1.17 1.41 | 0.76 0.83 |
| 2010  | 0.14 0.19 | 0.17 0.13 | 0.15 0.12 | 0.16 0.32 |
| 2011  | 1.72 1.45 | 1.83 2.07 | 1.81 1.79 | 1.94 2.09 |
| 2012  | 0.69 0.59 | 0.79 0.66 | 0.75 0.57 | 0.32 0.98 |
| 2013  | 0.94 0.86 | 0.84 0.74 | 1.01 0.85 | 1.00 0.81 |
| 2014  | 0.88 0.61 | 0.85 0.54 | 0.81 0.66 | 0.79 0.73 |
| 2015  | 0.24 0.25 | 0.26 0.23 | 0.22 0.23 | 0.26 0.23 |
| 2016  | 1.08 1.23 | 1.03 1.36 | 0.92 0.98 | 0.53 0.61 |
| 2017  | 2.65 3.17 | 2.79 3.25 | 2.65 3.10 | 2.48 2.85 |
| 2018  | 0.50 0.34 | 0.52 0.20 | 0.44 0.40 | 0.44 0.37 |
| 2019  | 1.27 1.42 | 1.20 1.69 | 1.15 1.67 | 0.80 1.45 |
| HCP\(_{0.05}\) | 0.33\(^c\) 0.43\(^d\) | 0.35\(^c\) 0.47\(^d\) | 0.36\(^c\) 0.48\(^d\) | 0.38\(^c\) 0.43\(^d\) |
|       | 0.13\(^d\) 0.17\(^d\) | 0.16\(^d\) 0.17\(^d\) |

\(a\) option without fertilizers  
\(b\) option with fertilizers  
\(c\) smallest significant difference  
\(d\) NDS for two nutrition options

In most research years, barley showed a positive reaction to mineral fertilizers. In cultivating barley after silage corn and using mineral fertilizers for 12 out of 18 years, the barley yield was higher in comparison with the non-fertilized option. After millet, peas and barley, the effective use of mineral fertilizers (with an increase in yield) was observed for 11 out of 18 years.

In 2006, 2011–2014 and 2018, the negative effect of fertilizers was observed. This is due to adverse weather conditions, which negatively influenced soil processes (activation of the microbiological environment). In dry years, due to the high concentration of soil solution, biological processes were slowed down; discomfort conditions were created for the decomposition of beneficial bacteria and a deficiency of available nutrients.

As a result of mathematical processing of data on the barley yield using an analysis of variance, it was found that the smallest difference between the experimental options was not significant. The smallest significant difference between the fertilized and non-fertilized nutritional background was in the second and third options, which indicates the equality of crop yield in crop rotations after millet and peas. Data processing indicates an increase in the yield due to the aftereffect of millet and peas. An analysis of variance indicates the accuracy of calculation of the yield data, which vary from 0.12 to 3.26 t/ha.

Soil bioactivity reached its highest values in wet 2003, during which the SCC was 1.09. In barley, in the aftereffect of crop rotation with millet, the highest degree of decomposition of flaxen linen was observed. It amounted to 30 % (Table 2).

In 2003 and 2006, there was a surge in biological activity in all variants of the experiment.

Mathematical processing of data on the biological activity of soil shows that the difference is significant in the options with sowing after spring soft wheat and millet. This observation is due to the fact that in wet 2003, the highest degree of decomposition by soil microorganisms was observed using fertilizers. It differed from other crops by 5–23.8 %. An analysis of the data showed that an increase in yield in a grain-steam crop rotation with millet occurs depending on the activity of cellulose-degrading bacteria.
Table 2. The biological activity of soil (percent of decomposition of flaxen cloth) under crops of barley in six-field crop rotation and monoculture, %

| Years | GTK of the vegetation period | soft spring wheat after peas | Predecessor soft spring wheat after millet | soft spring wheat after corn | Permanent sowing of barley |
|-------|-----------------------------|-----------------------------|------------------------------------------|----------------------------|---------------------------|
| 2002  | 0.46^                  | 9.5^                      | 4.5^                                    | 9.5^                     | 5.0^                      | 11.1^                   | 11.1^                   | 19.0^                   | 5.3^                     |
| 2003  | 1.09                   | 6.2                        | 6.7                                      | 11.8                     | 30.0                      | 25.0                    | 18.7                     | 16.7                    | 18.2                     |
| 2006  | 0.63                   | 16.7                       | 27.1                                    | 13.5                     | 9.2                       | 20.0                    | 18.0                     | -                       | -                        |
| 2008  | 0.70                   | 8.3                        | 16.9                                    | 8.3                      | 16.9                      | 6.8                     | 5.5                       | 7.1                     | 11.8                     |
| 2009  | 0.56                   | 2.9                        | 4.2                                      | 4.7                      | 4.6                       | 8.8                     | 4.8                       | 4.5                     | 7.0                      |
| 2012  | 0.34                   | 5.4                        | 6.2                                      | 8.5                      | 7.8                       | 15.7                    | 6.7                       | -                       | -                        |
| 2013  | 0.82                   | 2.0                        | 2.9                                      | 4.0                      | 3.7                       | 1.9                     | 3.9                       | 6.5                     | 2.5                      |
| 2014  | 0.24                   | 8.3                        | 5.0                                      | 6.0                      | 6.2                       | 2.7                     | 6.5                       | 6.7                     | 6.0                      |
| 2015  | 0.57                   | 5.9                        | 8.3                                      | 7.1                      | 4.7                       | 4.7                     | 5.8                       | -                       | -                        |
| 2016  | 0.33                   | 2.6                        | 2.6                                      | 4.5                      | 3.0                       | 3.1                     | 8.2                       | -                       | -                        |
| 2017  | 0.46                   | 4.7                        | 3.3                                      | 5.0                      | 3.4                       | 3.5                     | 4.8                       | 3.3                     | 3.3                      |
| 2018  | 0.34                   | 6.1                        | 4.2                                      | 6.4                      | 6.5                       | 9.1                     | 9.3                       | 6.2                     | 6.5                      |
| 2019  | 0.65                   | 9.8                        | 13.0                                     | 7.7                      | 7.5                       | 7.3                     | 10.9                      | 16.4                    | 15.1                     |
| HCP005|                       |                            |                                         |                          |                           |                         |                           |                         |                           |
|       | 2.4^                   | 4.3^                      | 1.8^                                    | 4.5^                     | 4.3^                      | 2.9^                    | 4.0^                      | 3.6^                    |                           |

^a hydrothermal coefficient for the growing season  
^b option without fertilizers  
^c option with fertilizers  
^d smallest significant difference  
^e NDS for two nutrition options

The study showed a decrease in the content of nitrate nitrogen in all options. The exception is dry 2002 and 2010, when soil bioprocesses were suppressed and the applied mineral fertilizers were not used by cultivated plants, but are accumulative in nature. In such dry years, an increase in the nitrate nitrogen content was two or more times.

Over the years of research, the barley yield in crop rotations with corn was 1.17 tons, with millet – 1.31 tons, with peas – 1.34 tons, with barely – 1.25 tons/ha (Table 3).

Table 3. Barley yield depending on the content of nitrate nitrogen in a 0-30 cm soil layer and biological activity on two nutrition backgrounds for 2002–2019

| Option No., precursor | content of nitrate nitrogen in the soil, mg per 100 g of soil during sowing | Indicator during harvesting | soil biological activity, % | productivity, t/ha |
|----------------------|--------------------------------------------------------------------------|----------------------------|------------------------------|--------------------|
| I. Spring soft wheat after corn | 5.8^                      | 5.0                        | 0.8                         | 9.2                | 1.13                   |
| II. Spring soft wheat after millet | 7.0^                    | 6.0                        | 1.0                         | 8.8                | 1.22                   |
| III. Spring soft wheat after peas | 6.4^                    | 5.5                        | 0.9                         | 9.0                | 1.17                   |
| IV. Barley (monosowing) | 5.5^                   | 5.1                        | 0.4                         | 7.5                | 1.21                   |
|                      | 7.5^                   | 5.2                        | 2.3                         | 8.3                | 1.42                   |
|                      | 6.5^                   | 5.1                        | 1.3                         | 7.9                | 1.31                   |
|                      | 6.2^                   | 4.8                        | 1.4                         | 6.8                | 1.25                   |
|                      | 7.7^                   | 6.2                        | 1.5                         | 8.1                | 1.43                   |
|                      | 6.9^                   | 5.5                        | 1.4                         | 7.4                | 1.34                   |
|                      | 6.8^                   | 5.8                        | 1.0                         | 6.3                | 1.14                   |
|                      | 7.5^                   | 6.1                        | 1.4                         | 6.3                | 1.25                   |
|                      | 7.1^                   | 5.9                        | 1.2                         | 6.3                | 1.19                   |

^a option without fertilizers  
^b option with fertilizers  
^c average for two nutrition options
In crop rotations in the aftereffect of millet and peas using fertilizers, the highest barley productivity was obtained – 1.42 and 1.43 tons/ha, respectively. Such results are due to the highest consumption and accumulation of nitrate nitrogen in a 0-30 cm soil layer. The maximum nutrient consumption was observed when using fertilizers in the second experiment and amounted to 2.3 mg per 100 g of soil. The accumulation of nitrates was observed in the third option during sowing and harvesting. It amounted to 7.7 and 6.2 mg per 100 g of soil.

It is well known that, as the plant moves away from the vapor field, attenuation of microbiological processes was observed. The corn field had a similar effect on the microbiological activity. In the experiment, the aftereffect of corn affects the degree of decomposition of linen under barley and over the course of eighteen years; the highest percentage without fertilizers was 9.2, with fertilizers – 8.8%. Low bioactivity was observed for monosowing of spring barley – 6.3%. Even with the deceleration of soil processes (soil bioactivity) in barley monosowing, its yield amounted to 1.25 tons/ha when using fertilizers and 1.14 tons/ha without fertilizers.

If fertilizers are not used, a decrease in the values of the factors can be observed. By the content and consumption of nitrates, the best results were achieved during the growing season of barley in grain-crop rotations and permanent sowing on fertilized plots.

On average, certain nitrate nitrogen content and consumption was observed for various precursors using fertilizers during barley sowing, harvesting and vegetation (Figure 1).

![Figure 1](image)

**Figure 1.** The content and consumption of nitrate nitrogen during barley vegetation with fertilizers according to various predecessors, mg per 100 g of soil

The figure illustrates the advantage of barley sowing after peas. This observation is due to the biological characteristics of peas, which enrich soil with nitrogen, accumulate nitrates over several years.

The content of nitrate nitrogen in crop rotation with millet is the same as for monosowing using fertilizers. This phenomenon occurs due to the maximum biological activity of microorganisms during observation, which increased nitrate nitrogen content in soil.

**4. Conclusion**

Application of fertilizers contributed to the highest barley yield and biological activity of oil when cultivating barley after millet. The results were obtained in 2017 and 2003. Application of mineral fertilizers in wet 2003 had a positive effect on productivity. The experiment indicated a decrease in the content of nitrate nitrogen in the soil in all options. The lowest activity of microorganisms was observed for the permanent sowing of barley, and the highest one was observed after spring soft wheat and silage corn. The highest nitrate consumption increased the barley yield cultivated after millet.
using fertilizers. The cultivation of barley after peas has an advantage of accumulation of nitrate nitrogen during biological activity, which increases the yield. The results made it possible to establish an increase in the barley yield from mineral fertilizers; it varied from 0.09 to 0.21 tons/ha. To increase the yield of barley in, it is necessary to implement grain-pair crop rotation with millet and peas using fertilizers. In some cases, it is recommended to use the permanent sowing method.

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