The influence of main factors on productivity of barley in the steppe zone of the Southern Urals

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Abstract. The article shows the results of studying the influence of soil moisture, cellulose-decomposing activity of microorganisms and the amount of nutrients on the productivity of barley in crop rotations and monocrops in Orenburg region. The purpose of the experiment is to identify the effect of moisture, cellulolysic activity of soil and macronutrients (nitrates, phosphorus, potassium) on increase of barley productivity in crop rotations and during its continuous growing. The following research methods are used: field, thermostatic-weight, application-weight, ionometric and method of Machigin. In average for 2002-2021 studies, it is observed that the yield of fodder and energy units of barley increases up to 2.10, 1.63 and 1.24, 0.96 t/ha on a fertilized background of nutrition in the second and fourth variants of the experiment. The yield of feed units increases due to the use of productive moisture by the plant during the growing season in the mount of 32.3, 32.2 mm nitrates - 4.20, 1.91 mg, phosphorus - 1.76, 0.50 and potassium - 2.47, 1.01 mg/100 g of soil with cellulose-destroying activity of microorganisms - 7.93 and 10.37%. For other variants of the experiment, various indicators of the studied factors and barley productivity are registered. The influence of moisture, activity of microorganisms, nutrients on increase of barley productivity due to influence of millet and peas in crop rotations after the application of mineral fertilizers was revealed. The dependence of the yield of energy fodder units of barley in a crop rotation with millet on the content of used nitrates in the arable soil layer has been established. The results of the study are of great importance for agronomy in the steppe zone of the Southern Urals.

1. Introduction
In the arid zone of the South Ural steppes of Russia, barley is the main grain forage crop, which is of great importance in the preparation of feed for animal husbandry. The use of mineral fertilizers for the main tillage in crop rotation creates favorable conditions for obtaining a high yield of barley in the drought conditions of Orenburg region.

The drought has become more frequent in Central Europe, in the cities of Dundee, Galle, Al-Karak, Dubai and Adelaide, which leads to large losses in grain crops, especially spring field crops. The development of new varieties with increased resistance to drought and nitrogen deficiency is a key tool for increasing the productivity of barley in agriculture [1-2].

In the arid conditions of Russia, on the chernozems of the southern Orenburg Cis-Urals, there is the same problem. The most important influence on the productivity of barley is exerted by the spring moisture reserves in the arable soil layer of 0-30 cm, which accumulate up to 47.1 mm. Barley varie-
ties in conditions of water availability during the growing season contribute to the formation of various sizes of plant organs, which affect productivity [3].

On average, over 18 years of research, we observed the consumption of nitrates up to 2.3 mg by the plant during the growing season of barley with the activity of cellulose-decomposing microorganisms in the soil of 8.3%, leading to an increase in grain yield up to 1.42 t/ha [4].

Mineral fertilizers have a positive effect on barley crops. As a result of the use of mineral fertilizers at a dose of 60 kg/ha of the active substance nitrogen, phosphorus and potassium, the highest yield of barley grain was revealed up to 3.84 tons per 1 ha with a seeding rate of 5.0 million germinating seeds per 1 ha [5]. The productivity of barley is higher on the mineral background of nutrition (N_{60}P_{60}K_{60}) by 0.75–0.93 t/ha compared to unfertilized [6]. Using mineral fertilizers against the background of nutrition, the return from 1 kg of the active substance is 10.1–16.5 kg of barley grain [7]. Under the conditions of the Samara Trans-Volga region, barley is most responsive to mineral fertilizers and, as a result, the yield increases by 0.35 t/ha [8]. Under certain conditions, it is required to increase the dose of N_{60}P_{60}K_{60} by 30–50% of nitrogen and phosphorus fertilizers for barley crops cultivated for spring wheat in crop rotation due to the deficiency of these elements [9]. With an increase in the doses of nitrogen fertilizers for cultivated barley on the background of P_{60}K_{60} nutrition, the yield increases to 4.11-5.20 t/ha, under the influence of phosphorus (N_{60}P_{60}) - 4.82-4.87 t/ha, under the influence of potash (N_{60}P_{60}) - 4.34-5.34 t/ha. The average yield of barley against the background without the use of mineral fertilizers is 2.29 t/ha [10]. Under the conditions of the Samara region, the use of mineral nitrogen fertilizers with a norm of N_{60} on barley crops increases the yield by 0.33 t/ha [11].

In connection with the urgent problem of increasing grain fodder production in the arid zones of the world, studies were carried out to identify the most important factors (humidity, cellulolytic activity and soil nutrients) affecting the increase in barley productivity in crop rotations and permanent crops under dry conditions of Orenburg region.

The purpose of the study is to reveal the influence of moisture, cellulolytic activity of the soil and macronutrients on increasing the productivity of barley cultivated in crop rotations and permanent sowing on chernozems of the southern Orenburg Cis-Urals.

2. Materials and methods
The studies were carried out in 2002-2021, near the village of Nezhinka, Orenburg region. Barley crops are located on a long-term stationary plot. During the laying of the station in 1988, barley was introduced into six-field (black fallow, durum wheat, soft wheat, harvested field "corn, millet, sorghum, peas", soft wheat, barley), two-field (barley, durum wheat) crop rotations and permanent sowing. The territory of the experimental field is located on the chernozems of the southern Orenburg Cis-Urals at the coordinates 51°46′31.1"N, 55°18′42.6"E. The climate is sharply continental, mostly arid.

The objects of the study are soil samples under the studied variants and barley crops in crop rotations and permanently. The soil of the experimental area is characterized as southern clayey chernozem on dark brown calcareous ancient alluvial sandy loams. The soil layer of 0-30 cm contains 3.7% humus, 0.27% total nitrogen, 0.22% phosphorus, NO_{3} - 12.7, P_{2}O_{5} 2.2, K_{2}O 37.0 mg/100 g, pH 7.2. In soil layers 0-100 and 0-150 cm, the lowest field moisture capacity is 28 and 24%, respectively. In the carbonate, medium-thick, low-humus and heavy loamy layers of the lower soil horizon, there is a decrease in the moisture content of stable wilting, maximum hygroscopicity and moisture capacity.

In the research work, the field research method is used according to the recommendations of B.A. Dospekhov. Field experiments were laid out in four repetitions and nineteen times in time according to the following scheme: 2A × 6B, where:

- Factor A - the background of mineral nutrition of the soil: A_{1} - fertilized and A_{2} - unfertilized.
- Factor B - is a precursor of barley; B_{1} - soft wheat after corn for silage; B_{2} - soft wheat after millet; B_{3} - soft wheat after sorghum for silage; B_{4} - soft wheat after peas; B_{5} - durum wheat; B_{6} - barley.
Six variants of barley plots have a systematic or sequential placement in each repetition of the experiment. The rectangular shape of the plots has a size of $3.6 \times 90$ m$^2$ with an area of $324$ m$^2$ in the last field of six-field crop rotations and $7.2 \times 90$ m$^2$ ($S_2 = 648$ m$^2$) in two-field and permanent crops. In six-field crop rotations, the area of the plot of fertilized background of mineral nutrition is $108$ m$^2$ and unfertilized - $216$ m$^2$. In a two-field crop rotation and permanent crops, respectively, $S_2 = 216$ and $432$ m$^2$. The total area of barley crops on the experimental plot is $10368$ m$^2$ or 1.0 ha. Complex mineral fertilizers (nitrophoska, ammophoska and nitrogen-phosphorus-potassium fertilizer) were applied under the autumn moldboard plowing with the SZ-3.6 seeder at a rate of nitrogen 40, phosphorus 80 and potassium 40 kg of active substance per 1 ha. The control variant of the experiment is the unfertilized background of mineral nutrition. In the first half of May, the following varieties of barley of the Orenburg selection were sown on the field experimental plot with the SZP-3.6 seeder with a norm of $3.9$ million pcs. germinating seeds per hectare or 190 kg/ha: Orenburgsky 11, Anna, Natalie, T-12 and Miar. The accounting area of the plot is $180$ m$^2$. In the first ten days of August, grain harvesting was carried out by direct combining (Terrion SR2010) with a spread of chopped straw (mulching) over the soil surface. Modern agrotechnics and agrotechnology of barley cultivation in crop rotations and permanent crops is generally accepted for this zone.

The following methods were used in the studies: thermostatic-weight, application-weight, ionometric and Machigin. In the laboratory of the Center for Collective Use (https://xn----btbzumgw.xn--p1ai) of the Federal Research Centre for Biological Systems and Agrotechnologies of the Russian Academy of Sciences, the content of nitrates, mobile phosphorus and potassium in the arable soil layer was determined 0-30 cm. In the department of agriculture and resource-saving technologies, all observations, records, analyzes and selection of soil samples were carried out according to the recommended methods.

3. Results and Discussion

The results of the study on moisture, cellulolytic activity, the amount of soil nutrients used by the plant and the productivity of barley depend on the predecessor of crop rotation, permanent sowing and the background of mineral nutrition. This is confirmed by data on productive moisture during sowing and harvesting, the degree of decomposition of linen fabric, the amount of nutrients consumed during the growing season, and the yield of fodder and energy units.

As a result of the study in 2002-2021, the effect of soil moisture on the cellulolytic activity of microorganisms is shown depending on the aftereffects of the predecessor and the background of nutrition with and without fertilizers. The maximum content of productive moisture, taking into account precipitation (120 mm) during the growing season, is observed during the sowing and harvesting period for crops after soft wheat (millet, peas) of the second and fourth variants of the experiment and amounts to 44.1, 43.8 on a fertilized background, 11.8 and 11.6 mm with a positive deviation from unfertilized (control) by 1.8, 1.1, 0.6 and 0.3 mm (table 1). The lowest productive moisture is observed in terms of sampling (the period of sowing and harvesting) in the sixth variant of the experiment of permanent sowing of barley and is 18.6, 3.9 mm against the background of nutrition with fertilizers, with a deviation from the control by 1.2, 0.4 mm and without them - 17.4 and 3.5 mm.

The best decomposition of linen fabric by microorganisms is 17.93, 10.37% on a fertilized background with a deviation from the control by 9.35 and 1.56%. The low activity of cellulolytics in the soil after the predecessors of durum wheat in a two-field crop rotation and barley in a permanent crop is 6.97, 5.24% against the background with fertilizers (deviation from the control by 0.44 and 1.19%) and without their use - 6.53 and 4.05%. Cellulose-decomposing activity of microorganisms in the soil is observed almost at the same level and is from 8.28 to 9.37% on a fertilized background of nutrition and 7.45-7.48% on an unfertilized background according to other variants of the barley experiment after soft wheat for corn and sorghum for silage.
Table 1. The impact of productive moisture on the cellulolytic activity of soil, depending on the after-effects of the predecessor and mineral nutrition (2002-2021).

| Experiment | Barley predecessor | Indicators of observations in the soil layer 0-30 cm | | | |
| --- | --- | --- | --- | --- | |
| | | productive moisture, mm | the degree of tissue decomposition, % | in sowing | in the cleaning |
| I | corn for silage | 40.2 /40.5<sup>a</sup> | 9.6/10.5 | 8.28/7.48 |
| II | millet | 44.1/42.3 | 11.8/10.7 | 17.93/8.58 |
| III | sorghum for silage | 41.7/38.2 | 10.2/8.5 | 9.37/7.45 |
| IV | peas | 43.8/43.2 | 11.6/11.3 | 10.37/8.81 |
| V | Durum wheat | 37.1/35.2 | 8.7/8.2 | 6.97/6.53 |
| VI | barley | 18.6/17.4 | 3.9/3.5 | 5.24/4.05 |

<sup>a</sup>a before the line - nutrient background with fertilizers; <sup>b</sup>after the line - background without fertilizers.

The largest amount of nitrates consumed during the growing season is noted in the second variant of the experiment on a fertilized background of nutrition and is 4.20 mg, exceeding the unfertilized (control) by 3.32 mg/100 g of soil (Table 2). The lowest content of soil nitrates was registered in the permanent sowing of barley and amounts to 0.53 and 0.05 mg/100 g against the background of nutrition, which is 0.48 mg less than the control.

Table 2. The influence of labile forms of nutrients on increasing the productivity of barley, depending on the options for experience and mineral fertilizers (2002-2021).

| Experiment | Barley predecessor | Indicators of observations in the soil layer 0-30 cm | consumed elements, mg/100 g | yield, t/ha of arable land |
| --- | --- | --- | --- | --- |
| | | | NO<sub>3</sub> | P<sub>2</sub>O<sub>5</sub> | K<sub>2</sub>O | FU<sup>c</sup> | EFU<sup>d</sup> |
| I | corn for silage | 1.08 /0.29<sup>a</sup> | 0.28/0.27 | 0.80/1.88 | 1.41/1.30 | 0.83/0.77 |
| II | millet | 4.20/0.88 | 1.76/0.31 | 2.47/1.89 | 2.10/1.39 | 1.24/0.82 |
| III | sorghum for silage | 1.11/0.13 | 0.29/0.16 | 0.95/0.86 | 1.44/1.28 | 0.85/0.76 |
| IV | peas | 1.91/1.04 | 0.50/0.40 | 1.01/2.92 | 1.63/1.44 | 0.96/0.85 |
| V | durum wheat | 0.76/0.13 | 0.12/0.11 | 0.30/0.18 | 1.39/1.17 | 0.82/0.69 |
| VI | barley | 0.53/0.05 | 0.04/0.07 | 0.15/0.05 | 1.30/1.16 | 0.77/0.68 |
| HCP<sub>0</sub><sup>a</sup> (factor A) | | | 0.34 | 0.15 | 0.06 |
| HCP<sub>0</sub><sup>a</sup> (factor B) | | | 0.59 | 0.26 | 0.10 |

<sup>a</sup>a before the line - nutrient background with fertilizers; <sup>b</sup>after the line - background without fertilizers; <sup>c</sup>FU – fodder unit; <sup>d</sup>EFU – energetic feed unit.

The maximum amount of labile phosphorus consumed after the application of mineral fertilizers is seen in the second variant of the experiment in the aftermath of millet and is 1.76 mg with a positive deviation from the control of 1.45 mg/100 g of soil. The minimum content of the nutrient phosphorus substance is observed in the sixth variant of the experiment and is 0.04 mg with a negative deviation from the control of 0.03 mg/100 g of soil. In other variants of the experiment (I, III, IV, V), the amount of phosphorus oxide assimilated by the plant in the soil on the background of nutrition is at a certain level and ranges from 0.11 to 0.50 mg/100 g.

The highest content of the nutrient potassium used by the plant in the arable soil layer of 0-30 cm is observed in the sowing after soft wheat on millet against the background with fertilizers and is 2.47 mg higher than the control by 0.58 mg/100 g. The smallest amount of exchangeable potassium consumed is observed after the application of mineral fertilizers in permanent sowing and is 0.15 mg lower than control by 0.10 mg/100 g of soil. For other options for sowing barley, the established level of the content of the used nutrient (K<sub>2</sub>O) in the soil against the background of nutrition is visible, which is in the range from 0.18 to 1.01 mg/100 g.
As a result of the research, it was found that the highest productivity of barley is observed in the second and fourth variants of the experiment in six-field crop rotations with millet and peas. On a fertilized nutrition background, the yield is 2.10, 1.63 tons of fodder and 1.24, 0.96 tons of energy units in comparison with the unfertilized one, higher than the control by 0.71, 0.19 tons and 0.42, 0.11 tons/ha. The lowest productivity of barley is registered in the fifth and sixth variants of the experiment in a two-field crop rotation with durum wheat and permanent sowing. The yield of feed and energy units is 1.39, 1.30 t and 0.82, 0.77 t/ha against the background with fertilizers and 1.17, 1.16 t and 0.69, 0.68 t/ha, respectively. In the first and third sowing options, as a result of the aftereffect of forage crops (corn and sorghum for silage), a low range of barley productivity is observed and amounts to 1.28 to 1.44 t of fodder and 0.76-0.85 t/ha of energy units against the background of nutrition.

As a result of the analysis of the two-factor experiment, it was revealed that the smallest significant difference in the content of nutrients and the yield of fodder, energy units (HCP05 A = 0.34, 0.15, 0.06, HCP05 B = 0.59, 0.26, 0.10) is observed for the fertilized nutrition background (factor A) in contrast to unfertilized (control) and barley precursor (factor B), soft wheat after millet and peas. The observation showed the influence of the second and fourth variants of the experiment on the increase in the productivity of barley after the application of mineral fertilizers compared with the control.

The best effect on increasing the productivity of barley is exerted by the nitrates used during the growing season on a fertilized nutritional background. After the application of mineral fertilizers, a positive dependence of barley productivity on the effect of manorial nitrates by the plant in the soil layer of 0-30 cm is observed. The spring soil moisture increases, which contributes to the favorable vital activity of the microflora under barley sowing in the aftereffect of millet and peas.

Based on the study, we recommend to introduce crops in crop rotations with millet and peas using complex mineral fertilizers at a dose of N40P80K40 kg/ha of the active substance in the arid conditions of the Orenburg region in order to obtain about 2 tons per 1 ha of barley productivity in agricultural production.

4. Conclusion
As a result of the aftereffects of millet and peas on barley crops and after the application of mineral fertilizers, an increase in productivity to 2.10, 1.63 tons of fodder and 1.24, 0.96 t/ha of energy units is observed in the second and fourth variants of the experiment. The productive moisture applied by the plant during the growing season (32.3; 32.2 mm) leads to the best cellulolytic activity (17.93; 10.37%) in the soil layer of 0-30 cm on a fertilized background of nutrition, which increases the productivity of barley in six-field crop rotations with millet and peas. Based on other variants of the experiment after the application of mineral fertilizers, an insignificant effect of moisture, cellulolytic activity of soil and labile forms of nutrients on increasing the productivity of barley was obtained. Based on the results of the research, the influence of the content of nitrates, phosphorus and potassium used by the plant (4.20, 1.76, 2.47 mg/100 g of soil) on the growth of barley productivity was established. In the experiment, the dependence of the yield of energy feed units of barley in a crop rotation with millet on the assimilated nitrates by the plant in the arable soil layer was determined.

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