Mobile forms effect of nutrients on grain yield productivity in crop rotation on soil-protecting experimental plot

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Abstract. On soils subject to water and wind erosion, there is a decrease in the content of macronutrients and grain yield of crops on various parts of the slope. This phenomenon was a prerequisite for the study of mobile forms of nutrients (NO₃⁻, P₂O₅, K₂O) and their effect on the yield of grain crops in grain-crop rotation in the soil-protecting experimental plot. The main goal of scientific research is to identify parts of the slope and crops that can increase grain yield depending on nutrients. As a result of field experiments and laboratory analyzes, it was found that the highest yield is observed in the twelfth version of the experiment in barley sowing with biological accounting of 15.6 centners and actual counting is 12.7 centners per 1 ha. On the lower part of the slope, this result was achieved based on the relationship between nitrate nitrogen, mobile phosphorus, and exchange potassium, and their influence on the maximum barley yield was 30.63, 28.65, and 39.52 %. The conducted experiment is important in the field of agricultural soil science, contour landscape agriculture and agriculture.

1. Introduction
In the Russian Federation, crop rotation is the central link in any farming system. In the arid conditions of the steppe zone of the Southern Urals, grain-steam crop rotation with black steam plays a decisive role in stabilizing grain production and increasing crop yields.

Among the main factors affecting crop yields, we can especially single out the content in the soil of the macronutrients necessary for plant nutrition. To solve the problem of increasing grain yield, one of the main methods is used, which consists in studying the content of mobile forms of nutrients in the soil and their influence on the growth and development of crops.

The main stages of the use of nitrogen are absorption and transportation, restoration and assimilation. Many studies have been conducted on the genes of the cultures involved in these phases, and on the transcription factors that regulate these genes [1]. The discovery of microRNAs involved in the reaction to nitrogen stress represents an important step towards functional analysis with the development of a strategy to increase the efficiency of nitrogen utilization in durum wheat [2]. Besides, researchers in a field experiment found that transgenic wheat lines expressing TaNAC2-5A had higher yields due to the accumulation of nitrogen in the soil and its high content in grain. These results indicate that the transcription factor is involved in the signalling of nitrates and shows that it is an exciting gene resource for breeding crops with more efficient use of fertilizers [3].

Field and virtual results of modelling the selection of the root from the soil showed that the volume of living bark by the length of the root decreased with depth in young plants. Ageing of the root bark can be an adaptive feature for obtaining nutrients (nitrogen, phosphorus, potassium) by redistributing...
them from ageing tissue and by reducing root respiration [4] and adaptation of wheat to soil phosphorus in conditions of intensive agriculture [5] and the potassium content in tissues and the level of drought tolerance between barley genotypes [6].

In this regard, the supply of mineral nutrients is of primary importance for maintaining crop productivity [7]. Many scientists investigate the increase in wheat and barley grain yield depending on various other factors and attributes [8–16].

The Orenburg Trans-Urals, the territory of Russia east of the Ural Mountains, is the principal scientific training ground for the study of crops on various parts of the slope in the conditions of southern chernozems susceptible to water and wind erosion of the soil. In this regard, the experiment was aimed at identifying parts of the slope and crops to increase productivity depending on the nutritional regime of the soil.

2. Materials and methods

The research work was carried out on a sizeable experimental field (established in 1987) on the soil-protective agriculture of the Federal Scientific Center in the FSUE “Soviet Russia” in the village “Elizavetinka” of the Adamovsky district of the Orenburg region. The study was carried out by the Department of Agriculture and Resource-Saving Technologies from 2014 to 2019 in the southern chernozems of the Trans-Urals. The laying of field experiments took place on medium-power heavy loamy soils subject to water and wind erosion, with the contour-strip organization of arable slopes located in the north-eastern part of the exposition.

The slope on the territory was divided into three parts: the upper one with a slope of 2–3°, the middle – 1–2° and the lower – 0–1°. On all parts of the slope, the length was 400 m, the width was 500 m. On the experimental plot, we studied three grain-steam crop rotation, placed pairs and crops in them according to the following options: I. Black steam, II. Durum wheat, III. Soft Wheat, IV. Barley – crop rotation in the upper part of the slope (control); V. Black steam, VI. Durum wheat, vii. Soft Wheat, VIII. Barley is in crop rotation in the middle part of the slope; IX. Black steam, X. Durum wheat, XI. Soft Wheat, XII. Barley is in crop rotation in the lower part of the slope.

The research method was a field experiment. The repetition of the experiment is three times in space and six times in time. At each replicate, the plots were rectangular with a size of 40 m x 160.7 m and $S^2 = 6428$ m$^2$. The total area of the experimental field was 60 ha. Crop rotation occupied 48 hectares, buffer strips (from perennial grasses) – 10.8 hectares, single-row shrubbery scenes (from golden currant) – 1.2 hectares.

On the plots of the field experiment were sown:
- zoned durum wheat varieties: Kharkivskaya 46, Orenburgskaya 10 and Orenburgskaya 21,
- zoned soft wheat varieties: Saratovskaya 42, Uchitel, Varyag, Orenburgskaya 13,
- zoned barley varieties: Anna, Natalie, Pervotselinnik.

Biological accounting of yields was carried out manually in the phase of complete ripening of the grain. Before harvesting, the sheaves were selected from 1 m$^2$ in ten replicates for all-grain plots and repetitions using acid (iron frames). As a result of the structural analysis of the sheaf material of grain crops, biological productivity was determined, that is, the average weight of grain in g from 1 m$^2$ was weighed and found in kg from 1 ha. Actual crop accounting was carried out using direct harvesting. From each plot, the bunker weight of the grain was weighed on specialized scales, and the yield was determined per centner per 1 ha of area, taking into account all standard indicators, that is, at 14 % moisture and 100 % grain purity.

On each part of the slope, soil samples were taken at two repetitions of the experiment with a hand drill at three points at a depth of 0-30 cm in the soil layer for all studied plots. The content of nitrate nitrogen, mobile phosphorus, and exchange potassium in soil samples was determined using the ionometric method and the Machigin method, according to GOST 26951-86 and 26205-91. Analyzes were carried out in the laboratories of the Federal Scientific Center for Biological Systems and Agricultural Technologies of the Russian Academy of Sciences.
For analysis using the ionometric method, a basic extracting solution (a solution of potassium alum with a mass fraction of 1 %) was prepared, which was added to a twenty-gram soil sample and shaken for three minutes. In the soil solution, the amount of NO₃⁻ was determined using the special “I-160” ionomer. The device automatically produced the measurement results in the required units of nitrate content in the selected soil sample (mg/kg) and displayed them on display. The data obtained were converted in mg per 100 g of soil.

The essence of the Machigin method is to extract the mobile forms of phosphorus and potassium from the soil with a solution of one per cent ammonium carbonate with soil to solution ratio of 1:20, the duration of shaking was 5 minutes, and the subsequent settling was 18–20 hours. The extraction of phosphorus and potassium from the soil was carried out at a temperature of 25±2 °C. The determination of phosphorus in the extract was carried out by the photocolorimetric method according to the colour intensity of molybdenum blue. As a molybdenum reducing agent, ascorbic acid was used in the presence of antimony, which acts as a catalyst. Oxidizing with permanganate, the extract was stained with organic matter. Extracted potassium was determined on a flame photometer.

For determining P₂O₅, solution samples were prepared: chemically pure monosubstituted potassium phosphorus (KH₂PO₄) 0.19 g was dissolved in a 1 % solution of (NH₄)₂CO₃ in a 1000 ml volumetric flask. The resulting standard solution contained 0.1 mg of P₂O₅ in 1 ml and was the initial one for the preparation of a spare scale of standard solutions. According to a particular table, the quantities of the initial solution (KH₂PO₄) were taken into volumetric flasks with a capacity of 500 ml and their volumes were adjusted to the marks of a 1 % solution of (NH₄)₂CO₃.

During the analysis, 5 g of air-dry soil, weighed and sifted through a sieve with holes with a diameter of 2 mm, was weighed on a balance and poured into 200 ml bottles installed in ten-position cartridges. From a ten-position dispenser, 100 ml of one per cent (NH₄)₂CO₃ are poured onto the weighed portions, the bottles are corked, and the mixture is shaken for 5 minutes with a shaker. After shaking the hoods, the cassettes were placed in a thermostat and left them at 25±2 °C for 18–20 hours. The next day, the cassettes were shaken by hand, and the suspension was filtered. 15 ml samples were taken from the filtrates with a syringe dispenser into conical heat-resistant flasks installed in stainless steel cassettes. For the extract samples, a 2 ml mixture of H₂SO₄ and KMnO₄ was added with a dispenser, and the solutions were boiled in a heating unit for 2 minutes. After cooling, 36 ml of staining reagent were poured into the flasks and mixed. Filtered solutions with a red filter no earlier than 10 minutes after staining. Thus, according to the table and calculation formula, the content of mobile phosphorus mg/kg of soil was determined, translating it in mg per 100 g of soil.

Samples of solutions for determining K₂O were prepared: chemically pure KCl was placed in a 1000 ml volumetric flask, dissolved in a 1 % solution of (NH₄)₂CO₃, and the solution was brought up to 1 litre. The solution contained 0.5 mg K₂O in 1 ml and was the standard for preparing standard solutions. Preparation of a spare scale is based on the quantities of the initial KCl solution indicated in the special table were selected in 500 ml volumetric flasks. The volumes of the solutions were adjusted to the marks with a filtered one per cent solution of (NH₄)₂CO₃. After analysis of mobile phosphorus, K₂O was determined on a remaining filtrate using a flame photometer. In this regard, according to the table and the formula, the content of exchangeable potassium in mg per 100 g of soil was calculated.

As a result of the study, the obtained data on the yield of grain crops and the content of mobile forms of nutrients in the soil were mathematically processed using a systematic analysis of multiple regression in the statistical program “Statistica 10.0” (Stat Soft Inc., USA).

3. Results and discussions
Based on the obtained data, it was found that the content of mobile forms of nutrients in the 0–30 cm soil layer and the level of crop productivity in crop rotation depended on different parts of the slope.

As a result of the action of autotrophic microorganisms in the arable soil layer, an intensive nitrification process took place on the middle part of the slope in the phase of full germination of crops. The nitrate content in the crops of durum wheat was 16.3 mg, soft wheat was 13.6 mg and barley was 13.5 mg per 100 g of soil (Table 1).
Over the years, the most significant amount of nitrate-nitrogen was observed in black vapour over the entire slope as a result of humus mineralization and amounted to 21.1 mg on the upper part of the slope, 22.1 mg on the middle part of the slope and 22.5 mg on the lower part of the slope. The maximum content of mobile phosphorus was noted in all variants of the experiment in a grain-vapour crop rotation on the middle part of the slope. It amounted to 4.3 to 4.5 mg in the phase of complete seedlings. High supply of soil with exchange potassium led to the accumulation of its amount in black vapours in the first, fifth and ninth variants of the experiment up to 36.5, 36.7, 38.9 mg. In cereal crops, a high K$_2$O content was observed in the phase of full germination and heading in the sixth, eleventh, and twelfth versions of the experiment.

The number of accumulated nitrates and exchange potassium was noted in black vapour over the entire slope, and its range was from 0.1 to 11.6 mg per 100 g of soil. This fact is explained by the lack of a source of consumption (cultivated plants) and a good supply of nutrients in the soil. The lost content of mobile forms of nutrients during the growing season was observed for all variants of the experience of grain crops in three parts of the slope, and their level was from 0.6 to 8.5 mg.

### Table 1. The content of mobile forms of nutrients in the 0-30 cm soil layer and crop yields in grain-crop rotation on the upper, middle and lower parts of the slope (average for 2014-2019)

| No. of option, steam, culture | The content of soil macronutrients during the growing season, mg per 100 g of soil | The number of nutrients in the soil during the growing season, mg | Productivity, centners per 1 ha |
|-------------------------------|----------------------------------|------------------|------------------|
| I. Black steam | $\text{NO}_3$ | P$_2$O$_5$ | K$_2$O | nitrate-nitrogen mobile phosphorus exchange potassium |
| The upper part of the slope with a slope of $2–3^\circ$ (control) | 11.2/21.1 | 4.3/3.6 | 34.8/36.5 | 9.9 | 0.7 | 1.7 |
| II. Durum wheat | 11.8/5.7 | 4.2/3.0 | 34.0/31.7 | 6.1 | 1.2 | 2.3 |
| III. Soft wheat | 12.8/5.9 | 4.0/3.4 | 35.7/32.4 | 6.9 | 0.6 | 3.3 |
| IV. Barley | 12.6/5.6 | 4.1/3.4 | 36.0/31.4 | 7.0 | 0.7 | 4.6 |
| The middle part of the slope with a slope of $1–2^\circ$ | | | | | | |
| V. Black steam | 10.5/22.1 | 4.4/4.2 | 36.6/36.7 | 11.6 | 0.2 | 0.1 |
| VI. Durum wheat | 16.3/7.8 | 4.3/3.2 | 36.5/33.8 | 8.5 | 1.1 | 0.4 |
| VII. Soft wheat | 13.6/7.3 | 4.5/3.3 | 36.5/32.2 | 6.3 | 1.2 | 4.3 |
| VIII. Barley | 13.5/6.2 | 4.5/3.0 | 34.1/30.9 | 7.3 | 1.5 | 3.2 |
| The lower part of the slope with a slope of $0–1^\circ$ | | | | | | |
| IX. Black steam | 11.2/22.5 | 4.1/3.9 | 38.3/38.9 | 11.3 | 0.2 | 0.6 |
| X. Durum wheat | 13.6/7.4 | 4.3/3.5 | 35.9/32.5 | 6.2 | 0.8 | 3.4 |
| XI. Soft wheat | 11.9/7.4 | 4.2/3.6 | 36.8/34.7 | 4.5 | 0.6 | 2.1 |
| XII. Barley | 11.9/5.8 | 4.4/3.6 | 36.6/33.8 | 6.1 | 0.8 | 2.8 |

| a before the line – in the phase of full germination, after the line – in the phase of earing |
| b part of the accumulated substance in the soil |
| c part of the lost substance in the soil |
| d before the line – biological accounting, after the line – actual accounting using a combine |

B On average, over the years of the experiment, the highest yield of crops was observed on the lower part of the slope. The highest yield of grain was shown by barley sowing in the twelfth experiment. It amounted to 15.7 centners per hectare, taking into account the analysis of sheaf material (actual), 12.7 centners per 1 ha. Positive results were achieved due to the highest availability of soil moisture and the influence of macropells.

As a result of mathematical processing of the obtained data, it was found that the nitrate-nitrogen content influenced the dairy wheat grain biological productivity in the full germination phase and its share on the upper part of the slope was 74.51 % and on the middle part of the slope was 43.80 %. The effect of nitrates on other cultures was not observed in these parts of the slope. On the upper and middle parts of the slope, the amount of mobile phosphorus and exchange potassium did not affect the yield of grain crops.
Statistical processing of the results showed positive data on beta, regression coefficients, Student's test and amounted to 1.22, 2.53, 8.91 for nitrate-nitrogen and 0.55, 4.35, 6.45 units for mobile phosphorus, respectively (Table 2).

### Table 2. Dependence of increasing the biological productivity of barley after soft wheat in a grain-crop rotation on the lower part of the slope on the relationship of the content of mobile forms of nutrients in the heading phase for 2014–2019

| Multiple Regression Indicators | y – intersection (free term) | Nitrate-nitrogen \((\text{NO}_3^-)\) | Mobile phosphorus \((\text{P}_2\text{O}_5)\) | Exchange potassium \((\text{K}_2\text{O})\) |
|-------------------------------|-----------------------------|-----------------|-------------------|------------------|
| **B-factor beta**             | –                           | 1.22            | 0.55              | -1.48            |
| **Beta Standard Error**       | –                           | 0.14            | 0.08              | 0.13             |
| **R – regression coefficient**| 52.78                       | 2.53            | 4.35              | -1.99            |
| **Regression Standard Error** | 5.12                        | 0.28            | 0.67              | 0.18             |
| **Student T-test (2)**        | 10.30                       | 8.91            | 6.45              | -11.2            |
| **P – significance level**    | 0.00                        | 0.01            | 0.02              | 0.00             |
| **Δ – coefficient delta**     | –                           | 0.31            | 0.29              | 0.40             |
| **The share of the influence of the factor, %** | – | 30.63 | 28.65 | 39.52 |

* the correlation coefficient is 0.99; the determination coefficient is 0.98; the Fisher criterion (3.2) is 57.24; the standard error of the estimate is 0.78 kg s 1 ha with significance levels <0.01.

In this regard, these indicators of exchange potassium differed in negative data in comparison with other values. The highest regression coefficient and student criterion were observed for the free term and amounted to 52.78 and 10.30 units. The smallest standard error of beta and regression was observed for the elements \(\text{P}_2\text{O}_5\), \(\text{K}_2\text{O}\) and contained 0.08, 0.18 compared to \(y\) – the intersection of 5.12 units. The significance level of the equation for all factors of the independent variable ranged from 0.00 to 0.02, with a set value of \(p <0.05\). The delta coefficient for nutrients was distributed differently and amounted to the highest value for potassium oxide 0.40 and the lowest for phosphorus oxide 0.29 units. Delta provided the determination of the share of influence of each factor by the ratio of pair correlation coefficients to beta and determination. The correlation and determination coefficients of the model were 0.99, 0.98 and showed that multiple regression was calculated 99 % accurately and 98 % better. When comparing the variance estimates, the Fisher criterion with a degree of freedom of 3.2 was 57.24 units, which is optimal for the model.

As a result of the calculated multiple regression, the relationship between the mobile forms of nutrients and productivity was established, since the significance level is less than 0.01 with a standard estimation error of 0.78 centners per 1 ha. Based on the calculations, a common effect of nutritional elements on increasing barley grain yield was revealed, and their share in nitrate-nitrogen was 30.63, mobile phosphorus 28.65, and exchange potassium 39.52 %.

### 4. Conclusions

The study showed that an increase in the yield of grain crops was observed on the lower part of the slope and did not depend on the influence of mobile forms of nutrients, except for sowing barley. As a result of the data obtained and processed using multiple regression, it was revealed that the highest biological productivity is observed due to the combined effect of nitrate nitrogen, mobile phosphorus and metabolic potassium on the lower part of the slope. In this regard, a mathematical model is constructed of the dependence of increasing the biological productivity of barley after the predecessor soft wheat in a grain-crop rotation on the lower part of the slope on the relationship between the content of macronutrients in the earing phase. This model proves the need for barley to consume batteries for high grain yield. In agriculture, to increase the forage base of animal husbandry on soils subject to water erosion and deflation, it is necessary to introduce barley crops after soft wheat in grain-crop rotation on the lower parts of the slope using buffer strips and wings. On the lower and
middle parts of the slope, farmers are advised to develop hard and soft wheat crops, and on the upper – perennial grasses.

Acknowledgments
The studies were carried out in accordance with the research plan for 2019–2020 of the Federal Research Center for Biological Systems and Agrotechnology of the Russian Academy of Sciences (№ 0761-2019-0003).

Conflict of Interest: The authors declare that they have no conflict of interest.

Ethical standards: All applicable international, national, and institutional guidelines for animal care and use have been followed.

References
[1] Zuluaga D L and Sonnante G 2019 The Use of Nitrogen and Its Regulation in Cereals: Structural Genes, Transcription Factors, and the Role of miRNAs Plants (Basel) 8(8) 294–15
[2] Zuluaga D L, De Paola D, Janni M et al 2017 Durum wheat miRNAs in response to nitrogen starvation at the grain filling stage PLoS One 12(8) e0183253–18
[3] He Xue, Qu Baoyuan, Li Wenjing et al 2015 The Nitrate-Inducible NAC Transcription Factor TaNAC2-5A Controls Nitrate Response and Increases Wheat Yield Plant Physiol. 169(3) 1991–2005
[4] Schneider H M, Postma J A, Wojciechowski T et al 2017 Root Cortical Senescence Improves Growth under Suboptimal Availability of N, P, and K Plant Physiol. 174(4) 2333–47
[5] Teng Wan, Deng Yan, Chen Xin-Ping et al 2013 Characterization of root response to phosphorus supply from morphology to gene analysis in field-grown wheat J. Exp. Bot. 64(5) 1403–11
[6] Cai Kangfeng, Gao Huaizhou, Wu Xiaojian et al 2019 The Ability to Regulate Transmembrane Potassium Transport in Root Is Critical for Drought Tolerance in Barley Int. J. Mol. Sci. 20(17) 4111–22
[7] Raddatz Natalia, de los Ríos Laura Morales, Lindahl Marika et al 2020 Coordinated Transport of Nitrate, Potassium, and Sodium Front Plant Sci. 11 247–18
[8] Korotkova A, Sizova E and Lebedev S Nov. 2015 Influence of iron of nanoparticles on induction of oxidative damage in triticum vulgare Ecol., Environment and Conservat. 21(suppl. iss.) 101–11
[9] Korotkova A M, Lebedev S V and Gavrish I A 2017 The study of mechanisms of biological activity of copper oxide nanoparticle CuO in the test for seedling roots of Triticum vulgare Environ Sci. Pollut. Res. Int. Apr 6; 24(11) 10220–33 DOI:10.1007/s11356-017-8549-9
[10] Korotkova A M, Sizova E A and Lebedev S V 2015 Influence of NPs Ni° on the induction of oxidative damage in Triticum vulgare Oriental J. of Chem. 31 137–45 Retrieved from: http://dx.doi.org/10.13005/ojc/31.Special-Issue1.17
[11] Korotkova, Gavrish I, Lebedev S and Halikov B July 2019 Comparative analysis of cell viability of Triticum vulgare after exposure to copper nanoparticles Febs Openbio Abstracts submitted to the 44th FEBS Congress, taking place in Krakow, Poland from 6th to 11th July 2019, and accepted by the Congress Organizing Committee are published in this Supplement of FEBS Open Bio. Vol 9 Suppl. 1 303 p DOI: 10.1002/2211-5463.12675
[12] Galaktionova L, Gavrish I and Lebedev S 2019 Bioeffects of Zn and Cu Nanoparticles in Soil Systems Toxicol. Environ. Health Sci. 11 259–70 DOI: 10.1007/s13530-019-0413-5
[13] Lebedev S, Gavrish I, Galaktionova L, Korotkova A M and Sizova E 2019 Assessment of the toxicity of silicon nanooxide in relation to various components of the agroecosystem under the conditions of the model experiment Environmental geochemistry and health 41(2) 769–82 Retrieved from: https://doi.org/10.1007/s10653-018-0171-3
[14] Peng F Y., Hu Zhiqiu and Yang Rong-Cai 2015 Genome-Wide Comparative Analysis of Flowering-Related Genes in Arabidopsis, Wheat, and Barley *Int. J. Plant Genomics* **2015** 874361–17

[15] Lebedev S, Korotkova A and Osipova E 2014 Influence of Fe0 nanoparticles, magnetite Fe3O4 nanoparticles, and iron (II) sulfate (FeSO4) solutions on the content of photosynthetic pigments in Triticum vulgare *Russ. J. of Plant Physiol.* **61(4)** 564–9 DOI: 10.1134/S1021443714040128

[16] González-Ribot Gerlitt, Opazo Marcela, Silva Paola and Acevedo Edmundo 2017 Traits Explaining Durum Wheat (Triticum turgidum L. spp. Durum) Yield in Dry Chilean Mediterranean Environments *Front Plant Sci.* **8** 1781–11