Response of cellulose-decomposing activity of microorganisms and nutrients to long-term cultivation of durum wheat

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Abstract. Determination of the main factors affecting the productivity of durum wheat is a prerequisite for studying the activity of soil microorganisms and the content of mobile forms of nutrients (NO₃⁻, P₂O₅, K₂O) on the chernozems of the Cis-Ural region. The aim of the study is to detect the response of each studied factor separately to an increase in yield for different predecessors of crop rotations. Studies of these factors are conducted for the first time in the field and in the laboratory. In the research work the field, application, ionometric and Machigina methods of the experiment on durum wheat are used. Positive results for 19 years of observations are observed in the second variant of the experiment. They lead to an increase in the yield of durum wheat grain after black steam to 9.2 c from 1 ha. The dependence on the influence of the activity of microorganisms and the content of macronutrients of nutrition consists 51.62; 52.43; 35.27 and 36.80%. A decrease in the biological activity of the soil leads to a low yield level in the seventh variant of sowing, reaching up to 5.1 c per 1 ha, despite the response of nitrates 45.45%, mobile phosphorus 31.91 and exchangeable potassium 42.63%. The results of the study have a major importance in the field of soil science, farming and agriculture.

1. Introduction

The organic soil matter consists of about 5-20% carbon and 8-14% cellulose. Their low content in the soil leads to the rapid decomposition of plant biomass consisting of 70% cellulose [1]. It is usually considered to be more unstable and decomposes in the growing residues faster than lignin due to its chemical composition and structure [2-3]. The destruction of cellulose in the soil occurs exclusively due to biological processes [4]. Crop residues contain significant amounts of organically bound nutrients, such as nitrogen and phosphorus. They may not be available for subsequent consumption by plants, so a biological decomposition process is necessary [5-6]. Studies on the decomposition of wheat straw (consisting of polymers: cellulose, hemicellulose and lignin) were carried out at an agricultural experimental station in China. The annual experiment showed temporary losses of carbon, nitrogen, and changes in the mass and chemical composition (NPK) of wheat straw residues in anaerobic and aerobic soil conditions [7]. In Tunisia, the influence of nitrates on the growth and development of various varieties of hard wheat was studied. As a result of the study, it was found that the supply of nitrogen to the plants caused an increase in the height of the footstalk in all varieties to varying degrees [8]. Some researchers have conducted research work to study the effect of different mobile phosphorus inputs from plant roots on its separation and renewal in two durum wheat varieties with a biomass distribution. The
results of the study showed that the nutrition of durum wheat varieties with phosphorus was limited after flowering and endogenous remobilization of phosphorus and can support grain growth with insignificant yield losses [9]. Intensive farming and crop systems require optimal potash nutrition. Depending on the increase in the content of exchangeable potassium in the soils, the regions of India were grouped into nine categories. As a result, specific recommendations for its sustainable management in soils and agricultural crops are proposed [10].

In the scientific field, many researchers [11-16] and others are engaged in studying the productivity and decomposition of wheat straw cellulose under various conditions and directions.

Orenburg Cis-Ural region is Russia territory, which adjacent to the western slope of the Urals. It is the main scientific center of research on crop rotations and monocrops. Identification of the main factors affecting the productivity of durum wheat in the arid conditions of the Orenburg region is one of the tasks of the dry farming system. In this regard, studies are being conducted on the effect of the cellulose-decomposing activity of soil microorganisms and mobile forms of nutrients on durum wheat crops in crop rotations and during monocrop cultivation on the chernozems of the southern Orenburg Cis-Ural region.

2. Materials and methods

Field studies were conducted from 2002 to 2020 on the territory of the former OPH named Kui-byshev near the Nezhinka village, Orenburg district. The experiment was conducted on a long-term stationary experimental site for crop rotations and monocrops, which was founded in 1988 by the Orenburg Research Institute of Agriculture.

In the field experiment, we consider a scheme that includes ten options for growing durum wheat on previous crops in six-field, two-field rotations and monocrop: 1) durum wheat for winter crops (wheat, rye); 2) durum wheat for black steam; 3) durum wheat for soil-protecting steam (Sudan grass); 4) durum wheat for sideral steam (oats + peas); 5) durum wheat for maize for silage; 6) durum wheat for soft wheat; 7) durum wheat for millet; 8) durum wheat for barley; 9) durum wheat for peas; 10) monoculture of durum wheat.

In the scientific work, the field method of research is used according to the recommendations of B. A. Dospekhov. Field plots on a stationary experimental site are studied fourfold over the nineteen-year period of the study. The plots have a rectangular shape with dimensions of: 14.4 × 60 m with an area of 864 m² in six-field crop rotations, 7.2 × 60 m with S² = 432 m² in double-field crop rotations and monocrop, 3.6 × 60 m with S² = 216 m² in alternating with peas. The total area of the field experiment is 23328 m² or 2.3 ha.

In the experimental plots in the first half of May, durum wheat varieties (Orenburg 10 and Orenburg 21) with the recommended norm for this zone of 4.0 million pieces of germinating seeds per 1 ha were sown using the SZP-3.6 seeder. The crops were rolled up with rollers 3KKSH-6. In the second half of August, the yield of durum wheat grain in monocrops and continuous sowing on an area of 120 m² was recorded using the Terrion SR2010 selection combine.

To assess the biological activity of the soil of the southern chernozem on the studied plots, the application method of decomposition of flax linen with the help of the vital activity of cellulose-decomposing microorganisms is used. On each plot after durum wheat sowing (II-decade of May) in the second repetition of the experiment, two samples were installed, representing glass rectangles wrapped in flax linen. They were buried to a depth of 0-20 cm of the soil layer. At the end of the growing season (II-decade of August), durum wheat samples were dug out in all plots. In laboratory conditions, the degree of decomposition was determined by weight loss of linen (the incubation period of the fabric is three months).

In the plots of the first and third repetition of the experiment, samples were taken at a depth of 0-30 cm of the soil layer using manual samplers during the sowing and harvesting of durum wheat. The content of nitrates, mobile phosphorus and exchangeable potassium in the soil was determined both by the nometric method and by the Machigin method under laboratory conditions. Soil samples were analyzed according to GOST 26951-86 and 26205-91.
The results of the study on the yield of durum wheat, the cellulose-decomposing activity of microorganisms and the nitrates content, mobile phosphorus and exchangeable potassium were mathematically processed using the method of multiple regression in the statistical program "Statistica 12.0" ("Stat Soft Inc.", USA).

3. Results and discussions

As a result of observations from 2002 to 2020, the average degree of decomposition of flax linen under durum wheat crops was established for various predecessors of crop rotations and monocrops. The best activity of soil microorganisms at a depth of 0-20 cm is observed in the fourth variant of the experiment of growing durum wheat after sidereal steam and is 12.6% (table 1). Due to the aftereffect of the sidereal culture (peas), the content of organic matter in the soil increases, which stimulates the production of nitric nitrogen and leads to an increase in the cellulose-decomposing activity of microorganisms.

Table 1. Results on the cellulose-decomposing activity of microorganisms, nutrients and yield of durum wheat, depending on the precursor and the determination period (2002-2020).

| Variant №, predecessor | Degree of decomposition of the tissue, % | Content of mobile forms of nutrients in the 0-30 cm layer of soil, mg per 100 g during the sowing period | Grain yield, c per 1 ha during the harvesting period | NO₃ | P₂O₅ | K₂O |
|------------------------|----------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------|------|------|------|
| 1. Winter crops (control) | 10.7 | 6.8 | 4.4 | 41.0 | 5.9 | 4.2 | 40.1 | 7.6 |
| 2. Steam black | 10.8 | 6.4 | 4.5 | 39.7 | 6.2 | 4.1 | 39.1 | 9.2 |
| 3. Soil-protection steam | 10.1 | 6.3 | 4.4 | 38.3 | 6.2 | 4.0 | 38.0 | 8.0 |
| 4. Sideral steam | 12.6 | 8.0 | 4.3 | 38.9 | 6.5 | 4.2 | 37.0 | 8.5 |
| 5. Maize for silage | 9.9 | 7.7 | 4.1 | 37.4 | 5.8 | 4.0 | 33.7 | 7.3 |
| 6. Soft wheat | 10.4 | 6.2 | 4.2 | 38.9 | 6.0 | 4.0 | 34.3 | 6.3 |
| 7. Millet | 5.9 | 6.7 | 4.3 | 34.9 | 5.4 | 4.1 | 31.9 | 5.1 |
| 8. Barley | 5.4 | 7.2 | 4.2 | 35.4 | 6.9 | 4.1 | 32.9 | 7.1 |
| 9. Peas | 10.6 | 7.3 | 4.3 | 36.8 | 7.1 | 4.0 | 32.5 | 6.6 |
| 10. Monoculture | 10.1 | 5.9 | 4.3 | 36.7 | 5.1 | 4.1 | 33.8 | 5.9 |

As a result of the analysis of the cellulose-decomposing activity of soil microorganisms, it was revealed that the lowest value was observed in the seventh and eighth variants of the experiment after millet and barley. The minimum percentage for these predecessors is 5.9 and 5.4%. The activity of microorganisms for other precursors ranges from 9.9 to 10.8%.

During the sowing period of durum wheat, the highest content of nitrates is observed in the fourth variant of the experiment after sidereal steam and it consists of 8.0 mg per 100 g of soil. During the harvesting period, the maximum amount of nitrate nitrogen is observed under durum wheat crops after peas in the ninth version of the experiment and it consists of 7.1 mg per 100 g of soil. This observation of the periods is explained by the biological characteristics of peas, that is, the accumulation of nitrogen by nodule bacteria in the soil. For both determination periods, the minimum amount of nitrates is seen under the monoculture due to the depletion of the nutrient content of durum wheat and it consists of 5.9 and 5.1 mg per 100 g of soil. The content of mobile phosphorus for the two terms of determination is almost at the same level and ranges from 4.0 to 4.5 mg due to low consumption by the cultivated plant. The amount of exchangeable potassium in the soil for all precursors during the growing season is in the range from 31.9 to 41.0 mg per 100 g of soil. The highest content of potassium oxide in the soil is observed in the first version of the experiment (control). After early harvesting of winter crops it is a long accumulation of the nutrient occurs in comparison with other precursors and it consists of 40.1 and 41.0 mg. The high availability of the soil with exchangeable potassium, in contrast to nitrates and mobile phosphorus, is explained by the characteristics of the southern chernozem of this experimental site. The mobile forms of nutrients in the soil were necessary for the growth and development of the grain crop.
The level of content and availability of these nutrients in the soil for durum wheat played a major role in the formation of yield. As a result of the study, it was found that the maximum yield of durum wheat grain is observed in the second version of the experiment after the previous black steam and it consists of 9.2 c per 1 ha. The minimum yield of grain crops is noted in the seventh and tenth versions of the experiment and it consists of 5.1 c for millet and 5.9 c for durum wheat per 1 ha. The effect of the cellulose-decomposing activity of microorganisms on the yield of durum wheat is observed in the second variant of the experiment and it consists of 51.62% with positive indicators of beta, regression, determination coefficients and the Student's criterion with a value level of 0.0005 (table 2).

Table 2. The influence of the activity of soil microorganisms and the content of mobile forms of nutrients during the sowing period on the yield of durum wheat as a result of the calculation of multiple regression for 19 years of observations.

| Independent variables (factors)         | Indicators of multiple regression analysis of the dependent variable (yield), units | The share of the factor influence, % |
|----------------------------------------|------------------------------------------------------------------------------------|-------------------------------------|
|                                        | $\beta_1^a$, $\beta_2^b$, $b_1^c$, $b_2^d$, $t^e$, $r^2^f$, $p^g$               |                                     |
| Durum wheat on black steam in a six-field crop rotation |                                      |                                     |
| Activity                               | 0.72, 0.17, 0.59, 0.14, 4.26, 0.51, 0.0005                                           | 51.62                               |
| Nitrites                                | 0.72, 0.17, 1.56, 0.36, 4.33, 0.52, 0.0004                                           | 52.43                               |
| Mobile phosphorus                       | 0.59, 0.19, 2.86, 0.94, 3.04, 0.35, 0.0073                                           | 35.27                               |
| Durum wheat for millet in a double-field crop rotation |                                      |                                     |
| NO$_3^-$                                | 0.67, 0.18, 0.61, 0.16, 3.76, 0.45, 0.0015                                           | 45.45                               |
| P$_2$O$_5$                              | 0.56, 0.20, 0.84, 0.30, 2.82, 0.31, 0.0117                                           | 31.91                               |
| K$_2$O                                  | 0.65, 0.18, 0.12, 0.03, 3.55, 0.42, 0.0024                                           | 42.63                               |

$a$ beta coefficient  
$b$ standard error beta  
$c$ regression coefficient  
$d$ standard error regression  
$e$ Student test  
$f$ coefficient of determination  
$g$ significance level

The highest yield was obtained after the black steam due to the influence of the cellulose-degrading activity of microorganisms and mobile forms of nutrients. Nitrates, mobile phosphorus, and exchangeable potassium have an effect on productivity. Their share of influence is 52.43, 35.27, and 36.80% when varying the positive numbers of the mathematical regression with a significance level of 0.0004, 0.0073, and 0.0059 (p≤0.05).

The lowest yield of durum wheat grain is observed after millet in the double-field crop rotation as a result of the attenuation of the biological activity of the soil, which limits the availability of nutrients. Macronutrients (NO$_3^-$, P$_2$O$_5$, K$_2$O) have a positive effect on grain formation by 45.45, 31.91, and 42.63%, with positive values of multiple regression with a confidence level of 0.0015, 0.0117, and 0.0024.

As a result of processing data for nineteen years of observations, it was found that the main variants...
of the experiment did not reveal the influence of the cellulose-decomposing activity of soil microorganisms and the content of nutrients on the increase in the productivity of durum wheat.

As a result of the study, we recommend to increase the yield of durum wheat in agricultural production to introduce crops after black steam in six-field crop rotations with a long rotation.

4. Conclusions
Statistical data processing for nineteen years of observations using multiple regression analysis showed that the influence of the cellulose-decomposing activity of soil microorganisms and the content of nitrate nitrogen, mobile phosphorus, and exchangeable potassium has an increase in the yield of durum wheat grain after black steam in a six-field crop rotation. In the seventh version of the experiment, a slight effect of the biological activity of the soil is observed in comparison with the influencing macronutrients (NO₃-, P₂O₅, K₂O) of nutrition. This effect leads to a decrease in yield in the double-field crop rotation due to the biological characteristics of millet. The greatest share of the influence of the activity of microorganisms, nitrates and phosphorus is observed on durum wheat during the sowing period after black steam in a long rotation cycle (the second version of the experiment), which leads to an increase in yield. The smallest share of the effect is seen in the content of nutrients in the soil after millet in a crop rotation with a short rotation (the seventh version of the experiment), except for the exchange of potassium, which contributes to a decrease in yield. A low grain yield was obtained for durum wheat monocultures due to soil depletion, which leads to a negligible effect of the cellulose-decomposing activity of microorganisms and nutrients. In other variants of the experiment, the response of the biological activity of the soil and mobile forms of nutrients to the long-term cultivation of durum wheat in crop rotations is not observed.

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