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Improving local farming systems in response to global climate change

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***Abstract*— *The purpose of the research is to identify the impact of biologized crop rotations and fertilizers on the content of organic matter - humus and grain yield in a changing climate. Field experiments were carried out in central Russia, in the steppe zone adjacent to the southern part of the Ural Mountains. The soil is medium loamy black soil. The weather conditions of the experimental work site were variable. In the first 3 years, warming was observed with an increase in the sum of effective air temperatures (SEAT) for a period of more than 10^0 C in the range of up to 2800^0 C. In the second three years, there was a cooling with a decrease in SEAT to 1900^0 C. In the first half of the years, precipitation of the growing season decreased to 84 and 71 mm, which is 2-2.6 times less than the long-term level. The second half of the years was characterized by an increase in atmospheric moisture up to 167-280 mm during the growing season. Under the influence of sharply changing weather conditions, crop rotations formed unstable productivity, when deviations by the years of the experiment reached 2 times or more. The greatest deviations from the average grain productivity were observed in the control grain-fallow crop rotation. Productivity changes in biologized crop rotations are 8-9% less. A moderate correlation (r = 0.55) was found between grain productivity of crop rotations and soil humus content. In the soil under biologized crop rotations, the average humus content was 0.7-1.0% higher. To increase the stability of grain productivity in the face of climate change in the steppe zone of the South Urals, it is advisable to improve the farming system based on the use of biologized crop rotations.*

***Keywords*— Agriculture, climate, crop rotation, chernozems, humus.**

I. INTRODUCTION

Global climate change also affects various regions of Russia. In recent decades, precipitation in the country as a whole has increased by 2.1% over 10 years. However, precipitation decreases in the summer in the European part of Russia, including in the Volga Federal District, part of the Ural District, where we conduct research. Since the beginning of the 1990s, there has been a rapid increase in the number of months with elevated air temperatures in Russia as a whole [1]. However, the increase in air temperature in certain territories is unstable. In the Trans-Ural steppe of the South Urals, a noticeable increase in air temperature for a period of more than 10 0 C occurred only in 2016... 2021, reaching a total of 2420 ^{0} C (Table 1).

Table 1. Climate change in the Trans-Ural steppe of the Southern Urals on the territory of the Republic of Bashkortostan of the Russian Federation for 1996... 2025 (30 years)

Indicators	Years				
	1996-2005	2006-2010	2011-2015	2016-2021	2022-2025
Sum of effective air temperatures for the period	2200	2280	2210	2420	2160

more than 10^0 C					
The amount of precipitation of the growing season, mm	186	162	171	117	214
Hydrothermal coefficient of growing season	0,84	0,71	0,77	0,48	0,98
Degree of aridity of the year according to the Selyaninov scale	Dry	Very dry	Dry	Very Dry	Dry

Then there was an excess of the indicator recorded at the beginning of the accounting interval from 1996-2005 by 220 ^{0} C. The relative increase in the sum of effective air temperatures (SEAT) is 10%, which is already a lot. But in the newest period, for 2022-2025, there is a decrease in the thermal component of the growth conditions of cultivated crops to 2160 ^{0} C. Such a difference is considered insignificant, but indicates at least at the time of stopping the growth of climate warming in a given area. Another important factor of crop vegetation is changing more contrastingly - precipitation (Table 1 and Fig. 1).

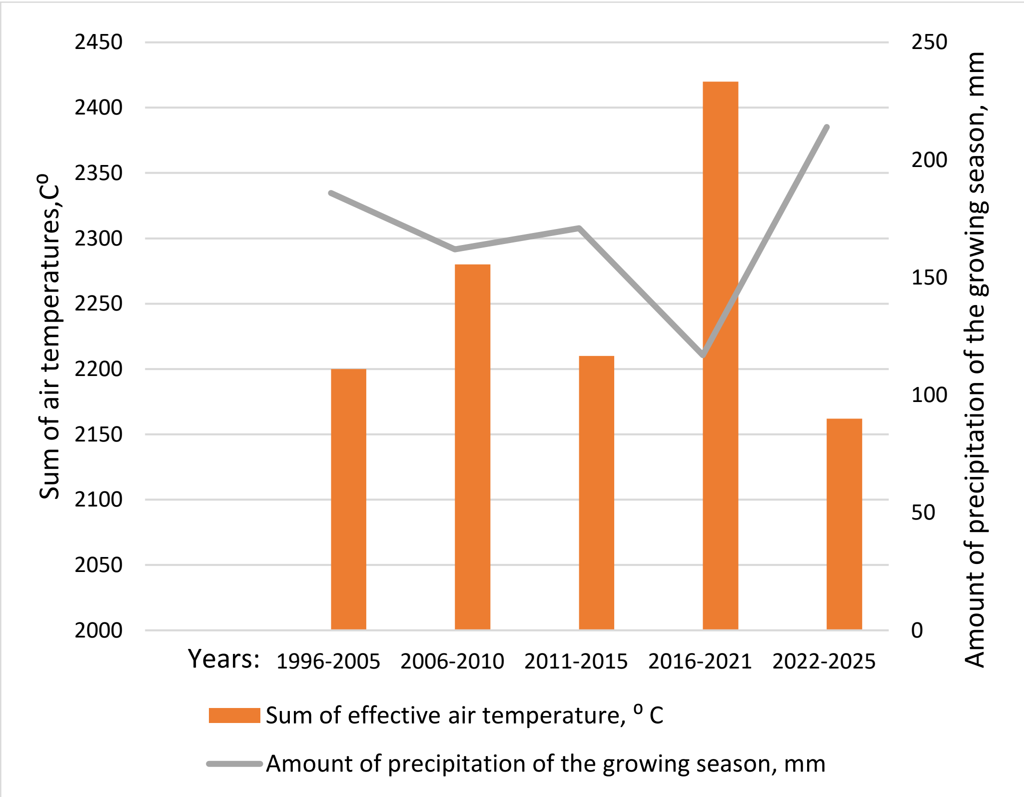

Fig.1. Climate change in the Trans-Ural steppe of the South Urals in the territory Republic of Bashkortostan of the Russian Federation for 1996-2025 (30 years)

As can be seen from the illustrations, over the past 30 years, the amount of atmospheric precipitation of the growing season has decreased significantly. If in the initial period from 1996-2005 it was 186 mm, then already in 2006-2010 and 2011-2015 decreased to 162 and 171 mm, respectively. Relative to the initial level, the indicators decreased by 13 and 8%. The greatest deficit of humidification of the territory was observed in 2016-2021, when the indicator reached the value of 117 mm - a record decrease of 37% from the initial reference level. However, over the past 4 years, precipitation has increased again, reaching 214 mm, which is even higher by 28 mm than in the initial 1996-2005. Hydrothermal coefficients (HTC) of the indicated accounting periods, gradually decreasing, reached the mark of 0.48 in 2016-2021. Moisture supply, correlated with the sum of effective air temperatures, decreased 1.8 times compared to the initial indicator observed in 1996-2005. In accordance with the increase in precipitation, in the final 2022-2025 HTC rose sharply to a value of 0.98. Thus, as on a global scale, drastic climate changes are taking place in the territory of our field experiments, which requires the development of more resistant farming systems to these changes.

In the special literature, a number of measures are proposed to adapt agricultural technologies, including agriculture, to changing climate conditions. Attention is drawn to the need to select species of crops and their predecessors in crop rotation, the most adapted to the local climate. In the conditions of the central forest-steppe aero-landscape region of the Novosibirsk region of the Russian Federation with chernozems leached on the basis of field experiments conducted in 2000-2016 revealed the most adapted crops. The least sensitive to changing conditions of growing seasons, when the hydrothermal coefficient (HTC) in some years ranged from 0.78 (drought) to 1.55 (moderate moisture) against an extensive background without fertilizers, were wheat after steam and wheat after clover. Mineral fertilizers have reduced the negative impact of drought on spring wheat yields [2].

Soil organic matter management is proposed as a decisive measure in climate change mitigation and adaptation [3, 4, 5]. For southern Africa, minimal tillage, cover crops, crop diversification are recommended to improve soil, reduce production costs and mitigate climate risks [6]. In long-term field experiments and on the basis of statistical processing of long-term data on yields in agricultural enterprises, it was shown that the stability of agriculture can be increased by selecting crops and using fertilizers. It is reported that climate-related risks are reduced in a number of spring wheat, barley, winter wheat. Optimization of mineral nutrition reduces the risk of crop shortages in the event of drought by one gradation in most cases [7]. It is possible for all farms to improve the drought resilience of their crops by investing in improving soil health. It is noted that organic soil matter, which performs numerous agroecological functions, is the main indicator of soil health. Measures that increase soil organic matter can increase its moisture capacity, water permeability and reduce runoff during intense rainfall. Conservation tillage and crop cover are effective methods of handling organic substances [8]. Indirect indicators of increasing the resistance of field crops to drought - improving water infiltration and reducing surface runoff through the use of cover crops are indicated in a review compiled by Samuel I. Haruna, Stephen H. Anderson, Ranjith P. Udawalta et all [9]. A study in India's Rangareddy of Telangana district showed high awareness among farmers about climate change in their area of residence. But only a small part of the surveyed study participants could name the reasons and effective measures to adapt production to these climate changes. The majority of respondents pointed to the use of organic and green fertilizers in crop rotation as effective measures to adapt to climate change [10].

According to our literature review, soil organic matter management is presented as a crucial measure in climate change mitigation and adaptation. Based on the studies carried out, directions for improving agricultural systems are recommended, contributing to the extended reproduction of organic soil matter. Among the studied agrotechnological solutions, the correct choice of cultivated crops and their alternation in crop rotation, the use of fertilizers and cover crops, and minimal tillage are listed. However, experimental data on the influence of these factors on the organic matter of the soil and the yield of cultivated crops under climate change are clearly insufficient. Experiments conducted in various territories are especially lacking, covering more soil and climatic conditions.

We set a goal - to identify the impact of biologized crop rotations and fertilizers on the content of organic matter - total humus and grain yield in a changing climate. To achieve the goal, field experiments and laboratory analyzes of soil and plant samples were carried out.

II. MATERIALS AND METHODS

Experimental fields are located in central Russia, in the steppe zone adjacent to the southern part of the Ural Mountains. The soil is medium-loamy black soil, with a humus horizon thickness of 45-48 cm. The initial (in 2019) soil condition of the experimental site was characterized by the following indicators in the arable layer 0-20 cm. The content of total humus is 7.6... 8.2%, mobile phosphorus 108…114 mg/kg, exchange potassium 140... 148 mg/kg. The reaction of the soil environment is close to neutral, with a pH of 5.6... 5.8.

The experiment scheme included 3 field rotations with the corresponding placement of crops (Table 2).

Table 2. Crop rotations and sequence of crops studied in the experiment

No.	Name of crop rotation	Sequence of crop placement						
		1	2	3	4	5	6	7
1	Grain-fallow	Bare fallow	Spring wheat	Spring wheat	Peas	Spring wheat	Barley	
2	Biologized type I	Bare fallow and green fallow	Spring wheat	Spring wheat + alfalfa	Alfalfa	Alfalfa	Spring wheat	Barley
3	Biologized type II	Peas	Spring wheat	Spring wheat + alfalfa	Alfalfa	Alfalfa	Spring wheat	Barley

The influence of crop rotations on the content of humus in the soil and the grain productivity of arable land was studied against the background of the use of straw of grain crops, sideral fertilizer from peas. In addition to organic fertilizers, mineral fertilizers were used - nitrogen in a dose of 30 kg of active substance (AS) per 1 hectare for grain crops and phosphorus - 20 kg AS per 1 hectare for all crop rotation crops when sown in rows. Nitrogen fertilizers for the joint sowing of alfalfa with wheat and in two fields with independent alfalfa were not introduced, relying on the use of nitrogen from the atmosphere by symbiotic bacteria. Straw in the form of crushed post-harvest residues at a dose of 1.5-2 t/ha, depending on yield, was scattered in the fields of grain crops and peas as fertilizer for subsequent crops. In the field where they planned to create green fallow in the spring, in the first decade of May, they sowed small-seeded peas and fertilizer plowdown in the flowering phase of the culture in the first decade of July. The yield of the green mass of the peas at the time of plowing into the soil was 165-180 c from 1 ha.

The laying of experimental plots was carried out according to the method of B.A. Dospekhov (1985). The placement of options is systematic in one tier. The repetition in the experiment is three times in space and two times in time. The plot area with the crop rotation field is 660 m^2, the elementary plot with the background of fertilizers is 165 m^2. Soil samples in a layer of 0-20 cm to determine the humus content were taken with a reed drill annually, before sowing crop rotation crops. The content of total humus was determined by the Tyurin method in the modification of CNAO, according to GOST 26213. The method is based on the oxidation of organic matter with a solution of potassium dihydroxide in sulfuric acid and the subsequent determination of trivalent chromium, equivalent to the content of organic matter, on a photoelectrocolorimeter. Yields of spring wheat, barley and pea grains were determined by the direct method using a combine according to the method of B. A. Dospekhov (1985). The yield of alfalfa green mass was determined by mowing in test sites with subsequent conversion to air-dry mass. Grain productivity of crop rotations was determined by the method of converting crop yields into grain units using conversion factors according to the methodology of the Ministry of Agriculture of Russia (2017).

III. RESULTS AND DISCUSSION

The weather conditions of the growing season of cultivated crops in the experiment by the years of the experiment are presented in Table 3.

Table 3. Weather conditions of the growing season (May... September) during the years of field experiments

Indicators	Years						Average for 6 years
	2019	2020	2021	2022	2023	2024	
Sum of effective air temperatures for the period more than 10^0 C	2667	2800	2630	2569	1991	1855	2418
The amount of precipitation of the growing season, mm	160	84	71	167	145	280	151
Hydrothermal coefficient of growing season	0,60	0,30	0,27	0,65	0,72	1,51	0,62
Degree of aridity of the year according to the Selyaninov scale	Veri dry	Droughtly	Droughtly	Veri dry	Veri dry	Humid	Veri dry

The climate of the area where we conducted field experiments has undergone an even sharper change. This is demonstrated by indicators of weather conditions during the growing seasons of individual years. In the first 3 years - from 2019 to 2021, the sum of effective air temperatures (SEAT) for a period of more than 10^0 C was kept within the range of 2600-28000 C, which is 400-600^0 C higher than the baseline level (BL) of 1996-2005 (Table 3). The relative difference was 18-27%, which is sufficient to characterize the first half of the years of field experiments as significantly warmer. In the second three-year period, in 2022-2024, there was already a gradual cooling with a decrease in the SEAT to an average of 2500-1900^0 C, which is 4-32% less than in 2019-2021. The amount of precipitation changed more sharply during the years of the experiments. In the first half of the years, the precipitation of the growing season continued to decrease compared to the 1996-2005 starting point. The largest decrease in precipitation occurred in 2020 and 2021 with values of 84 and 71 mm, which is 2-2.6 times less than BL. The HTCs of the above period of years of field experiments decreased to 0.60-0.27, which gives reason to assign the degree of aridity to the years under consideration as very dry and dry according to the Selyaninov classification (1958). The second half of the years, 2022-2024, was characterized by an increase in atmospheric moisture up to 167-280 mm during the growing season and a decrease in the sum of effective temperatures to 1850-20,000 C. Accordingly, the sums of temperatures and precipitation, in the second half of the years of experiments, HTCs sharply increased to values 0.65-1.51, with an increase in the degree of moisture in years from very dry to humid. Illustrative changes in the climate and weather of our research sites are presented in Fig. 2.

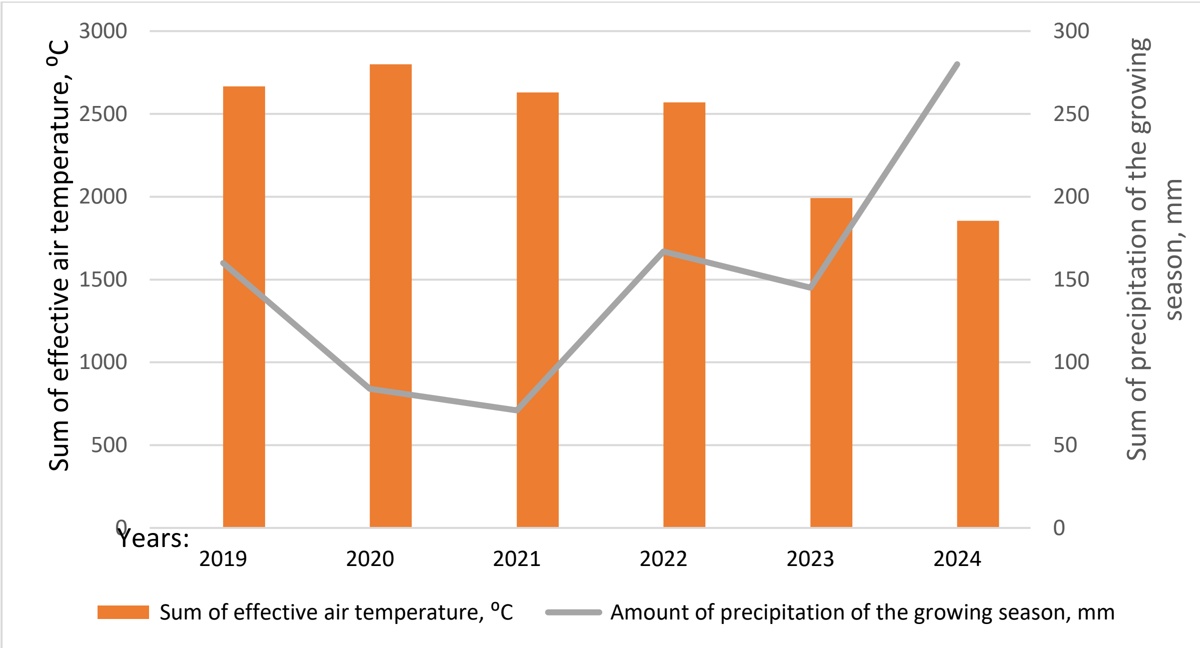

Fig.2. Weather conditions of the growing season (May-September) during the years of field experiments

The grain productivity of crop rotations in the experimental field primarily depended on the precipitation of the growing season, which is a factor of the minimum in the study area. This is evidenced by multiple changes in productivity indicators depending on the same multiple changes in the amount of precipitation over the years (Fig. 3). As can be seen from Figure 3, in 2020 and 2021 the amount of precipitation was 84 and 71 mm, which is about 2 times less than the level of 160 mm in 2019. Grain productivity of crop rotations averaged: in 2020 and 2021 7.5 and 8.0 c/ha, in 2019 - 18 c/ha. The multiplicity of changes in the productivity of crop rotations in the corresponding years is expressed by the number 2.4, which approximately coincides with the ratio of changes in precipitation. In the next 2022 and 2023 Crop rotations provided grain collection in the amount of 22-26 centners from an area of 1 hectare, with an excess of the 2019 indicator by 22-33%. At the same time, the amount of precipitation of the growing season in the above years was almost the same: 167, 148 and 160 mm. Significant differences the grain productivity of crop rotations here is most likely due to the thermal factor. Starting in 2022, the sum of effective temperatures began to decline, reducing the stress effect of drought, which caused an increase in the productivity of crop rotations in comparison with the initial value in 2019.

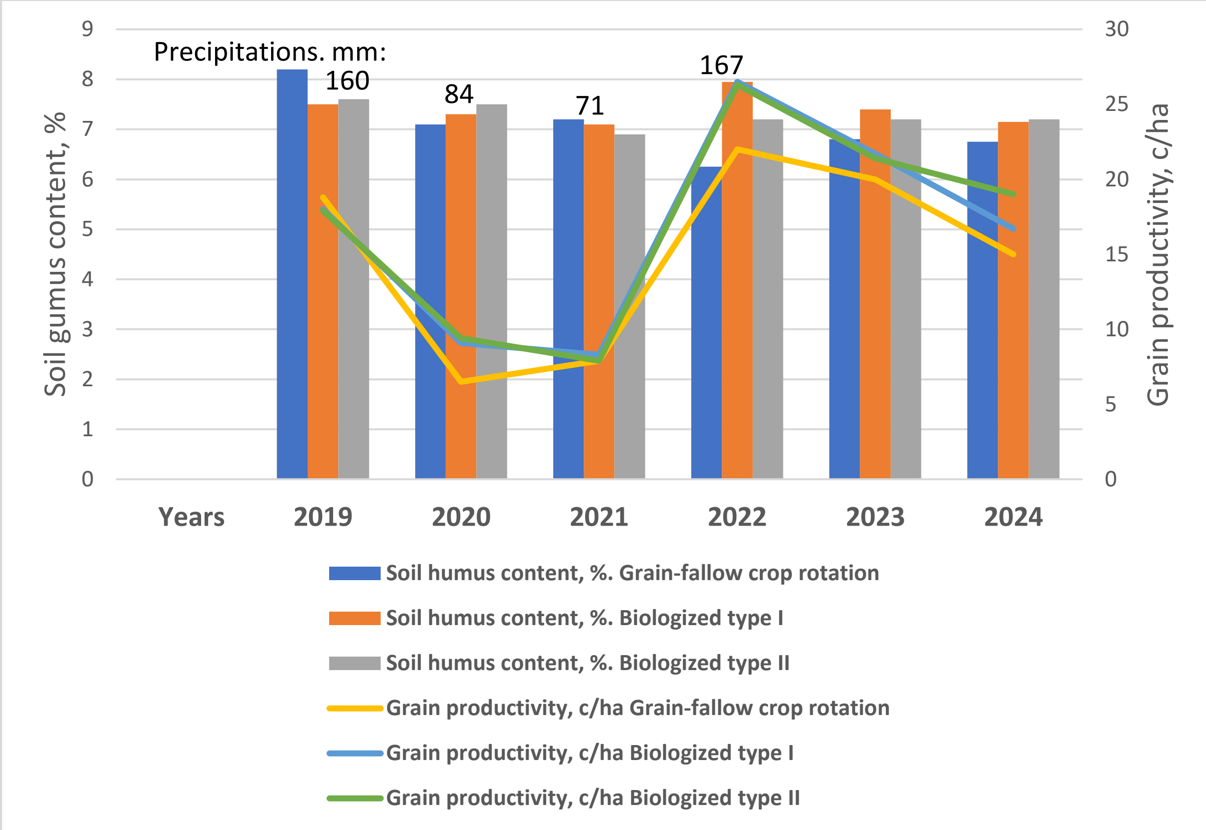

Fig.3. Dynamics of changes in precipitation, humus content in the soil and grain productivity of crop rotations for 2019-2024

In the final 2024, two unfavorable factors acted on the productivity of crop rotations at once - low air temperatures and increased precipitation. The sum of effective temperatures was 1855^0 C - 23% less than the average for the years of experiments; and the amount of precipitation is 280 mm, which is almost 2 times higher than the average for the same years (Table 2 and Fig. 2). As a result, in the wet year of 2024, the grain productivity of crop rotations was even lower compared to the dry years 2022 and 2023, amounting to 15-18 c/ha. Thus, under the influence of dramatically changing weather conditions, crop rotations formed an unstable productivity when deviations over the years of the experiment reached two times or more. Variational analysis shows that the greatest deviations from average productivity are observed in the control grain-fallow crop rotation. With an average annual productivity of 15 c/ha, the average coefficients of variation over 6 years with a plus sign were 35%, with a minus 52% sign. In biologized crop rotations, the corresponding coefficients were significantly lower and amounted to 32% and 48%. Relative differences in variations reach 8-9%, which is already a lot. In addition to variational statistics, the advantage of biologized crop rotations is more convincingly confirmed by their average grain productivity during the years of the experiment (Table 4).

Table 4. Average grain productivity of crop rotation over the years of field experience

Crop rotation	For the entire period 2019 - 2024			For the last 2022 - 2024		
	c/ha	Control deviations		c/ha	Control deviations	
		c/ha	%		c/ha	%
Grain-fallow (control)	15,0	—	—	19,0	—	—
Biologized type I	16,7	1,7	11,2	21,6	2,6	13,9
Biologized type II	17,0	2,0	13,0	22,2	3,2	17,0
Smallest significant difference (SSD_{05})		1,2			1,8	

The lowest grain productivity for the entire period of the experiments was 15.0 c/ha, the control grain-fallow crop rotation showed. Biologized crop rotations provided an additional productivity of 1.7-2.0 c/ha to the level of grain-fallow crop rotation. Over the past 2022-2024. grain harvest in biologized crop rotations increased by an even higher amount, by 2.6-3.2 c/ha, compared to grain-fallow crop rotation. This shows that the biologized crop rotations we are developing provide higher stability in grain productivity compared to traditional grain-fallow crop rotation in conditions of increasing climate variability.

We also analyzed the change in the humus content in the soil and its correlation with the grain productivity of experimental crop rotations. The initial content of humus in the plots of experience was not much different, which was explained by the spatial variability of this feature. In 2019, 8.2% of humus was contained in the fields of control grain-fallow crop rotation, and slightly less in biologized crop rotations - 7.5-7.6% (Fig. 3). In 2020, under the influence of an acute moisture deficit caused by drought and hot weather, and a slowdown in the decomposition of aboveground and root debris, there was a general decrease in humus content in all three crop rotations. As can be seen from Fig. 3, in grain-fallow crop rotation humus decreased to the greatest extent - to 7.2%, and in biologized crop rotations it decreased slightly - to 7.3 and 7.5%, remaining practically at the level of the initial values.

Semenov V.M., Lebedeva T.N., Zinyakova N.V. et al. In laboratory studies, they showed a rapid decrease in the content of soil organic matter during drought and a gradual recovery to the initial level when the wet period occurs [12]. Under the influence of repeated drought in 2021, the humus content in the arable soil layer in experimental crop rotations remained still low, in the range of 6.9-7.2%. Under conditions of increasing atmospheric moisture in 2022, the root and crop residues of perennial grasses (alfalfa) accumulated in previous years decomposed better, supplying building material for the synthesis of new organic substances in the soil. As a result, the humus content in biologized crop rotations increased to 7.2-7.9%, exceeding the level of grain-steam crop rotation by 0.9-1.5%. In 2023-2024 the humus content in the soil of biologized crop rotations remained consistently higher compared to grain-steam crop rotation, with differences of 0.4-0.5% in favor of biologized crop rotations.

A regression analysis of the interdependence of two features - the humus content in the soil and the grain productivity of crop rotations was carried out using the method of B. A. Dospekhov (1985) [13]. The conjugacy index of these features was calculated in the form of a correlation coefficient, which was expressed as r = 0.55. According to the method, this correlation size indicates the presence of an average relationship between the two features indicated above (interval r = from 0.3 to 0.7). However, the amount of correlation we calculated between the two paired features according to strict estimates is still low. To obtain higher correlation coefficients, when the condition r > 0.7 is met, it is necessary to increase the number of observations of the studied features in the experiment. This dependence is clearly explained when analyzing the formula by which the standard error of the correlation coefficient is determined:

$$S_r = \sqrt{\frac{1-r^2}{n-2}}$$

where n is the number of observations. As n increases, the error Sr will decrease, and the accuracy in determining the correlation coefficient r will increase. In our experiment, the sample size can only be increased by continuing the number of years of field experience. Thus, at present, we can only talk about the tendency to increase the stability of grain productivity of crop rotations as the humus content in the soil increases, depending on the use of biologization factors. Further field studies are required to improve the reliability of the patterns of interaction of humus content and other soil indicators on the stability of grain productivity of crop rotations in conditions of increasing variability of the local climate.

IV. CONCLUSION

In addition to many years of variability, the climate of the field experiment site, located in the steppe zone of the south of the Ural Mountains of the Russian Federation, continued to change. Under the influence of sharply changing weather conditions and the course of accumulation and decomposition of plant residues, there was a change in the dynamics of the content of total humus in the soil. By the end of the field experience, in 2023-2024 the humus content in the soil of biologized crop rotations remained consistently higher compared to grain-fallow crop rotation, with differences of 0.4-0.5% in favor of biologized crop rotations. Under the influence of sharply changing weather conditions, crop rotations formed unstable productivity, when deviations by the years of the experiment reached 2 times or more. The greatest deviations from the average grain productivity were observed in the control grain-fallow crop rotation. Productivity changes in biologized crop rotations are 8-9% less. Biologized crop rotations provided an average annual productivity of 1.7-2.0 c/ha of grain units, which was additional to the level of grain- fallow crop rotation. A moderate correlation (r = 0.55) was found between grain productivity of crop rotations and soil humus content. In the soil under biologized crop rotations, the average humus content over the years of research turned out to be 0.7-1.0% higher, which was accompanied by their higher grain productivity compared to grain-fallow crop rotation. Thus, biologized crop rotations in the steppe zone of the Southern Urals provide higher and more stable grain productivity under climate change conditions compared to traditional grain-fallow crop rotation. The leading factor contributing to the increase in the stability of the productivity of biologized crop rotations is an increase in the content of organic matter in the soil.

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