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STUDY OF THE SOIL WATER AND NUTRIENT REGIME IN THE CULTIVATION OF SPRING WHEAT USING CONSERVATION TECHNOLOGY IN A GRAIN-FALLOW CROP ROTATION ON SOUTHERN CHERNOZEMS OF THE KOSTANAY REGION

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Abstract. The studies were conducted on the experimental plots of "AES 'Zarechnoye'" LLP, located near the village of Zarechnoye. The study area has a long history of agricultural use, and since 2001 a conservation farming system based on No-till technology has been implemented here. Since 2023, within the framework of the research, a field experiment with a 4-field grain-fallow crop rotation has been established: herbicide fallow – wheat – wheat – wheat. No-till technology is applied. The crop used is spring wheat of the Omskaya 18 variety. In 2024, the highest grain yield was recorded on plots used for sowing the first crop after herbicide fallow in the grain crop rotation – 27.47 c/ha. Analysis of the grain crop rotation showed that spring wheat grown as the first crop after fallow was classified as second quality class. Wheat grown as the second and third crops after fallow was classified as third quality class due to lower gluten indicators.

Keywords: conservation farming, spring wheat, soil moisture, nitrate nitrogen, available phosphorus, yield, grain quality.

INTRODUCTION

Wheat, as a grain crop, plays a key role in the economy of many countries of the world. Kazakhstan occupies a significant place in the international wheat market as an exporter. This crop is the basis of the country's food security [1]. In the scientific community, there is a growing understanding that climate change has a significant impact on the yield and quality of agricultural products. Research on the consequences of climate change should pay special attention to studying the impact of extreme weather events oncrop growth [2]. Only a detailed study of plant responses to cyclic climate fluctuations will make it possible to develop rational systems of environmental management and increase the efficiency of crop production [3].

Modern farming practices demonstrate the possibility of increasing the productivity and quality of spring wheat even in difficult weather conditions [4]. The choice of predecessor plays an important role in increasing the yield of spring wheat and the overall productivity of crop rotation [5]. In modern conditions, when resources in the agricultural sector are limited, the use of ecological-biological methods becomes a key factor in maintaining soil fertility and ensuring stable high yields [6-10].

Weather conditions, especially during the growing season, have a significant impact on crop productivity. Climate change is characterized by increased aridity (decrease in precipitation and increase in average daily temperature), while most precipitation falls in the cold period of the year [11, 12]. This requires the revision and development of new cultivation technologies for agricultural crops adapted to specific regional conditions [13-15].

Changes in temperature regime and precipitation lead to transformation of the structure of biogeocenoses and the appearance of pests, weeds, and diseases atypical for the given region [16]. To minimize the negative impact of climate change, it is necessary to use rational crop rotations, recommended agronomic technologies of crop cultivation and soil treatment. In addition, it is required to study the soil water and nutrient regimes depending on predecessors and their influence on the efficiency of spring wheat cultivation [17, 18].

The novelty lies in the fact that under the conditions of the Kostanay region, the soil water and nutrient regimes were studied in a grain-fallow crop rotation with spring wheat cultivated using conservation technology, and an analysis of their interrelation with yield and grain quality of spring wheat depending on its position in the crop rotation was made. The objective of the study: determination of the most effective variant of placement of spring wheat in a grain-fallow crop rotation cultivated using conservation technology under the conditions of the Kostanay region, taking into account the soil water and nutrient regime and crop productivity.

MATERIALS AND METHODS

The studies were conducted on the experimental plots of "AES 'Zarechnoye'" LLP, located near the village of Zarechnoye. These plots are characterized by a gently sloping plain representing the upper floodplain terrace of the right bank of the Tobol River. The soil cover was formed by Quaternary alluvial deposits, including sandy loams, sands, clayey sands, loams, and clays. The study area has a long history of agricultural use, and since 2001 a conservation farming system based on No-till technology has been implemented here.

Sowing was carried out by specialized seeders with anchor-type openers and the FreeSelect precision metering system. Since 2023, within the framework of the research, a field experiment with a 4-field grain-fallow crop rotation has been established: herbicide fallow – wheat – wheat – wheat (GPS coordinates: 53.2177247, 63.7744477). No-till technology is applied. The crop used is spring wheat of the Omskaya 18 variety.

Agrometeorological data, including average daily air temperature, sum of effective temperatures, and precipitation during the growing season, were obtained from the Kostanay agrometeorological station (RSE "Kazhydromet").

Determination of productive moisture reserves in the one-meter soil layer was carried out layer by layer (every 10 cm) before sowing, according to the methodology described by Vorobyev S.A. et al. [19].

Analysis of nitrate nitrogen ($N\text{-}NO_3$) and available phosphorus (P_2O_5 according to Chirikov) was performed in soil layers of 0-20 and 20-40 cm before sowing, with georeferencing. To assess yield, productivity and structure of plant biomass, sheaf sampling was carried out in two replications. During yield accounting, grain samples were taken to analyze its moisture, contamination, 1000-seed weight, and nutritional value. Statistical data processing was carried out according to the methodology of B.A. Dospekhov with a significance level of 5% ($LSD_{0.05}$).

RESULTS AND DISCUSSION

The climate in the research region is characterized as sharply continental with pronounced temperature contrasts. Winters are cold and with little snow, and summers are hot and dry. A distinctive feature of the climate of this zone is the duration of spring frosts and the early onset of cold weather in autumn, which distinguishes it from other arid territories such as the Volga region.

High solar radiation, significant daily temperature fluctuations, low air humidity, clear weather and frequent winds contribute to intensive evaporation of moisture, exceeding the amount of atmospheric precipitation by 2-5 times. Especially critical in terms of aridity is the period from the end of May to mid-June, when spring grain crops are in the tillering and stem elongation phases. During this period, plants are forced to use limited moisture reserves accumulated in the soil over the winter. It should be noted that all climatic factors demonstrate significant interannual variability both in intensity and in timing of manifestation.

Long-term observations show the average annual precipitation in the area of the experiments to be 340 mm. At the same time, 71.2% of the total precipitation falls in the warm period (April-October), and most of it falls in the second half of summer. In 2024, the total precipitation for the period from October to September amounted to 478.2 mm, which exceeds the annual norm by 40% (table 1).

Table 1 – Distribution of precipitation by periods of the year in comparison with the long-term norm

Year	Total precipitation, mm			
	total for the year (October-September)	cold period (November-March)	warm period (April-October)	during vegetation (May-August)
Long-term norm	340.0	98.0	242.0	162.0
2024	478.2	163.4	260.1	209.3

Research of the water regime of sown areas during the 2024 growing season demonstrates the following trends. In May, a reduced amount of precipitation was observed (83.9% of the long-term norm), amounting to 30.2 mm. In combination with lower than usual air temperatures, this created favorable conditions for conducting the sowing campaign and formation of sufficient soil moisture reserves. In June, starting from the end of the first decade and continuing until the third decade, significant precipitation occurred, exceeding the long-term norm by 48%. This contributed to intensive growth of cultivated plants at the initial stage of development. However, warm weather conditions in June and night dew created a favorable environment for the development of certain diseases.

Analysis of the relationship between grain crop yield and the amount and distribution of precipitation showed that in the northern region of Kazakhstan, yield level (among other factors) is determined by the amount of precipitation that fell in June-July. Grain quality, in turn, depends on the amount of precipitation and air temperature in August-September. Thus, sufficient precipitation in June-July contributes to increased grain yield, and a smaller amount of precipitation and higher temperature at the end of the ripening and harvesting period improve technological grain qualities (figure 1).

In the reporting period, the average daily air temperature demonstrated significant fluctuations. In April, an excess of the long-term average by 4.7°C was observed, and in June – by 2.1°C. In subsequent months, the temperature regime turned out to be somewhat lower than long-term values, which led to slowing of vegetation processes of agricultural crops (figure 2).

Monitoring of precipitation indicates favorable hydrological conditions during the period of yield formation and maturation, since the amount of precipitation exceeded the long-term average norm by 29.2%. However, abundant precipitation in August negatively affected quality indicators of grain crops sown at early dates. Warm weather and increased humidity in the second half of summer contributed to widespread rust in the region. As a result of this epiphytotic outbreak, grain crops that did not undergo timely fungicide treatment demonstrated a significant decrease in quality indicators and yield.

In the arid steppe conditions of Northern Kazakhstan, a key factor of successful farming is sufficient soil moisture throughout the growing season. Annual precipitation is distributed unevenly: 82 mm in autumn, 46.0 mm in winter, and 70 mm in spring, which in total amounts to 62% of the total norm. Only 156 mm of precipitation falls during the period of active plant growth, while more than 300 mm is required for optimal development of spring wheat.

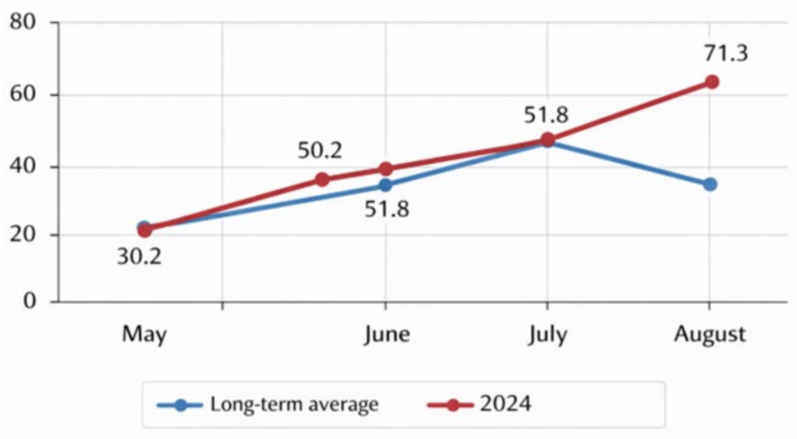

Figure 1 – Distribution of precipitation by months, 2024

Figure 2 – Distribution of temperature by months, 2024

Thus, atmospheric precipitation during the growing season provides only half of the necessary moisture for spring wheat. This dictates the need for more effective accumulation of moisture in the soil in other seasons of the year and development of methods for its preservation and rational use in all fields of the crop rotation. One of the ways to improve moisture supply of wheat is the choice of optimal predecessors. Numerous studies confirm that under moisture deficit conditions, the best predecessor for grain crops is fallow field. The significance of fallow field in combating drought and increasing yield is determined primarily by the creation of a favorable soil water regime for subsequent crops. This is confirmed by results of scientific studies conducted both in our country and in other republics of the former USSR.

Winter precipitation plays a special role in soil moisture accumulation. Studies conducted at the Kostanay Research Institute of Agriculture showed that during winter (1972-1981), on average 79.6 mm of precipitation falls, which constitutes more than a quarter of the annual norm. Taking into account spring precipitation, this amount reaches 103.4 mm (33.5% of the annual average). Preservation of such a volume of moisture could significantly improve moisture supply of field crops and increase their yield. Accumulation of autumn-winter precipitation in the soil depends on its initial moisture before winter, intensity of snowmelt, rate of meltwater infiltration and other factors. It is important to understand what part of this precipitation is preserved by the time of sowing and whether the volume of soil moisture depends on the type of crop rotation and predecessors.

We observed the nature of moisture accumulation from winter-spring precipitation in all studied fields. Analysis of precipitation assimilation by seasons of the year showed that, despite certain features of this process in different crop rotation fields, precipitation is far from fully assimilated. As a rule, two-thirds of fallen precipitation are lost and do not contribute to production of plant products. Increasing the share of effectively used precipitation would allow significant increase in crop yield and fuller realization of the natural-climatic potential of the region. In this context, more complete use of plant residues after harvesting to form a mulching layer on the soil surface is of considerable interest. Numerous studies confirm that chopped straw positively affects the soil's ability to retain moisture and allow air passage. Data obtained by the Kostanay Research Institute of Agriculture during 2002-2011 also indicate the benefit of mulch from chopped straw for moisture accumulation in fallow when refusing traditional soil treatment.

Figure 3 presents the actual soil moisture reserves before sowing in various fields of the grain-fallow crop rotation.

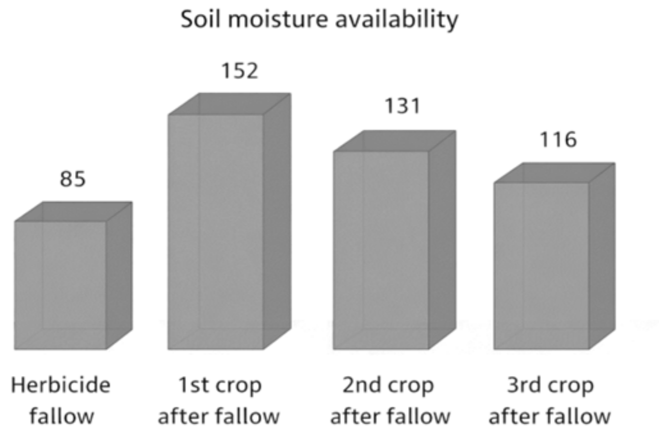

Figure 3 – Productive moisture reserves before sowing in the grain-fallow crop rotation, 2024

During the sowing campaign of 2024, the best moisture supply level in the grain-fallow crop rotation, which we used as the control variant, was observed in the first crop after fallow – 152 mm. At the same time, productive moisture reserves in herbicide fallow at the beginning of the fallow period amounted to 85 mm. Quite good moisture reserves before sowing were also observed in the second and third wheat after fallow – 131 mm and 116 mm, respectively. It should be noted that favorable weather conditions of May and of 2024 as a whole contributed to good plant development. However, significant difficulties arose with effective plant protection from diseases and weed control. To assess the initial soil condition in terms of main mineral nutrients, in spring before sowing we analyzed the content of nitrate nitrogen ($N\text{-}NO_3$), available phosphorus (P_2O_5) and exchange potassium (K_2O) in the 0-40 cm layer. The results of analyses for 2024 are presented in table 2.

Table 2 – Content of main nutrients in the 0-40 cm soil layer before sowing by fields of the grain-fallow crop rotation, 2024

Crop rotation field	Soil layer, cm	Content, mg/kg of soil	
		$N\text{-}NO_3$	P_2O_5
Herbicide fallow	0-20	9.2	22
	20-40	9.7	20
	0-40	9.5	21
1st wheat after fallow	0-20	17.4	62
	20-40	17.8	40
	0-40	17.6	51
2nd wheat after fallow	0-20	10.5	37
	20-40	7.8	10
	0-40	14.4	23
3rd wheat after fallow	0-20	9.1	26
	20-40	4.9	13
	0-40	7.0	19

If we take into account that the optimal nitrate nitrogen content is at least 10-15 mg/kg, then according to 2024 data, the soil before sowing of the third crop of the grain-fallow crop rotation had low nitrate content – only 7.0 mg/kg (in the 0-40 cm layer). On the contrary, the nitrate nitrogen content inthe first crop was high – 17.6 mg/kg (in the 0-40 cm layer). The lowest nitrate nitrogen content (9.5 mg/kg in the 0-40 cm layer) was recorded in herbicide fallow. This is explained by the fact that the third crop in 2023 actively consumed nitrate nitrogen.

The content of available phosphorus in these fields was at medium and elevated levels. The main objectives of our research consist in further reduction of non-recoverable energy costs, increase of yield, more complete use of plant residues and, as a consequence, accumulation of organic matter in the upper soil layer. The result of work in this direction is the previously developed resource-saving technology based on No-till technology by "AES 'Zarechnoye'" LLP. Currently, we are developing a complex of conservation farming practices, which includes, in addition to crop diversification, optimization of plant nutrition. This will allow increasing economic efficiency.

The three-year research period started in 2024 is conducted on the basis of a stationary experiment founded in 2001. This long-term experiment has significant scientific potential for evaluating the effectiveness of conservation farming technologies (table 3).

Table 3 – Yield of spring wheat in grain-fallow crop rotation, 2024

Crop rotation field	Wheat grain yield, c/ha			
	1	2	3	Average
1st wheat after fallow	26.97	26.55	28.89	27.47
2nd wheat after fallow	13.67	14.29	13.00	13.65
3rd wheat after fallow	13.24	12.00	14.53	13.23
$LSD_{0.05}$ = 2.51				

Analysis of yield for 2024 revealed that the most productive were plots where the first crop was grown after fallow within the grain-fallow crop rotation, showing a yield of 27.47 c/ha. On the contrary, the second crop after fallow demonstrated a significant decrease in yield. This is due to more intensive soil drying and nutrient consumption by the first crop, which is associated with its better development, including the root system. As a result, the water regime for the second crop in 2024 turned out to be less favorable. Naturally, these yield fluctuations affected the quality characteristics ofthe studied crops (table 4).

Table 4 – Indicators of wheat grain quality in grain-fallow crop rotation, 2024

Crop rotation field	Protein, %	Gluten, %	Test weight, g/L	Quality class
1st wheat after fallow	15.4	27.5	783	II
2nd wheat after fallow	14.8	26.3	771	III
3rd wheat after fallow	14.5	25.8	776	III

In the grain-fallow crop rotation, spring wheat grown as the first crop after fallow was classified as grain of second class. Wheat obtained as the second and third crops after fallow was classified as third class, with reduced gluten content indicators.

CONCLUSION

During the sowing campaign of 2024, the best moisture supply level in the grain-fallow crop rotation, which we used as the control variant, was observed in the first crop after fallow – 152 mm. At the same time, productive moisture reserves in herbicide fallow at the beginning of the fallow period amounted to 85 mm. Quite good moisture reserves before sowing were also observed in the second and third wheat after fallow – 131 mm and 116 mm, respectively.

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In 2024, the highest yield of grain crops was recorded in plots used for sowing the first crop after herbicide fallow in the grain crop rotation – 27.47 c/ha. Analysis of the grain crop rotation showed that spring wheat grown as the first crop after fallow was classified as second quality class. Wheat grown as the second and third crops after fallow was classified as third quality class due to lower gluten indicators.

Thus, when cultivating exclusively cereal crops in a crop rotation (mono-culture), the fallow field remains a necessary predecessor for the regions of risky farming in Northern Kazakhstan. It should be noted that in a cereal-fallow crop rotation with monoculture, there is an irrational use of reserves of productive soil moisture and nutrients, a decrease in yield, and a decline in its quality indicators.

According to the results of our research, for the successful cultivation of spring wheat under conservation agriculture, in the absence of the possibility of including leguminous and oilseed crops in the rotation, it is recommended to incorporate a herbicide fallow field. Under the conditions of Northern Kazakhstan, herbicide fallow serves as a stabilizing element of the crop rotation, providing the subsequent spring wheat field with readily available nutrients and moisture, which ensures high-quality yields in certain years and has a positive impact on the economics of production.

The influence of predecessors and cultivation technology on yield and grain quality of spring wheat studied in the southern forest-steppe of the Omsk Region in a stationary experiment of the Resource-Saving Technology Laboratory of the Siberian Research Institute of Agriculture in meadow chernozem soils in the 2005-2016 timeframe. Repeated sowing of spring wheat to the third wheat after bare fallow and lower intensity of tillage from combined to minimum-zero, depending on the forecrop, leads to decreased in crop productivity by 33.4% and 5.3-19.2%, respectively. As the crop moves from the bare fallow, gluten content in the grain decreases by an average of 3.3% in repeated spring wheat sowings [20].

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ТҮЙІН

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ҚОСТАНАЙ ОБЛЫСЫНЫҢ ОҢТҮСТІК ҚАРА ТОПЫРАҚТАРЫНДА ДӘНДІ ДАҚЫЛДАРДЫҢ АУЫСПАЛЫ ЕГІСТЕ САҚТАУ ТЕХНОЛОГИЯСЫ БОЙЫНША ЖАЗДЫҚ БИДАЙДЫ ӨҢДЕУ КЕЗІНДЕ ТОПЫРАҚТЫҢ СУ ЖӘНЕ ТАҒАМДЫҚ РЕЖИМІН ЗЕРТТЕУ

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Зерттеулер Заречное ауылының маңында орналасқан «Заречное» АШТС» ЖШС тәжірибелік учаскелерінде жүргізілді. Зерттелетін аумақтың ауыл шаруашылығын пайдаланудың ұзақ тарихы бар және 2001 ж. бастап нөлдік өңдеуге негізделген үнемдеу егіншілік жүйесі енгізілді. 2023 ж. бастап зерттеу 4 танапты дәнді дақылдардың ауыспалы егісімен далалық тәжірибе жүргізілді: гербицидтік сүрі жер – бидай – бидай – бидай. Нөлдік өңдеу технологиясы қолданылады. Дақыл ретінде Омская 18 сортының жаздық бидайы қолданылады. 2024 ж. дәнді дақылдардың ең жоғары өнімділігі дәнді дақылдардың ауыспалы егісіндегі гербицидтік сүрі жерден кейін бірінші дақыл егу үшін пайдаланылатын учаскелерде тіркелді – 27,47 ц/га. Дәнді дақылдардың ауыспалы егісін талдау сүрі жерден кейінгі бірінші дақыл ретінде өсірілген жаздық бидайдың сапаның екінші класына жатқызылғанын көрсетті. Сүрі жерден кейін екінші және үшінші дақыл ретінде өсірілген бидай ақ уыздың төмен деңгейіне байланысты үшінші сапа класына тиесілі.

Түйінді сөздер: сақтау егіншілігі, жаздық бидай, топырақ ылғалдылығы, нитратты азоты, жылжымалы фосфор, өнімділік, астық сапасы.

РЕЗЮМЕ

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ИЗУЧЕНИЕ ВОДНОГО И ПИЩЕВОГО РЕЖИМА ПОЧВЫ ПРИ ВОЗДЕЛЫВАНИИ ЯРОВОЙ ПШЕНИЦЫ ПО СБЕРЕГАЮЩЕЙ ТЕХНОЛОГИИ В ЗЕРНОПАРОВОМ СЕВООБОРОТЕ НА ЮЖНЫХ ЧЕРНОЗЁМАХ КОСТАНАЙСКОЙ ОБЛАСТИ

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Исследования проводились на опытных участках ТОО «СХОС «Заречное», расположенных вблизи с. Заречное. Исследуемая территория имеет длительную историю сельскохозяйственного использования, а с 2001 г. здесь внедрена система ресурсосберегающего земледелия, основанная на нулевой обработке почвы. С 2023 г. в рамках исследования заложен полевой опыт с 4-польным зернопаровым севооборотом: гербицидный пар – пшеница – пшеница – пшеница. Применяется нулевая технология возделывания. В качестве культуры используется яровая пшеница сорта Омская 18. В 2024 г. наибольшая урожайность зерновых культур была зафиксирована на участках, используемых для посева первой культуры после гербицидного пара в зерновом севообороте – 27,47 ц/га. Анализ зернового севооборота показал, что яровая пшеница, выращиваемая в качестве первой культуры после пара, была отнесена ко второму классу качества. Пшеница, выращиваемая в качестве второй и третьей культуры после пара, была отнесена к третьему классу качества из-за более низких показателей клейковины.

Ключевые слова: сберегающее земледелие, яровая пшеница, влажность почвы, нитратный азот, подвижный фосфор, урожайность, качество зерна.

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