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Spring Wheat Productivity and Profitability Under Various Crop Rotations in Northern Kazakhstan's Chernozem

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ABSTRACT

Rational land use and sustainable agriculture are crucial due to population growth and climate change. Crop rotation, with scientific approaches, maintains soil productivity and crop sustainability. The purpose of the study is to compare the production potential of different wheat cropping systems, including continuous spring wheat cropping and grain-fallow crop rotations. The research included a control variant with spring wheat sown without changing the predecessor and variants of grain and steam crop rotations with different numbers of fields. Plant productivity indicators were evaluated - the number of productive stems per 1 m^2, weight of 1000 grains, and yield. All experiments were repeated 3 times for each variant. In the process, field experiments were conducted from 2014 to 2022 at the territory of LLP "North Kazakhstan Agricultural Experimental Station" in the steppe zone of the North Kazakhstan Region, Akkayin district. It was found that spring soft wheat monoculture has a grain yield per 1 ha higher by 4 metric centners compared to two-field crop rotation. However, three-field and four-field crop rotations showed even higher grain yield, exceeding monoculture by 5.6 metric centners and 4 metric centners, respectively. The profitability of monoculture is 22%, which is 17.4% lower than the two-field crop rotation. The profitability of three-field and four-field crop rotations exceeds monoculture by 99.7% and 55.5%, respectively. The four-field crop rotation reaches a maximum profit of 167.3 USD/ha, and a minimum profit of USD 39.3 is established with wheat monoculture. Thus, the use of three-field and four-field grain-fallow crop rotations can significantly increase the profitability of wheat cultivation. These crop rotations provide a higher yield of grain from 1 ha of crop rotation area and have higher profitability.

1. INTRODUCTION

Crop rotation is a fundamental agricultural practice that involves the planned and systematic sequencing of different crops on the same piece of land over a defined period. This agricultural strategy is essential for various reasons, touching upon ecological, social, and economic aspects of crop production. Crop rotation plays a crucial role in maintaining soil health and fertility. Different crops have different nutrient requirements and root structures. By alternating crops, it helps prevent nutrient depletion and reduces the build-up of specific pests and diseases in the soil. Leguminous crops, for example, can fix nitrogen from the atmosphere, enhancing soil fertility. Sustainable agriculture is becoming increasingly important due to concerns about environmental impact. Crop rotation is a sustainable practice that helps reduce soil erosion, minimize water usage, and lower the carbon footprint associated with farming. Crop rotation contributes to food security by ensuring a diverse range of crops are available. This diversity helps mitigate the risks of crop failures due to unforeseen circumstances [1]. Bogunovic et al. [2] note that an important element of crop rotation is the alternation of crops, which contributes to maintaining soil fertility, reducing littering, controlling pests and plant diseases. Crop rotation also helps in protecting soils from wind and water erosion. In North Kazakhstan, the main areas of the land economy are occupied by grain crops, among which spring soft wheat occupies a leading position. This crop is relatively well adapted to the local climate and, with a proper application of agricultural technology, is able to provide high yields with good technological qualities of grain. However, the yield of spring soft wheat in the region varies greatly from year to year [3].

Kim et al. [4] note that in the climatic conditions of Northern Kazakhstan, one of the main factors contributing to an increase in the yield of spring soft wheat is the choice of predecessors. The placement of spring wheat crops after particular previous crops is an important condition for increasing its yield, and in case of insufficient precipitation, grain-fallow crop rotations with black fallow are the most favourable fallows for this crop. A similar opinion is also expressed by Holman et al. [5] and Bukhari et al. [6], who argue that one of the main reserves for increasing the yield of spring soft wheat are the best predecessors, and black fallow, especially in the arid climate of Kazakhstan, is considered one of the best previous crops for spring wheat. It helps increase moisture availability, the accumulation of mineral nitrogen in the soil, improve the phytosanitary situation, and reduce weed contamination.

In the northern regions of Kazakhstan, an agricultural approach centered around soil protection employs grain-fallow crop rotations. In this system, a significant portion, typically 20-25%, of the crop rotation cycle is dedicated to fallow land. This strategy has proven to be effective not only in North Kazakhstan but also in other areas sharing comparable climatic conditions and facing erosion challenges. However, some researchers, namely: Jørgensen et al. [7] and Karavidas et al. [8] began to express doubts about the use of the fallow predecessor in crop rotation. They indicate a decrease in the content of organic matter and nitrogen in the soil under the influence of the fallow predecessor, as well as the possibility of exposure to wind erosion. In this regard, the opinion has been established in the agricultural science of North Kazakhstan that the use of black fallow in crop rotation should be limited or practically excluded. Also, a number of researchers, namely Kunanbayev et al. [9], Su et al. [10] and Palojärvi et al. [11], persistently propose to replace the fallow predecessor in crop rotations in the grain area of the northern regions of Kazakhstan. Simultaneously, it is argued that crop rotations predominantly focused on spring wheat monoculture would offer the highest economic benefits.

Consequently, the significance of investigating the selection of suitable fallows for spring soft wheat in the northern regions of Kazakhstan is underpinned by various factors, including adaptability to climate variations, economic viability, soil resilience, and environmental sustainability [9]. Hence, examining the choice of preceding crops for spring soft wheat in North Kazakhstan holds great relevance and plays a pivotal role in enhancing crop yields, economic efficiency, and the overall sustainability of agricultural practices in the region [10, 11]. Consideration of climatic conditions, soil characteristics, and observation methods during the study allows obtaining valuable practical recommendations for agricultural enterprises and farms. The purpose of the study is to comparatively analyse the production potential of grain-fallow crop rotations with spring soft wheat monoculture, considering yield and economic efficiency. In order to achieve this goal, the following tasks were set and implemented: to compare the productivity and yield of spring soft wheat grain in monoculture with other types of grain-fallow crop rotations, to evaluate the economic efficiency of growing spring soft wheat.

2. MATERIALS AND METHODS

A field experiment was conducted to comparatively assess the productivity of spring soft wheat monoculture with the productivity of various types of crop rotations on regular chernozem of the steppe zone of North Kazakhstan in 2014-2022. The research was carried out on the territory of LLP "North Kazakhstan Agricultural Experimental Station" in the steppe zone of the North Kazakhstan Region, Akkayin district. The region is characterised by a sharply continental climate with arid conditions and average level of heat. The average annual precipitation is 240-330 mm, the average annual sum of positive temperatures is about 2400-2500°C, and the duration of the growing season is about 136-137 days. The soils are represented by ordinary carbonate chernozem with a neutral or slightly alkaline reaction, containing 56.5% physical clay and 43.5% physical sand in the arable layer. The humus content is approximately 4.5-5%, nitrogen content – 28-30%, phosphorus – 0.13-0.14%, potassium – 2.1-2.2%. The soil quality class is 65. The terrain is flat, not characterised by forest vegetation.

Spring soft wheat grown as monoculture provided for the cultivation of this crop on the same plot of land for several years in a row (control option). Grain-fallow crop rotations included in the sowing plans fallow and spring soft wheat according to the following scheme: fallow-wheat; fallow-wheat, wheat; fallow-wheat, wheat, wheat; fallow-wheat, wheat, wheat. In the course of the study, the methodology of the state variety testing of agricultural crops was used, which provided for strict monitoring of the parameters of the growth and development of wheat plants. The productivity indicators were determined, namely: the number of productive stems per 1 m^2 and the weight of 1000 grains. The number of productive stems of spring soft wheat was estimated by counting the number of stems on an area of 1 m^2. In addition, the weight of 1000 grains were determined on each variant, two samples of 500 seeds were taken for analysis and weighed with an accuracy of 0.01 g. The grain yield of spring soft wheat was evaluated by harvesting in the full ripeness phase from each variant separately. After threshing, the seeds were weighed and the yield was recalculated in dt/ha. In addition to physical analyses, an assessment of the economic efficiency of growing spring soft wheat was also carried out, which was determined by comparing production expenditures with the proceeds from the sale of the crop.

The experiment was conducted using plots of various sizes for each crop rotation variant to assess the productivity of spring soft wheat monoculture and different types of crop rotations. The specific plot sizes for each variant were as follows. Spring soft wheat was grown continuously on the same plot of land for several consecutive years. The plot size for this group was 1 hectare (10,000 square meters).

Crop rotations within the grain-fallow category encompassed a variety of sequences involving fallow periods and the cultivation of spring soft wheat:

1. Fallow-wheat rotation: this rotation consisted of a 1-hectare plot where fallow was followed by wheat.
2. Fallow-wheat-wheat rotation: this rotation was tested on a 0.5-hectare plot and involved fallow followed by wheat and then wheat again.
3. Fallow-wheat-wheat-wheat rotation: the plot size for this rotation was 1.5 hectares, and it included fallow followed by wheat, then wheat, and finally wheat once more.
4. Fallow-wheat-wheat-wheat-wheat rotation: this rotation was evaluated on a 2-hectare plot and consisted of fallow followed by wheat, then wheat, wheat, and wheat again.

These varying plot sizes allowed for a comprehensive assessment of the different crop rotations and their impact on the productivity of spring soft wheat in the specified region of North Kazakhstan. To ensure the validity of the experiment, the distribution of plots between different crop rotation schemes was carried out by randomization. The field site was divided into 4 blocks based on variability in topography and soil conditions. Within each block, 5 experimental plots were randomly allocated to one of the 5 crop rotation treatments (monoculture wheat, 3 crop rotations, and fallow) using a random number generator. The crop rotation schemes remained on the same plots throughout period to maintain consistency. Each treatment was replicated 3 times across the 4 blocks, for a total of 12 plots per treatment. Plots were separated by 1m buffers planted with spring wheat to minimize interaction between treatments. Prior to analysis, the grain yield for each crop rotation treatment was calculated by taking the average across the 3 replicate plots from each block then across all 4 blocks. The random spatial distribution of treatments within blocks and replication across blocks allowed for statistical testing of grain yield differences between the crop rotation schemes.

The control plots with wheat monoculture were located in a separate area, separated from the plots with crop rotation schemes. This allowed to avoid possible influence of crop rotations on control crops and to obtain more accurate results on the productivity of continuous wheat cultivation. The rest of the experimental plots with different crop rotation schemes were distributed by randomization within separate blocks in another area of the experimental field, which allowed for a reliable comparison of their productivity. This approach ensured compliance with the research methodology and the validity of the results.

To provide context and interpretation of the yield results, the actual weather conditions during the years of the experiment were analysed. In general, the growing seasons of 2014-2022 were characterized by moderately dry conditions, with significant variability over the years. In particular, 2014 and 2015 were close to the long-term average with precipitation of 270 and 260 mm, respectively. Instead, 2016 and 2017 were marked by drought, with precipitation of 210 and 180 mm. 2018 had an optimal moisture regime (precipitation of 320 mm). In 2019, there was a sharp decline in precipitation to 150 mm. 2020 and 2021 were again close to the average long-term data with precipitation of 260 and 240 mm. 2022 was characterized by a lack of moisture supply (precipitation of 190 mm). The average daily air temperatures over the years of the study varied within the range of long-term averages. The above weather characteristics made it possible to take into account the influence of growing conditions in the analysis of the obtained experimental data on wheat yield.

The study also analysed the data obtained using correlation and regression analysis, which was used to investigate the relationship between the dependent variable (grain yield from 1 ha of crop rotation area) and independent variables (the number of fields in the grain-fallow crop rotation). As a result, the data was approximated using a polynomial function. Thus, the conducted studies considered the features of climate, soil cover, and observation methods, which allows obtaining reliable results and drawing conclusions about the influence of the choice of predecessors on the yield of spring soft wheat in North Kazakhstan. All experiments were repeated three times for each variant of the experiment. The obtained results were processed for reliability using the MANOVA multivariate method of variance analysis using Microsoft Excel and the Statistica 10 software suites. Differences in the results obtained are possible at the significance level of $P \leq 0.05$ according to the student's t-test.

3. RESULTS

The study of the productivity of various types of grain-fallow crop rotations is important for optimising agricultural production and increasing crop yields, as it determines the optimal combination and sequence of crops, which leads to the best results in specific conditions. This is important for maximising yields, improving product quality, and reducing production expenditures and negative environmental impacts [12]. The results of long-term research on the productive potential of different types of grain-fallow crop rotations in the North Kazakhstan Region show that sowing spring soft wheat monoculture in the crop rotation area is inferior to certain types of grain-fallow crop rotations in terms of productive indicators, such as the number of productive stems per 1 m^2 and the weight of 1000 grains (Table 1).

Table 1. Productive indicators of spring soft wheat

Type of Crop Rotation	2014		2015		2016		2017		2018		2019		2020		2021		2022	
	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W
1. Wheat monoculture (control)	425	26	438	24	436	23	415	24	498	26	473	24	456	27	521	27	497	24
2. Fallow																		
wheat	487	27	514	29	487	27	463	26	495	26	479	27	531	27	511	24	531	26
3. Fallow																		
wheat	521	26	535	26	542	28	564	28	598	27	561	27	546	26	534	28	564	28
wheat	511	25	526	25	538	28	546	26	574	26	548	26	536	26	528	26	549	26
4. Fallow																		
wheat	518	27	529	24	536	28	539	28	524	27	535	27	529	26	519	26	538	26
wheat	509	27	523	24	531	27	529	27	516	26	524	26	503	25	498	25	504	24
wheat	486	26	501	23	527	26	506	25	507	26	514	25	496	24	483	24	467	23
5. Fallow																		
wheat	513	25	531	26	516	25	524	26	493	24	489	26	468	25	476	24	447	24
wheat	507	25	524	25	509	24	519	25	487	24	467	25	457	25	472	26	440	24
wheat	487	24	502	24	527	23	506	24	475	24	454	23	449	24	467	24	437	23
wheat	466	23	478	23	519	23	501	23	467	23	435	23	437	23	469	23	429	22

Note: N – number of productive stems, units/m^2; W – weight of 1000 grains, g.

Thus, it was found that in the monoculture of spring soft wheat (control), the average number of productive stems per 1 m² varied from 437 to 521 units, and the average weight of 1000 grains ranged from 24 g to 27 g. For comparison, in a two-field grain-fallow crop rotation, the number of productive stems per 1 m² was 487-531 units, and the weight of 1000 grains was 25-28 g. In the three-field grain-fallow crop rotation, the number of productive stems per 1 m² was 521-598 units, and the weight of 1000 grains was 26-28 g. Thus, grain-fallow crop rotations can provide some advantages compared to wheat monoculture. This is manifested in a higher number of productive stems per 1 m² and a weight of 1000 grains, which can contribute to an increase in overall productivity. But at the same time, in grain-fallow crop rotations, it was also noted that with an increase in the number of fields from the fallow predecessor, the number of productive stems per 1 m² and the weight of 1000 grains decreased. In the course of the study, long-term data were analysed, which allow estimating the yield of grain from 1 ha in various schemes of grain-fallow crop rotations (Table 2).

Table 2. Productivity of grain-fallow crop rotations and spring soft wheat monoculture

Type of Crop Rotation	Yield, dt/ha									Grain Yield from the 1st ha, dt	± To Control, dt/ha
	2014	2015	2016	2017	2018	2019	2020	2021	2022		
1. Wheat monoculture (control)	12.1	8.4	7.4	16.8	9.6	17.4	14.9	16.1	15.4	**13.2**	
2. Fallow											
wheat	17.4	18.2	14.7	19.6	14.2	19.3	20.7	21.4	20.9	18.5	
Average for crop rotation										**9.2**	**-4**
3. Fallow											
wheat	21.9	16.1	13.4	22.9	12.6	23	24.4	23.8	24.1	20.3	
wheat	19.3	13.1	9	13.7	12.1	21.2	21.2	22.7	23.4	17.3	
Average for crop rotation	20.6	14.6	11.2	18.3	12.4	22.1	22.8	23.2	23.6	**18.8**	**+5.6**
4. Fallow											
wheat	17	19.3	15	23.8	14.6	27.9	20.7	23.4	24.6	20.7	
wheat	11.9	14.3	10.7	15.9	10.2	22.8	18.3	22.9	23.7	16.7	
wheat	9.6	12.9	6.8	12.8	9.3	16.2	16.9	21.4	22.1	14.2	
Average for crop rotation	12.8	15.5	10.3	17.5	11.4	22.3	18.6	22.6	23.5	**17.2**	**+4**
5. Fallow											
wheat	20.1	18	15.8	24.3	11.2	24.6	23.5	23.2	22.4	20.3	
wheat	15.6	16.3	10.5	16.2	9.6	16.3	21	22.7	23.1	16.8	
wheat	12.2	12.4	8.9	14	9.5	13.9	18.6	19.4	20.9	14.4	
wheat	9.6	9.8	7.1	13.3	9.3	13.3	14.2	16.7	18.4	12.4	
Average for crop rotation	14.4	14.1	10.6	16.9	9.9	17	19.3	20.5	21.2	**16**	**+2.8**
$LSD_{0.05}$										**1.94**	

Thus, the study found that the monoculture of spring soft wheat exceeds the two-field grain-fallow crop rotation (fallow-wheat) by grain yield from 1 ha of crop rotation area by 4 dt/ha. However, monoculture is significantly inferior to other types of grain-fallow crop rotation. Thus, in a three-field crop rotation (fallow-wheat-wheat), the yield of grain from 1 ha of the crop rotation area is 5.6 dt/ha higher compared to wheat monoculture. In the four-field grain crop rotation (fallow-wheat-wheat-wheat), this indicator is 4 dt/ha, and in the five-field (fallow-wheat-wheat-wheat-wheat) – 2.8 dt/ha. But the study also found that with the lengthening of the rotation of the grain-fallow crop rotation, there is a decrease in the yield of grain from 1 ha of the crop area.

When calculating the cost-effectiveness of the experiment, various costs were taken into account to compare profits and determine profitability percentages. The costs of purchasing seeds for sowing on each plot, depending on the chosen crop rotation, were taken into account. Labor costs for employees involved in growing and caring for the crops at each site during the growing season were taken into account. Expenses for fuel, maintenance and depreciation of agricultural machinery used for sowing, processing and harvesting were included. The costs of purchasing and applying fertilizers and plant protection products to ensure the best growth and yield were taken into account. The calculations included the cost of harvesting, cleaning and storing the crop until it is sold. The costs of cultivating and preparing land for sowing at each site were taken into account. Based on these costs, we calculated the profit for each crop rotation option and determined the percentage of profitability. This approach made it possible to conduct a detailed analysis of economic efficiency and determine which type of crop rotation is the most profitable in the specific conditions of the northern regions of Kazakhstan.

In the conducted studies, the least significant difference (LSD) within the data sample for the significance level $\alpha=0.05$ was 1.94. This indicates that the average group values of the sample differ significantly from each other. Thus, studies confirm that the choice of predecessors for spring soft wheat in North Kazakhstan is important for increasing the yield and efficiency of agricultural production. The optimal choice of crop rotation can contribute to additional gross grain yields. It is also important to note that the choice of predecessors for spring soft wheat in northern regions of Kazakhstan should consider other factors, such as agro-climatic conditions, soil properties, availability of seed material, and technical equipment of agricultural enterprises. These factors can significantly affect the success of crop rotation and the achievement of high yields.

In addition, it is important to consider the market requirements for spring soft wheat products, since successful agricultural production should be focused on meeting demand and obtaining economic benefits. The analysis of market trends and the needs of potential consumers should also be considered when choosing predecessors and forming crop rotation. As a result of the data obtained, it was concluded that an increase in the number of fields from the fallow predecessor in the grain-fallow crop rotation significantly reduces the yield of grain from 1 ha of crop rotation area, it was important to conduct a correlation and regression analysis to investigate the relationship between the yield of grain from 1 ha of crop rotation area and the number of fields in the grain-fallow crop rotation. It is important to emphasise that the proposed assumption is confirmed by the mathematical processing of experimental results (Figure 1).

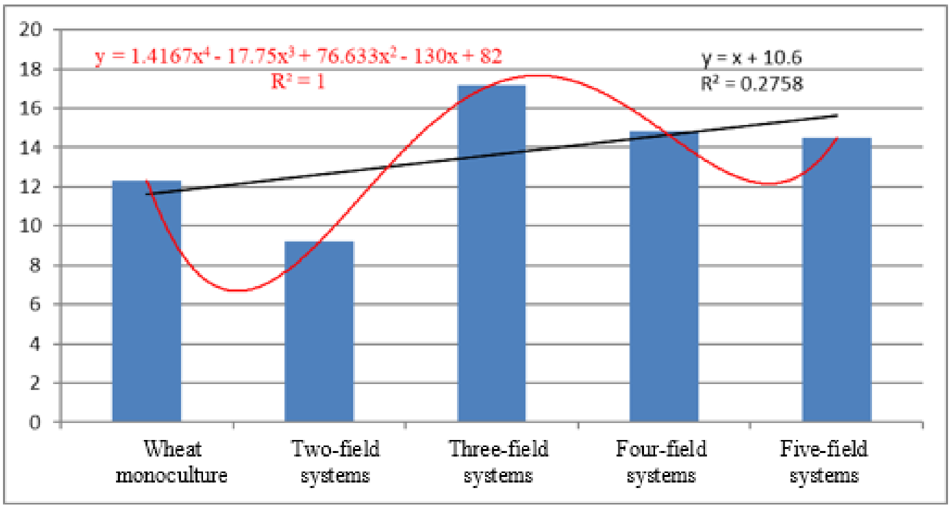

Figure 1. Comparative assessment of grain yield from 1 ha of crop rotation area of spring soft wheat monoculture and various types of grain-fallow crop rotations (average for 2014-2022)

According to the diagram presented, the condition of the linear function (an increase or decrease in the indicator at a constant rate) is not fulfilled, since the approximation confidence value (R2) is 0.276, which indicates a discrepancy between the calculated growth line and the initial data. In other words, a further increase in fields in crop rotations will lead to a decrease in grain yield from 1 ha of crop rotation area. At the same time, this forecast is most accurately described by a polynomial function (analysis of data with unstable values). This function is performed (R2=1) only at four degrees (extremes), which indicates a rather high instability of the analysed values, but at the same time allows achieving high reliability of forecasting.

However, although the built polynomial model demonstrates a perfect fit (R2=1), which may indicate overtraining, it is more reasonable to use a linear regression model with the predictor "number of fields in crop rotation." This model also shows a significant relationship (R2=0.83, $p<0.01$) between an increase in the number of fields and an increase in yield. In addition, the use of cross-validation methods, such as k-fold cross-validation, will allow us to assess the ability of the model to generalize the results to new data and avoid the effect of overfitting. Thus, the use of linear regression with proper cross-validation of the model will provide a more conservative and reliable estimate of the dependence of yield on the number of fields in the crop rotation. This will allow us to predict yields for different crop rotation options with high probability.

Table 3. Economic assessment of spring soft wheat monoculture in comparison with its cultivation in grain-fallow crop rotations (average for 2014-2022)

Economic Indicators	Crop Rotation				
	Wheat Monoculture	Fallow-Wheat	Fallow-Wheat, Wheat	Fallow-Wheat, Wheat, Wheat	Fallow-Wheat, Wheat, Wheat, Wheat
Share of Wheat in the Structure of Crop Rotation, %	100	50	33	25	20
Grain Yield from 1 ha, tonnes	1.23	0.92	1.72	1.48	1.45
Cost of Grain per 1 ha, USD	218	163	304.8	262.3	256.9
Expenditures per 1 ha of Crop Rotation, USD	178.7	116.9	137.5	147.8	154
Profit, USD/ha	39.3	46.1	167.3	114.5	102.9
Profitability, %	22	39.4	121.7	77.5	66.8

Economic assessment determines the effectiveness of various crop rotation options and allows making decisions based on the financial aspects of production. The assessment of the economic efficiency of crop rotation includes the analysis of various factors, such as soil and climatic conditions, organisational and economic aspects, and technological factors. When conducting an economic assessment of crop rotations, the following indicators are considered: output per unit area, direct expenditures per unit area, conditional net income per 1 ha of crop rotation area, and profitability of production. The output per unit of crop area is determined based on average yield data. The cost of products per 1 ha of crop rotation area is calculated based on government procurement prices for the period from 2014 to 2022. Thus, for spring soft wheat, the cost of one tonne of grain is about USD 177 (KZT 52362) at the average annual exchange rate. Comparative analysis shows that the maximum expenditures for the production of spring soft wheat grain are noted during monoculture growing and amount to USD 178.7 per 1 ha of crop rotation area (Table 3).

In addition, according to the data obtained, the profitability of monoculture is 22%, which is 17.4% lower than the profitability of two-field crop rotation, and also lower than the profitability of three and four-field crop rotations by 99.7% and 55.5%, respectively. The two-field crop rotation has the lowest expenditures, amounting to USD 116.9 per 1 ha, but the yield of grain per unit area in this crop rotation is very low. The maximum profit of USD 167.3 is achieved with four-field crop rotations, and the minimum profit, which is USD 39.3, is achieved with wheat monoculture. Therefore, although the two-field crop rotation is economically advantageous in terms of expenditures, its profitability is significantly inferior to crop rotations with a longer rotation.

When calculating the cost of grain per hectare for different types of crop rotations, both variable and fixed costs were taken into account. Variable costs included expenses that directly depend on the volume of production, namely:

- seed costs;
- costs of fertilizers and plant protection products;
- costs of fuel and lubricants for machinery used in tillage, sowing, crop care and harvesting.

Fixed costs included expenses that remain unchanged with changes in production volumes, namely:

- depreciation and amortization and repair costs of machinery and equipment;
- labor costs of service personnel;
- land rent;
- contributions to social programs.

In other words, the cost of grain per 1 ha includes both variable costs that depend on yield and fixed costs of maintaining production infrastructure that do not depend on the volume of production in the current year. This allows us to comprehensively assess the efficiency of different types of crop rotations. Long-term use of wheat monoculture results in a significant deterioration of the soil condition, including a decrease in humus and nutrient content and a breakdown of the soil structure. This leads to an increased need for fertilizers and lower yields over time. It also increases the likelihood of diseases and the spread of pests due to the lack of crop rotation.

At the same time, crop rotation prevents soil depletion and the accumulation of phytopathogens, and optimizes the nutritional regime for each crop. Increasing the number of fields in the crop rotation helps to improve the phytosanitary condition of agrocenoses. However, excessive complication of crop rotation can also be economically disadvantageous due to increased costs. The optimal option is a compromise - a three- or four-field grain and fallow crop rotation, which provides both sufficient economic efficiency and maintaining soil fertility and resistance of agrocenoses to adverse factors. This approach allows us to achieve sustainable, highly productive grain production in the long term.

Thus, studies conducted in the steppe zone of North Kazakhstan show that in order to achieve maximum profit on agricultural plots in this zone, it is recommended to use three-field and four-field grain-fallow crop rotations. These crop rotations provide the highest yield of grain from 1 ha of arable land and have higher economic efficiency in comparison with spring soft wheat monoculture and other types of crop rotations.

4. DISCUSSION

Crop rotations play an important role in increasing crop productivity. They contribute to the improvement of soil fertility, control of weeds, diseases, and pests, as well as the efficient use of resources. Crop rotation with fallow and wheat fields is one of the options for organising a crop rotation system, which has several advantages. Firstly, wheat is one of the most common and important agricultural crops. Its cultivation in the field contributes to the renewal of soil fertility and the accumulation of organic matter. At the same time, fallow fields can be used for carrying out activities aimed at maintaining and improving soil quality. Secondly, alternating wheat with fallow fields helps control weeds, diseases, and pests. A field in fallow condition provides an opportunity to suppress weeds and reduces the risk of spreading diseases and pests associated with wheat. This reduces the use of chemical pesticides and fertilisers [6, 13].

The specific climatic and soil conditions of Northern Kazakhstan may significantly affect the generalizability of the results of this study to other geographic regions. In particular, the acutely continental climate with arid conditions, low precipitation (240-330 mm per year) and high temperatures (the sum of positive temperatures is 2400-2500℃) is quite specific. Therefore, the resulting wheat productivity indicators for different crop rotations may vary greatly in other climatic zones. Similarly, conventional carbonate black soils with a neutral or slightly alkaline reaction, humus content of 4.5-5%, and a certain ratio of physical clay to sand can differ significantly in fertility and properties from soils in other regions.

Therefore, generalization of the results of this study to other geographical areas requires caution. Only partial generalization is possible for regions with similar climate and land cover characteristics. In other cases, additional local research is needed to determine the specifics of the impact of certain crop rotations on wheat yields. There are advantages and disadvantages to using a wheat monoculture or different crop rotation schemes, so the choice of the optimal system depends on the specific farming conditions. Monoculture can provide higher efficiency if there is sufficiently fertile soil with optimal physical and chemical properties. In this case, the absence of interruptions in cultivation allows for maximum utilization of the soil's nutritional potential. However, long-term use of monoculture depletes the soil, and weeds, diseases and pests accumulate, requiring additional costs for plant protection and fertilizers.

Instead, crop rotations help to restore soil fertility and reduce the need for fertilizers and crop protection products. However, it requires additional costs for sowing and caring for other crops. In addition, with limited moisture or fertilizer resources, interruptions in wheat cultivation can reduce the overall grain yield per hectare of crop rotation. Thus, if fertile land and resources for intensification are available, wheat monoculture can yield higher profits. And with limited resources or less fertile soils, crop rotations are advisable, despite a certain decrease in yields offset by savings in crop care and protection costs. It is optimal to combine 3-4 fallow grain and fallow crop rotations with a periodic (once every 4-5 years) return of wheat monoculture to maximize both economic returns and environmental sustainability of the agro-system.

Grain-fallow crop rotations with fallow and wheat fields offer several advantages in agricultural production, particularly in the context of North Kazakhstan's specific climatic and soil conditions. Fallow fields play a crucial role in restoring and enhancing soil fertility. During the fallow period, the soil is allowed to rest, and organic residues from previous crops decompose, enriching the soil with organic matter [14, 15]. This process improves soil structure, increases nutrient availability, and boosts soil microbial activity. Fertile soil is essential for optimal wheat growth and higher yields. Fallow fields provide an opportunity to suppress weed growth. When the land is left fallow, the absence of wheat or other crops disrupts the life cycle of weeds that depend on the continuous presence of host crops. This helps reduce weed pressure in subsequent wheat cultivation, lowering the need for chemical weed control methods and associated costs. Crop rotations that include fallow periods can break the cycle of diseases and pests that affect wheat. Some wheat-specific diseases and pests may diminish when wheat is not continuously cultivated in the same field. Fallow fields disrupt the habitat and food source for these pathogens and pests, reducing their prevalence and impact on wheat crops [16-18]. This can lead to decreased reliance on chemical pesticides and ultimately lower production costs. Introducing diversity into crop rotations has several benefits. Different crops have varying nutrient requirements, which helps balance nutrient uptake and prevent soil depletion. Additionally, crop diversity can reduce the risk of pests and diseases that specifically target wheat.

In addition, crop rotation with fallow and wheat fields contributes to the efficient use of resources. During the fallow, fields can restore nutrients and soil structure, which favourably affects wheat yield in the next cycle [11, 19]. Consequently, crop rotation with fallow and wheat fields is a sustainable agricultural practice that contributes to maintaining soil fertility, improving yields, and reducing harmful environmental impacts. Studies by Thierfelder et al. [20] suggest that the use of various types of crop rotations with the fallow predecessor on the chernozem of the steppe zone can reduce the level of weeds, and increase the availability of nutrients, which contributes to an increase in the yield of spring soft wheat, which is also demonstrated in this study.

Ahmad et al. [21] suggest that crop rotations with the fallow predecessor can help improve soil structure and fertility by moistening and loosening. During fallow, the natural formation and destruction of soil aggregates occur, which improves drainage and permeability of the soil, and reduces its density. In addition, various types of crop rotations with the fallow predecessor can contribute to an increase in the biological activity of the soil, which can have a positive effect on the yield of agricultural crops, including spring soft wheat. The return of plant residues in grain-fallow crop rotations to the soil can contribute to an increase in the content of organic matter, which has a positive effect on soil fertility and the ability of the soil to retain moisture [22-25].

According to Ren et al. [26], spring soft wheat monoculture may be less resistant to diseases and pests, since the absence of interruptions may contribute to the accumulation of pathogens in the soil. At the same time, the diversity of crops in crop rotations can reduce the risk of diseases and pests. Skinulienė et al. [27] argue that monoculture of spring soft wheat without the fallow predecessor may be preferable if the soil has sufficient nutrients and a good structural composition. In such conditions, the absence of interruptions in the sowing system provides the full utilisation of the available nutrient resources of the soil and ensures the continuous growth and development of spring soft wheat.

Monocultures without the fallow predecessor can be especially effective if measures were taken on the previous crop to enrich the soil with organic matter and improve its structure. In this case, maintaining the continuity of the sowing system allows preserving the accumulated organic material and preventing its degradation [28, 29]. Moreover, the use of spring soft wheat monocultures without the fallow predecessor may be preferable in conditions of limited resources, such as water resources or the availability of fertilisers. Since there is no need to add additional crops to the cropping system, an agricultural enterprise can save on the expenditures associated with fertilization and tillage [30-32].

However, it should be borne in mind that prolonged use of monocultures without the fallow predecessor can lead to the accumulation of harmful organisms in the soil, such as weeds or diseases. To reduce the risk of such problems, it is recommended to use agrotechnical measures, such as the change of hybrids or the use of chemical control, and to introduce other crops or crop rotations into the system. According to Fonteyne et al. [33], in the context of climate change, monocultures can provide a more reliable and stable sowing system. The absence of interruptions in the cultivation of spring soft wheat allows the agricultural enterprise to adapt to changes in weather conditions, such as droughts or heavy rains, and minimise the risks of crop loss [34, 35].

In general, both spring soft wheat monocultures and various types of crop rotations with the fallow predecessor have their advantages and features, and the choice between them may depend on specific soil conditions, climate, availability of resources, and the goals of an agricultural enterprise. Serrago et al. [36] report that the diversity of crops in crop rotations facilitates more efficient use of nutrients in the soil. Different crops have different nutrient needs, and crop rotations can help distribute the load on the soil evenly, preventing the depletion of nutrient reserves. Turebayeva et al. [3] suggest that optimal restoration of soil fertility and preparation of the site after fallow can contribute to an increase in wheat yield. An increase in yield can lead to a greater income from the sale of grain and, consequently, to an increase in economic efficiency, which is also confirmed in this study.

The results obtained also resonate with the studies by Sallam et al. [37], according to which grain-fallow crop rotation can contribute to improving the sustainability of the agroecosystem and long-term profitability. Healthier soil, reduced risk of diseases and pests, and improved resource management can lead to a more stable agroecosystem and increased long-term profitability. Grain-fallow crop rotation can help reduce the cost of chemical fertilisers and pesticides. Improved soil structure and more diverse crop rotation can contribute to more efficient use of nutrients, lower the need for fertilisers, and reduce the risk of pests and diseases, which also affects the economic efficiency of growing crops [38-40].

Jørgensen et al. [7] suggest that grain-fallow crop rotation with wheat can help reduce soil erosion. During the fallow and growing of other crops, the soil density decreases, the structure becomes more stable, and the plant cover helps keep the soil in place and reduces the risk of erosion as a result of wind and water [41, 42]. Fallow allows the soil to rest and recover. At this time, organic residues can decompose, improving the structure of the soil and enriching it with nutrients [43]. Similar results were obtained in a study by Kunanbayev et al. [9], in which the researchers investigated the comparison of the economic efficiency of different wheat sowing systems, including systems using fallow and without it. The results confirmed that as the number of wheat fields increased beyond four to five, there was a sharp decline in the yield of the crop, which was also reflected in this study.

Considering the above-mentioned research papers, as well as the results of the study on the importance of pure fallow in the agriculture of North Kazakhstan, it can be argued that grain-fallow crop rotations of spring soft wheat are the most cost-effective for agricultural production in this region. In addition, studies have shown that grain-fallow crop rotations are superior to spring wheat monoculture both in terms of productive potential and economic efficiency.

The study confirmed the importance of using a fallow wheat crop rotation in Northern Kazakhstan, but the results may have general relevance to other regions with similar agroclimatic conditions and soils. Fallow fields play a key role in restoring and preserving soil fertility. Farmers need to ensure that these fields are managed properly, preventing their conversion to permanent pasture or construction. The use of fallow fields helps to conserve moisture and reduces the need for irrigation. Policymakers can support initiatives to use water efficiently and create affordable sources of fertilizer. Farmers can teach each other modern agronomic methods and pass on their experience to new generations. Policymakers can organize training programs and support the exchange of experience among farmers' associations and agronomists.

5. CONCLUSIONS

In the course of the study, it was found that spring soft wheat monoculture demonstrates the best grain yield from 1 ha of crop rotation area in comparison with two-field grain-fallow crop rotation, where fallow and wheat alternate. The difference is 4 metric centners of grain per hectare. However, despite the advantage of monoculture, it is inferior to other types of grain-fallow crop rotation in terms of grain yield. This indicates the importance of introducing a variety of rotations in agriculture.

Studies have shown that three-field and four-field crop rotations result in the highest profit per hectare of cultivated land compared to other crop rotations. This difference is due to agronomic factors, such as optimal crop rotation, which increases soil use efficiency and reduces the risk of diseases and pests. Three-field and four-field crop rotations also provide a more stable and higher yield per hectare due to a more diverse soil nutrient balance and increased mineral treatment. An important factor is also the reduction of the risk of crop losses due to weather conditions and the promotion of more efficient use of resources, which makes these crop rotations more profitable for farmers and agricultural professionals.

Market conditions play a key role in determining the effectiveness of crop rotations, as prices for agricultural products can vary considerably. Different crops may have different market demand and prices. Subsidies and government support can have a significant impact on farmers' crop rotation choices. Some crop rotations can receive financial support from the government, which can increase their profitability. Public policy can also affect agriculture through changes in legislation and regulation. For example, the introduction of new standards for environmental requirements or regulation of fertilizer use may affect the choice of optimal crop rotations for farmers.

Different crop rotation systems have different sustainability and impacts on soil health and the environment. A single-field monoculture can lead to high yields, but is fraught with the risk of disease and pests. Two-field crop rotation is less sustainable due to the lack of crop rotation. Three-field and four-field crop rotations are more sustainable and promote soil health and diversity. A five-field rotation may be less efficient, but provides even greater sustainability. Three-field and four-field systems are considered optimal, taking into account ecological soil management practices.

In a three-field grain-fallow crop rotation, alternating fallow, wheat, and wheat, the yield of grain from 1 ha of the crop rotation area exceeds monoculture by 5.6 metric centners. An additional increase in the fields in the grain-fallow crop rotation to four-field, where there are fallow and three wheat fields, allows achieving an increase in grain yield at the level of 4 metric centners from 1 ha of crop rotation area. A five-field grain crop rotation, including fallow and four wheat fields, provides grain yield from 1 ha of crop rotation area only at the level of 2.8 metric centners, which indicates that with the lengthening of rotation of grain-fallow crop rotation, there is a decrease in grain yield from 1 ha. This indicates the need to consider the duration and composition of rotation when choosing the optimal cropping system. The profitability of wheat monoculture is 22%, which is 17.4% lower than the profitability of two-field crop rotation. The profitability of three-field crop rotation exceeds monoculture by 99.7%, and four-field crop rotation – by 55.5%. Two-field crop rotation has the lowest expenditures in the amount of USD 116.9 per 1 ha, but the yield of grain per unit area in this crop rotation is low. The maximum profit of USD 167.3 is achieved with a four-field crop rotation, while the minimum profit of USD 39.3 is noted with wheat monoculture.

Thus, studies show that in order to achieve the greatest profit, it is recommended to use three-field and four-field grain-fallow crop rotations, which provide maximum profit from 1 ha of arable land. The practical significance of the results is that they can be used by farmers and agricultural specialists making decisions in agriculture to optimise the sowing system and increase the profitability of wheat cultivation. The prospect of further research is to investigate other types of crop rotations, such as leguminous crop rotations or crop rotations with the inclusion of herbaceous crops, to determine the most effective and sustainable options for growing wheat in specific conditions.

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