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The Possibility of Environmentally Sustainable Yield and Quality Management of Spring Wheat (*Triticum aestivum* L.) of the Cornetto Variety When Using Sapropel Extract

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Abstract: Sustainable development is one of the main directions of modern agriculture. First of all, sustainability in the agricultural sector can be achieved through the possible abandonment of traditional mineral fertilizers. Many decades of using these fertilizers have led to the degradation of arable soils and to soil and environmental pollution. As a result, this causes reductions in yields and the environmental quality of agricultural products and affects the health of the population. An alternative to traditional mineral fertilizers may be the use of innovative organomineral fertilizers obtained from local resources. These include manure, humus, compost, sediments, etc. In recent years, fertilizers obtained from the sapropels of the bottom sediments of lakes have become widespread. Their distinctive feature is the environmental friendliness and completeness of the content of chemical elements and substances necessary for the development and growth of plants. In addition, the methods of obtaining and applying these fertilizers allow us to talk about their effectiveness in use. The range of applications of these fertilizers is diverse, from use in the form of a dry extract applied directly to the soil to the use of liquid suspensions used at various stages of processing and from pre-sowing seed treatment to watering and spraying plants at different periods of vegetation. Moreover, an important aspect is the research work on the variational use of sapropel fertilizers on different crops, with different methods of production and concentrations and at different stages of processing. This publication contains the results of a study of the effect of the obtained innovative sapropel fertilizer on productivity, wheat grain quality, and economic efficiency (*Triticum aestivum* L.). To identify the optimal concentration of sapropel extract, laboratory studies were carried out to determine the germination energy and germination of wheat seeds of different varieties when they were soaked in various concentrations: 0.4, 0.8, 1.2, 1.6, and 2.0 g/L. The best indicators of germination energy and germination of wheat seeds during treatment with the extract were obtained at a concentration of 1.2 g/L. The research was conducted at an accredited variety testing laboratory. A field experiment was conducted in the fields of the agrobiological station of North Kazakhstan University named after Manash Kozybayev. The treatment of the seeds was carried out by soaking them in sapropel extract to evenly distribute the substance. The scheme of the field experiment included the option of using foliar treatment with a solution of sapropel extract at the tillering stage. As a result of the application of the obtained extract in the field, environmental and socio-economic efficiency was noted. The conducted field studies note its positive effect and effectiveness on the morphological, qualitative, and quantitative indicators of the wheat harvest. In the areas where wheat seeds were pretreated, as well as where foliar treatment with the resulting sapropel suspension

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was carried out, the best yield indicators were revealed. In these variants of the experiment with pre-sowing and pre-sowing and foliar treatment with the sapropel extract solution, the yield was 3.63 and 3.81 tons per hectare, respectively. The introduction of sapropel extract at the stage of seed treatment before sowing, as well as foliar processing of wheat at the tillering stage, will increase the efficiency and profitability of the agricultural industry and obtain a synergistic effect in the form of socio-economic efficiency and environmental safety of production. In our opinion, this will contribute to the development of sustainable agriculture and the production of environmental products.

Keywords: sustainability; sapropel; sediments; sapropel extract; North Kazakhstan region; lakes; natural resources; organic farming; innovative fertilizer; wheat

1. Introduction

Agriculture is one of the oldest and most important industries in the world, which plays an important role in ensuring food safety and sustainable development [1–4].

Despite this, agriculture is currently facing a variety of serious challenges that must be overcome to ensure global food security and sustainability [5–7].

In modern economic conditions, grain production determines the development of the agricultural and food market [8].

In order to meet food needs, due to population growth, there is a need to increase crop yields. Of course, the main crops for consumption by the world's population are wheat, corn, rice, and soybeans. In this regard, it is necessary to increase the yield of these crops, in conditions of increasing anthropogenic load, soil degradation, and climatic changes [9–13].

In these dynamic conditions, it is necessary to search for innovative methods of growing food crops [14–16].

Nevertheless, the sustainable future of agriculture is vital and is one of the strategies of many countries. This is caused not only by the need to ensure sustainability and food security but also by the desire to reduce the negative impact on the environment and increase the productivity of agricultural crops [17,18].

These aspects can be achieved with the integrated use of mineral and organic fertilizers, which is an effective and sustainable approach to providing plants with the necessary nutrients. Each type of fertilizer has its advantages, and their combination can ensure optimal plant development and increase yields. The use of both types of fertilizers allows a user to achieve a synergistic effect, providing plants with everything necessary for full growth and development. This can contribute to improving the economic efficiency of agriculture by increasing the yield and quality of products. Maintaining and increasing the productivity of agricultural crops, especially cereals, without compromising environmental sustainability are key tasks of the future [19–23].

At the same time, improving crop productivity is a key factor for improving the environmental and economic efficiency of this industry. In recent years, increasing attention has been paid to the use of natural resources and biological products to increase crop yields and quality [24–28].

At the present stage, the use of environmentally friendly fertilizers is becoming significant for the production of grain crops. The prohibition of the use of water-soluble mineral fertilizers and pesticides in a number of countries has led to the need to review the organization of grain farming within the framework of sustainable development. Organic fertilizers are becoming widespread, which leads to studies of their effect on traditional varieties, as well as the need for breeding new varieties. This range of research works, among other things, affects the peculiarities of obtaining and growing wheat in organic and traditional agriculture [11,29–31].

Due to climate change, there is a research interest in the peculiarities of wheat cultivation in various agro-climatic conditions, which leads to experimental work on the adaptation of wheat varieties [32–38].

At the same time, researchers are actively searching for environmentally friendly fertilizers for growing organically pure grain. One of the innovative directions is the use of bottom sediments of lakes, from which sapropel fertilizers are created. Sapropel is a substance formed during the natural decomposition of organic matter at the bottom of swamps, lakes, and other types of reservoirs [39–41].

Sapropel, as a result of the biological decomposition of organic substances in the aquatic environment, has a unique composition. Studies conducted by a number of scientists emphasize its richness in trace elements, macronutrients, organic acids, and other substances [42–44].

Studies have also shown that sapropel has unique properties that can positively affect the growth and development of plants, especially in areas with a lower humus content. In particular, the use of sapropel-based fertilizers can help to increase their resistance to stressful conditions, improve nutrient absorption, and increase yields [45–49].

At the same time, it is necessary to study the possibility of using environmentally friendly organic–mineral fertilizers based on local resources to develop innovative technologies for its production and application. It is also becoming relevant to study the effect of seed treatment before sowing. This, in turn, will make it possible to achieve the effectiveness of the use of organomineral fertilizers and will also have a positive economic effect. It will manifest itself when the technology of production and the use of innovative fertilizers changes.

The purpose of this study is to study the effectiveness of pre-sowing and off-root treatment of seeds obtained by sapropel suspension of local lakes on the yield and quality of spring wheat. As part of the study, experimental studies were conducted, as well as analyses of quantitative and qualitative indicators of the resulting harvest of Cornetto spring wheat. The variety is used for the production of bakery products. The variety selected for this study is fairly well distributed for cultivation in Kazakhstan and, in particular, in the North Kazakhstan region.

This study aims to study the sustainable development of the agricultural sector of the region's economy. It will contribute to obtaining economic, environmental, and social effects. The economic effect will manifest itself in reducing the cost of production and use of fertilizers; at the same time, it will allow a higher and better yield to be achieved with variable application. At the same time, the qualitative composition of the resulting fertilizer will not have a negative environmental impact on the environment. Organic farming, normalization of the use of organomineral fertilizers, and environmentally friendly agricultural products may have a positive impact on the health of the population. The organization of new jobs will help to achieve a social effect.

2. Materials and Methods

2.1. Obtaining Sapropel Extract

The sapropel suspension or extract was obtained using the method of extracting organic and inorganic substances from the bottom sediments of a local natural lake. Sapropel of Lake Penkovskoye, North Kazakhstan region, was used for this purpose. The peculiarity of this lake is the small depth and significant thickness of the bottom sediments, the proximity of the location, and the availability of sapropel harvesting [50].

The extraction of sapropel mass was carried out in aqueous and aqueous alcohol solutions with further concentration and combination. This was achieved by centrifugation and evaporation in a rotary evaporator at a temperature of no more than 39 °C using a vacuum pump. This allowed us to preserve the organic substances. A series of solutions with different concentrations were prepared from the resulting concentrate of 2.98 g/L (0.4, 0.8, 1.2, 1.6, and 2.0 g/L) [51,52].

A patent of the Republic of Kazakhstan has been obtained for this method of obtaining sapropel extract [53].

2.2. Laboratory Tests

Laboratory research to determine the optimal concentrations of the obtained sapropel fertilizer, which affects the energy and germination of spring wheat seeds, was carried out in accordance with GOST 12038-84 "Seeds of agricultural crops" [54].

This experiment was conducted in the laboratory of "Kazakhstan Agrarian Expertise". The optimal concentration was established experimentally, in terms of energy and germination rate of wheat seeds. In laboratory conditions, the germination energy and germination of wheat seeds were determined. To do this, the seeds were selected and soaked on two or three layers of filter paper in Petri dishes moistened with various concentrations (0.4, 0.8, 1.2, 1.6, and 2.0 g/L). Water was used for the control sample. All experimental variants were placed in a thermostat at a temperature of 20 $\pm$ 2 °C. The percentage of normally germinated seeds or germination energy was determined on the 3rd day. By counting the number of normally germinated seeds on the 7th day, the germination of seeds was determined. According to the results of the experiment, the optimal concentration of the solution used was determined, at which the best result was obtained. Laboratory studies were carried out on three wheat varieties: Novosibirsk 31, Cornetto, and Omsk 28. The working concentration of the optimal sapropel extract was 1.2 g/L.

2.3. Field Studies

The experiment on the cultivation of spring wheat was conducted in the field season of 2023 at the agrobiological station of the M. Kozybaev Agricultural University in accordance with the generally accepted methodology [55]. During the field study, preference was given to Cornetto wheat due to its resistance to many diseases and resistance to shedding on the root. This wheat variety is also widely used by farmers in the studied region.

Weather conditions during this growing season were characterized as unfavorable. The spring and summer periods were hot and arid [56].

Sowing of wheat seeds was carried out on 22th May 2023. The work on laying the field experiment was carried out four times in each variant. The sowing of the crop was carried out on plots of 4 m^2 in size. The sites where the field experiment was conducted were placed randomly in order to eliminate possible distortions of the experimental results.

In this study, a total of four experimental variants were conducted. The scheme of the field experience is represented by the following options:

1. Control without fertilizers, background + dry seeds.
2. Background + pre-sowing water treatment.
3. Background + pre-sowing seed treatment (soaking for 6 h) of sapropel extract in a volume of 10 mL/52 g of seeds.
4. Background + pre-sowing and foliar treatment at the tillering stage.

Figure 1 shows the scheme of the experiment at the stage of vegetation.

Figure 1. Scheme of field experience at the stage of vegetation.

The seeding rate per 1 plot is 52 g of wheat grain. The row spacing was 30 cm wide, and the sowing depth was 6–8 cm. The prepared crop seeds were soaked in sapropel extract for 6 h before sowing to evenly distribute the substance and then sown into the soil. Foliar treatment at the tillering stage was carried out by spraying with a working liquid (100 mL of water + 10 mL of sapropel extract). At the end of the field experiment and harvest, the following parameters were studied: ear length, number of grains, moisture, nature, protein, vitreousness, mass fraction of crude gluten, gluten quality, and number of drops.

The yield value was determined on laboratory scales. The analysis of grain quality indicators was carried out in laboratory conditions.

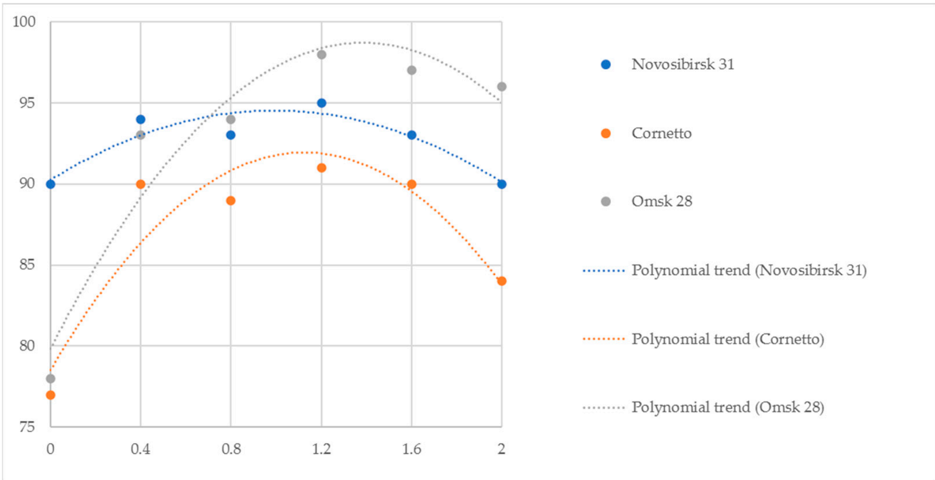
3. Results

3.1. Determination of the Optimal Concentration of the Sapropel Product

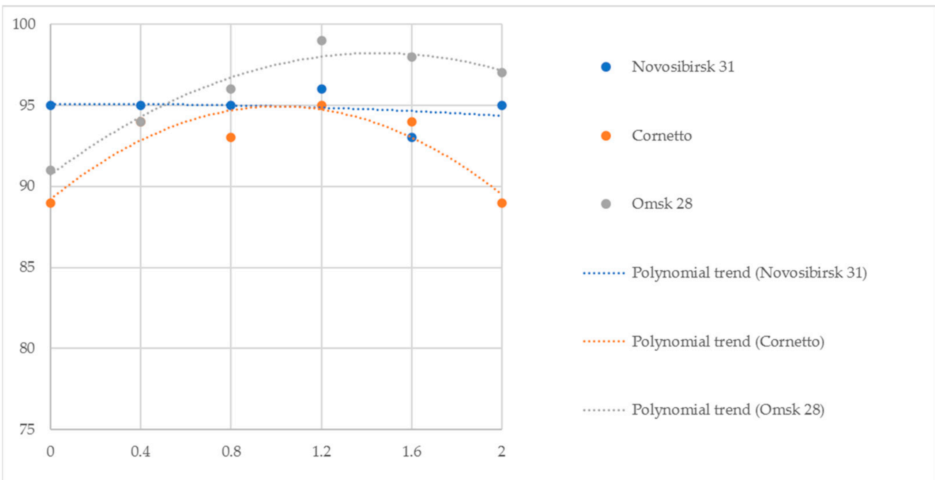
During laboratory studies, five variants were used to determine the optimal concentration of sapropel extract (0.4, 0.8, 1.2, 1.6, and 2.0 g/L). The basis for choosing the optimal concentration was the indicators of germination and germination energy of wheat seeds of three varieties. The results of a laboratory study of these indicators are shown in Tables 1 and 2.

According to the data given in Tables 1 and 2, it was found that the maximum indicators of germination and seed germination energy are noted when using each concentration.

A polynomial regression model was built to confirm the results of a laboratory experiment. Thus, the relationship between the concentrations used and the indicators of germination energy and seed germination is shown on a graph with the plotted polynomial trends (Figure 2).



(**a**)



(**b**)

Figure 2. The polynomial trend of determining the optimal concentration of the effect of sapropel extract "Saprolin" on (**a**) the germination energy of different wheat varieties; (**b**) the germination of seeds of different wheat varieties.

Table 1. The results of a laboratory study to determine the energy of germination of wheat seeds.

Sapropel Extract Concentration, g/L	Novosibirsk 31	Cornetto	Omsk 28
0	90	77	78
0.4	94	90	93
0.8	93	89	94
1.2	95	91	98
1.6	93	90	97
2.0	90	84	96

Table 2. The results of a laboratory study to determine the germination of wheat seeds.

Sapropel Extract Concentration, g/L	Novosibirsk 31	Cornetto	Omsk 28
0	95	89	91
0.4	95	94	94
0.8	95	93	96
1.2	96	95	99
1.6	93	94	98
2.0	95	89	97

According to the results of the analysis, the optimal concentration was 1.2 g/L, at which the greatest effect was revealed. This concentration was later applied in field experiments.

The analysis of the study of the qualitative composition of the innovative fertilizer, carried out in a certified laboratory, shows a high content of organic humus and matter—36.94% and 38.1%, respectively. It was revealed that the composition of the resulting fertilizer includes a sufficient amount of all necessary chemical elements, for example, phosphorus, potassium, manganese, zinc, etc. In addition, the environmental friendliness of the resulting product is confirmed by the absence of an exceedance of the maximum permissible concentrations of Co, Cr, Pb, Hg, As, and other chemical elements [57].

3.2. The Results of the Field Study

After harvesting, the yield indicators in the phase of full ripeness of wheat were studied.

Table 3 shows the results of comparing the productivity indicators of Cornetto wheat in various experimental variants, including the control, pre-sowing treatment with water, and the pre-sowing and foliar treatment with sapropel extract solution at the tillering stage.

Table 3. Productive indicators of Cornetto wheat.

Indicators	Experience Options			
	Control	Pre-Sowing Water Treatment	Pre-Sowing Treatment with Sapropel Extract Solution	Pre-Sowing and Foliar Treatment with Sapropel Extract Solution
Number of plants per 1 m^2	207.25 ± 17.23	279.50 ± 29.1	283.75 ± 34.19	300.50 ± 44.15
The number of productive stems per 1 m^2	337.25 ± 21.31	360.50 ± 21.5	397.25 ± 58.64	403.00 ± 40.7
The average number of grains per ear	18.11 ± 0.9	19.61 ± 1.8	21.13 ± 1.27	22.07 ± 1.11
Weight of 1000 grains (g)	40.36 ± 0.1	42.70 ± 0.21	42.84 ± 0.25	43.34 ± 0.17
Average yield ton/ha	2.63 ± 0.16	2.82 ± 0.14	3.63 ± 0.33	3.81 ± 0.68

The size of the grain harvest largely depends on the formed elements of the crop structure. These include the germination index (the number of plants per 1 m^2), the productive bushiness of the plants, the number of grains in the crop, and their mass. The analysis of Table 3 showed that, according to a number of indicators, the wheat differed with each experiment scheme. The highest germination rate (number of plants per 1 m^2) was observed in the experiment with pre-sowing and foliar treatment with the sapropel extract solution and amounted to 300.50 ± 44.15 plants, which is almost 100 plants more than in the control. The second and third highest were found in the experiment with pre-sowing water treatment and foliar treatment with the sapropel extract: 279.50 ± 29.1 and 283.75 ± 34.19. In terms of number of productive stems, the experiment with pre-sowing and foliar treatment with the sapropel extract solution showed the highest result, at 403.00 ± 40.7. The maximum value for the average number of grains in an ear was also seen in the experiment with pre-sowing and foliar treatment with the sapropel extract (22.07 ± 1.11), indicating increased productivity in grain formation. The value of the mass index of 1000 grains in all variants of the experiment was very close to each other, but the highest mass was observed in the pre-sowing treatment with a sapropel solution of 43.34 ± 0.17 g. The highest yield was noted in the experiment with pre-sowing and foliar treatment with the sapropel extract solution (3.81 ± 0.68), and the lowest in the control group (2.63 ± 0.16) (Figure 3).

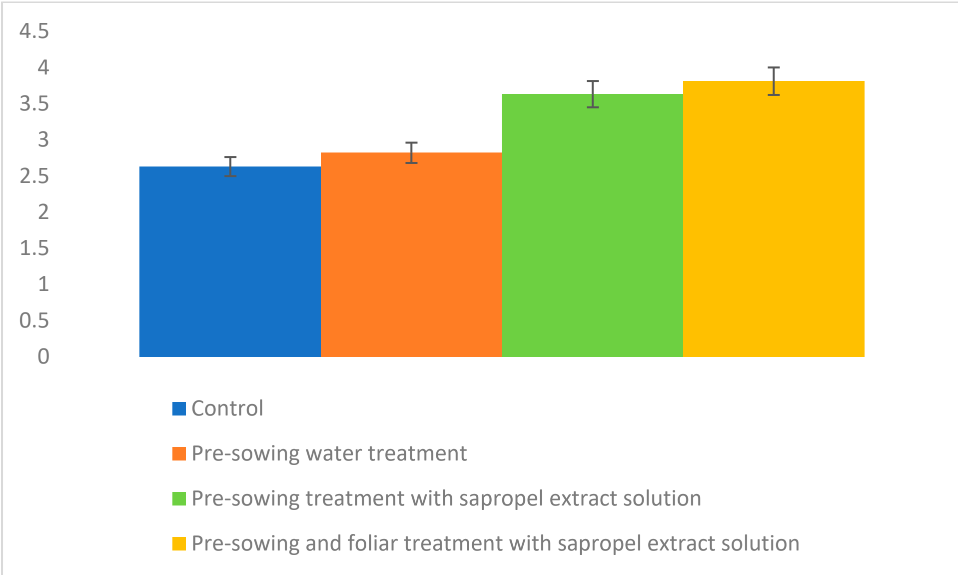


Figure 3. The average yield of wheat, according to the results of the experiment, tons per hectare, with a percentage margin of error.

Thus, based on the presented data, it can be concluded that the pre-sowing seed treatment with sapropel extract solution, as well as the pre-sowing and foliar treatment with sapropel fertilizer solution showed the highest results in germination, the number of productive stems, and the average number of grains per ear, as well as in yield. This indicates that this technique can be effective in increasing wheat yields. The pre-sowing treatment with water also showed positive results, although it did not reach the level of the pre-sowing treatment with sapropel extract solution. Nevertheless, it should be noted that the experiment where the seeds were soaked with water also showed an improvement in performance compared to the control, which indicates the potential effectiveness of this method.

It is believed that the use of sapropel extract can also have a positive effect on the quality of grain crops. Due to the content of useful organic compounds in it, cereals grown on soil fertilized with propel can have a richer taste, brighter color, and increased nutritional content. We plan to study this in the future, with a variable experiment.

At the next stage of this study, laboratory studies were conducted to assess the qualitative indicators of the resulting harvest. The following were determined: humidity, in kind, protein, vitreousness, mass fraction of crude gluten, gluten quality, and number of drops (Table 4).

According to the results shown in Table 4, in all variants of the experiment scheme, grain moisture was within the normal range, that is, no more than 14.0%. In the second version of the experiment scheme, in which water treatment was carried out, the maximum indicator was 13.5%. The lowest indicator was recorded in the control sample, at 12.4%.

Table 4. Physico-chemical (qualitative) properties of Cornetto wheat.

Indicators	Norms	The Actual Indicator for the Experience Options			
		Control	Pre-Sowing Water Treatment	Pre-Sowing Treatment with Sapropel Extract Solution	Pre-Sowing and Foliar Treatment with Sapropel Extract Solution
Humidity (%)	No more than 14.0	12.4	13.5	12.7	12.8
In kind, g/L	Not less than 710	747	757	756	757
Protein (%)	Not less than 9.5	16	16	14.9	16
Vitreousness (%)	Not less than 40	48	43	45	48
Mass fraction of crude gluten (%)	Grade 1—28.0 Grade 2—25.0 Grade 3—23.0 Grade 4—18.0	27.7	25.3	27.4	27.5
Gluten quality, GDI units (gluten deformation index)	20–100—I-II group	78	75	77	77
The number of falls, seconds	Grade 1—200 Grade 2—200 Grade 3—160 Grade 4—80	305	297	300	324

The indicator characterizing the natural weight of grain also corresponded to the established standards, not falling below 710 g/L. The highest indicator was noted in the second and fourth versions of the experiment scheme and amounted to 757 g/L. The control had a minimum value of 747 g/L.

The protein content in the grain in all variants of the experiment was in the range of 14.9% and 16%, remaining within the normal range of 9.5% and above.

The vitreous content of the grain also corresponded to the norm, having values from 43% to 48%. The mass fraction of crude gluten in the experimental variants ranged from 25.3% to 27.7%. The quality of gluten in all variants of the experiment was at the level of 75–77 units, that is, it corresponds to the norm. The number of falls was also within the normal range and ranged from 297 to 324 s.

Thus, all indicators of the physico-chemical (qualitative) properties of wheat obtained during the field experiment are within the normal range. At the same time, the variant with foliar treatment with the sapropel extract solution at the tillering stage showed higher values for a number of indicators. The analysis of wheat yield indicators, according to the scheme of the experiment, allows us to draw conclusions about the effectiveness of pre-sowing and foliar treatment with a sapropel extract. These parameters allow us to talk about the sustainable development of organic farming in the region.

The values of these parameters are directly related to the technological requirements of grain processing [58–61], especially in terms of the quality of flour products, as well as a number of studies showing that they affect people even from a functional point of view [62,63].

Also, a number of studies indicate a direct correlation between wheat parameters and the quality of bakery products [64,65].

In addition, in order to study the possibility of environmentally sustainable yield management, the efficiency indicators for growing Cornetto wheat under various experiment were calculated and are presented in Table 5.

According to the results shown in Table 5, despite the increase in production costs, at a price of USD 264.9 per ton for Class 3 wheat grain, the most economically feasible option is pre-sowing and foliar treatment with the sapropel extract solution. This is confirmed by the above indicators of increased productivity, gross harvest, and profit.

It should be noted that the use of sapropel extract makes it possible to produce organic products that are in high demand in the world. Even with a decrease in yield to 1.6 t/ha, but with an average market price of USD 662.3 per ton of wheat grown using organic farming technology, the yield from a sown area of 100 hectares will amount to USD 105,968. With lower production costs (reduction in mineral fertilizers and chemical plant protection products) and higher prices for organic products, organic agriculture technology will become more economically efficient and environmentally safer than using traditional technologies. All this is the basis for environmental safety and sustainable development of organic farming in the studied region.

Table 5. Productive indicators of Cornetto wheat.

Indicators	Experience Options			
	Control	Pre-Sowing Water Treatment	Pre-Sowing Treatment with Sapropel Extract Solution	Pre-Sowing and Foliar Treatment with Sapropel Extract Solution
Acreage (ha)	100	100	100	100
Yield, t/ha	2.63	2.8	3.81	3.63
Yield increase, t/ha	0	0.17	1.18	1.0
Gross collection, tons	263.0	280.0	381.0	363.0
Production costs, thousand US dollars *	493.5	495.8	522.5	533.0
Revenue **, thousand US dollars	696.7	741.7	961.6	1009.3
Profit, thousand US dollars	203.2	245.9	439.1	476.3
Return on production, %	41.2	49.6	80.4	93.2
Return on sales, %	29.2	33.2	44.6	48.2

*—at the exchange rate of 1 May 2023, 453 tenge per USD 1. **—the price of Class 3 wheat on 31 October 2023 was USD 264.9/ton without VAT.

We believe that the use of sapropel extract in the production of wheat grown using organic farming technology, on the one hand, will strengthen the impetus for the development of a new business area for Northern Kazakhstan and, on the other hand, will form a positive image of the region at the global level, with products under the brand "Qazaqstan Organics" offered by us.

4. Discussion

Soil, as a factor of production, is subject to degradation under the influence of natural factors and anthropogenic impact, which affects its quality and negatively affects soil cover and yield. The current global trend in the development of agriculture is aimed at sustainable development and environmental safety [66,67].

In this regard, it becomes important not only to obtain maximum yield but also to make it safe. And, this is possible with the use of environmentally friendly fertilizers.

At the same time, the irrational use of traditional mineral fertilizers has led to soil degradation and environmental pollution. It is necessary to rationally use a complex of agro-reclamation measures with the use of organomineral fertilizers, which is confirmed by field studies conducted on wheat. When using them, an increase in yield is noted [68].

It is noted that natural organomineral fertilizers are able to increase the content of elements in agricultural plants, such as wheat, at the same time, increasing productivity [69,70].

The use of organomineral fertilizers in the cultivation of grain crops contributes to ensuring food and environmental safety; this trend is aimed at sustainable development [71].

The use of environmentally friendly fertilizers not only leads to an economic effect but also reduces the level of environmental pollution. This is confirmed by the results of field experiments conducted on grain crops. It is noted that organomineral fertilizers can be an alternative to traditional mineral fertilizers [72].

Field experiments have become widespread to study the reaction of wheat during foliar fertilization with extracts based on organic matter. It was found that fertilization carried out at different vegetation stages, including the tillering stage, has a significantly higher yield compared to the control [73,74].

In addition, it has been found that aqueous extracts of fertilizers can accelerate the ripening of wheat, with late crops. This is very important for territories with difficult agro-climatic conditions. The use of aqueous organic fertilizer solutions used at critical stages of agricultural crop growth potentially increases yields [75,76].

Studies prove that the yield and morphobiological parameters of grain depend, among other things, on the use of fertilizers [77–80].

Organic and organomineral fertilizers contain humic and fulvic acids, which are an alternative to mineral fertilizers and pesticides. Studies confirm the effectiveness of the use of organic and biological fertilizers on the growth, yield, and biochemical properties of wheat during foliar processing. The traditional way of applying fertilizers is to apply them directly to the soil [81–83].

But, saturation with substances necessary for plant growth and development is possible already at the stage of pre-sowing seed treatment. Pre-sowing treatment of seeds with organomineral fertilizers may provide the highest germination rate and better germination, which, in conditions lacking moisture and nutrients in the soil, plays a huge role for wheat seedlings. This will lead to the passage of the root system growth stage in more favorable conditions, and a well-formed root system will thereby strengthen the plant and provide it with everything necessary to pass through the phases of plant growth. This will affect the improvement in morphobiological parameters and, as a result, plant productivity [84].

The basis of the economic development of the North Kazakhstan region is a large proportion of arable land with chernozem soils, which makes it possible to grow crops such as wheat, barley, oats, rapeseed, etc.

It is necessary to take into account the fact that the arable lands of the North Kazakhstan region are subject to wind and water erosion, and the process of dehumidification, which is associated with their long-term use. At the same time, wheat needs sufficient amounts of nitrogen, phosphorus, and potassium for good grain growth and formation; therefore, it is necessary to carry out necessary agro-reclamation measures [85–87].

The conducted research proves the effectiveness of the use of sapropel fertilizers on the yield of vegetable and grain crops [88,89].

Our research was conducted in order to study the pre-sowing treatment of Cornetto wheat seeds with the obtained sapropel suspension for germination, yield, and biometrics. A feature of the agro-climatic conditions during the 2023 field season was the lack of the necessary amount of precipitation due to the dry summer, which may have significantly affected the results of the field research (Kazhydromet) [56].

Experimental studies of the pre-sowing treatment of Cornetto wheat seeds, carried out with a solution of an organomineral fertilizer based on lake sapropel, have shown the effectiveness of its application. There is an improvement in the qualitative and quantitative indicators of wheat yield of this variety. The data obtained as a result of statistical processing confirm the difference between the control and experimental groups. Thus, all indicators of the physico-chemical (qualitative) properties of wheat obtained during the field experiment are within the normal range. At the same time, the option with foliar treatment with sapropel extract solution at the tillering stage has higher values for a number of indicators. The analysis of wheat yield indicators, according to the scheme of the experiment, allows us to draw conclusions about the effectiveness of a pre-sowing treatment with a sapropel extract [57].

The effectiveness of the application of the obtained extract allows us to conclude that it can be used in pre-sowing seed treatment not only for various wheat varieties but also for other grain crops. In our opinion, promising opportunities are opening up for the use of sapropel extract at the stage of foliar seed treatment, which will also contribute to increasing crop yields. The resulting innovative sapropel fertilizer will make the agricultural production process optimal, which will affect the economic growth and productivity of the grain industry.

In turn, the use of innovative ecological fertilizers will increase crop yields, ensure environmental and food security, and lead to sustainable agriculture.

To analyze the possibilities and prospects of using sapropel fertilizers for the development of sustainable organic farming in the North Kazakhstan region, a SWOT analysis was performed (Table 6).

Table 6. SWOT analysis of the possibilities and prospects of using sapropel fertilizers for the development of sustainable organic farming in the North Kazakhstan region.

Strengths	Weaknesses
• Sustainable agricultural orientation of the region. • The presence of lakes with sapropel deposits. • The possibility of obtaining fertilizers of different concentrations. • Variation of fertilizers in the cultivation of different crops. • Improvement in morphobiological parameters and productivity when using fertilizers. The environmental friendliness of fertilizers. • Economic efficiency in production in the region by reducing transport costs. • Low cost with a positive effect.	• Conducting research to determine the concentrations of the fertilizer used. • Conservatism of farmers and their low awareness of sapropel extract.
Opportunities	**Threats**
• Implementation of aspects of sustainable development in the region. • Growing demand for environmentally friendly and organic products. • Attracting public and private investors. • Formation of technological bases for the production of fertilizers based on local lake resources. • Development of digital and cognitive technologies that contribute to the growth of competencies of subjects of the agro-food market.	• Lobbying for the interests of enterprises producing mineral fertilizers and other chemical plant protection products by authorized government agencies. • Permissible changes in legislation concerning the use of fertilizers. • Monitoring compliance with sanitary standards and the level of substances accumulating in bottom sediments. • The impact of sapropel extraction on the biodiversity of bottom communities.

The analysis of Table 6, in our opinion, showed the predominance of strengths, opportunities, and prospects for the use of sapropel fertilizers for the development of sustainable organic farming in the North Kazakhstan region. In addition, the conducted studies allow us to conclude that there is a need for a possible transition to the use of sapropel organomineral fertilizers at the stage of pre-sowing and foliar seed treatment. The agricultural sector of the studied region needs environmentally friendly fertilizers, which will contribute to increasing yields and the development of organic farming. This will contribute to the economic growth of the region and lead to the implementation of a global strategy aimed at sustainable development. The variable use of this innovative organic mineral fertilizer based on bottom sediments for agricultural efficiency can ensure food security and increase the sustainability of the agricultural sector not only in the studied region.

5. Conclusions

Sustainable agriculture is the foundation of the country's economy, and food and environmental security. The focus on organic farming and the production of ecological products, first of all, should cover agricultural crops that are the most important. These are crops that are included in the daily necessary diet of the population. Wheat occupies one of these spots among food crops.

Laboratory and field studies conducted using the obtained sapropel extract revealed its economic effectiveness at the stage of pre-sowing and foliar processing of wheat. The optimal concentration of the obtained innovative fertilizer was experimentally determined, which is confirmed by the indicators of germination energy and seed germination.

After processing wheat seeds of this variety with the resulting fertilizer, an improvement in qualitative and quantitative indicators was noted. It has been established that all the indicators studied during the phase of full ripeness of wheat are within normal limits. In addition, the use of the sapropel extract showed the best results not only when used at the stage of pre-sowing treatment but also during foliar treatment in the tillering phase.

The socio-economic efficiency of the application of the obtained extract allows us to conclude that it can be used in pre-sowing seed treatment not only for various varieties of wheat but also for other grain crops. In our opinion, promising applications of sapropel extract at the stage of foliar seed treatment will also have a synergistic effect due to an increase in crop yield and environmental friendliness.

Thus, the effective use of this innovative fertilizer, as well as the need to conduct further research on other varieties, crops, and applications can be concluded. In turn, the use of innovative ecological fertilizers will increase crop yields, ensure environmental and food security, and lead to sustainable agriculture.

In addition, the production of organic mineral fertilizers based on the natural resources of local lakes will help reduce the cost of purchasing standard fertilizers. The use of sapropel extract will reduce the environmental burden on the soil, while at the same time making grain production environmentally safe.

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