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# The Effect of Using Sapropel Extract on Biometric Indicators and Yield of Beet (*Beta vulgaris* L.) in the North Kazakhstan Region

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**Abstract:** Research has been conducted on the development of an innovative organomineral fertilizer based on local lake resources as a stimulator of germination and growth of crops, as one of the factors in achieving the goal of environmental sustainability. The results obtained are based on the environmental friendliness of the technology, increasing yields, and obtaining environmentally friendly products. This, in turn, will not only save mineral resources but also make it possible to use the resources from the bottom sediments of local lakes, and their rational extraction will contribute to the sustainable development and restoration of lake ecosystems. This article highlights the results of laboratory and field studies on the use of sapropel extract at the stage of pre-sowing seed treatment obtained by extraction of bottom sediments from lakes in Northern Kazakhstan. Solutions of aqueous alcohol extract of sapropel extract with concentrations of 0.4, 0.8, 1.2, 1.6, 2.0 g/L and table beet seeds (*Beta vulgaris L.*) of Bordo 237 variety were used as objects of research. Statistical analysis of laboratory experience data, based on the determination of germination energy and seed germination, allowed us to identify the optimal concentration of sapropel working solution for pre–sowing seed treatment—1.6 g/L. The index of germination energy and germination of seeds during pretreatment with sapropel extract of this concentration was 40% and 50%, respectively. This contributed to an increase in germination energy by almost 2 times and in seed germination by more than 40%. Pre-sowing treatment of seeds with sapropel extract at a concentration of 1.6 g/L in a field experiment contributed to the improvement of biometric indicators of beet fruits, such as diameter, length, and weight. The results of the data on fetal weight of the experimental variant compared with the control were 27% higher, and they were 26% and 32% higher compared with other experimental variants. In the experimental group, the highest yield index was also established, which is 2.15 times, or 53%, higher than the control, which emphasizes the effectiveness of pre-sowing seed treatment with the resulting sapropel suspension. A patent of the Republic of Kazakhstan was issued for the method we developed for obtaining a sapropel product for pre-sowing treatment of seeds: "A method for obtaining a sapropel product for pre-sowing treatment of vegetable seeds". The research presented in the article confirms its effectiveness. The use of this product in pre-sowing seed treatment reduces the number of agrotechnological operations and costs, which makes this method more efficient and economically beneficial for the agricultural industry. Thus, the principle of food security will be implemented, contributing to the preservation of sustainable development and having a positive impact on the health of the population.



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## 1. Introduction

At the present stage of development, the basis of human activity is the achievement of sustainable development goals. For agriculture, these goals are primarily related to ensuring food security, improving nutrition, promoting sustainable agricultural development, restoring terrestrial ecosystems, and promoting their rational use, as well as stopping and reversing the process of land degradation. The peculiarities of the direction of modern agriculture are the production of environmentally friendly products. As a result of long-term land use, soil degradation has occurred; therefore, the use of fertilizers is necessary for the production of agricultural products [1,2].

The mineral fertilizer produced by the chemical industry occupies the main place among the fertilizers used because it is associated with greater availability and proven technologies for its application. But taking care of the environment and the health of the population makes it necessary to use environmentally friendly types of fertilizers in various physical conditions and combinations, including at different stages of growing agricultural plants. In this regard, the natural resources of the lakes, represented in the form of sapropel deposits, are of interest for use in agriculture.

Sapropel is a substance rich in organic and mineral components, which makes it a valuable fertilizer for plants. Its chemical composition contains almost all the necessary elements for plant nutrition, such as nitrogen, phosphorus, potassium, trace elements, and organic substances. When applied to the soil, sapropel helps improve the soil structure, increase fertility, and enrich the soil with essential nutrients. Sapropel and fertilizers based on it, as environmentally friendly and high-quality organic mineral fertilizers, are used for all types of soils and all types of crops. The world experience of using sapropel as a fertilizer has a positive effect on plants [3,4].

Sapropel contains all the macronutrients and trace elements necessary for plants, as well as organic matter [5]. The use of sapropel in crop production leads to an increase in yield [6,7]. Also, studies prove that using bottom sediments has a positive effect on the nutrient content of plants [8].

The most favorable conditions for the accumulation of sapropels are the high degree of overgrowth of lakes. Above-water vegetation softens or prevents the wave activity of water, thereby preventing its intensive mixing. Thus, organic residues of aquatic plants and animals accumulate in lakes, which together with mineral residues form lake bottom sediments, many of which are represented by sapropels [9,10].

In the North Kazakhstan region, there are many lakes with similar conditions for the accumulation of bottom sediments represented by sapropel. However, in the Republic of Kazakhstan, sapropel is not included in the register of natural resources. In addition, its full-fledged use is limited by mining difficulties and a lack of public awareness. In the regions of Kazakhstan, lake ecosystems, with their unique diversity, are an integral part of the natural and recreational potential, and bottom sediments have various uses, including in balneology [11–13].

At the same time, the positive effect of removing the excess organomineral mass of lakes will be their purification and dredging [14–16]. This will improve the condition of the reservoir ecosystem and its aquatic inhabitants, such as fish, and make it possible to grow valuable species. The use of organic fertilizers, including sapropel, has environmental and economic benefits, which are confirmed by the research results obtained by a number of scientists [17]. Fertilizers have a significant effect on the qualitative composition of the soil, contributing to an increase in the concentration and activity of important chemicals, improving their accessibility to plants [18,19]. Numerous studies conducted on beet, with the introduction of combined fertilizers, have shown the effectiveness of their use, which has been characterized by an increase in yield [20,21].

Considering promising organomineral fertilizers, it is worth paying attention to the sapropels of lakes, which are ecologically clean and balanced natural resources. Sapropel contains a unique complex of nutrients and minerals, which is considered favorable for the growth and development of many plants.

One of the agricultural crops included in the diet of the population is beet (*Beta vulgaris* L.). Beet is a popular vegetable plant: root vegetables are well stored throughout the year, and fruits are included in the diet of the world's population and are an integral part of cooking various dishes [22–24].

Beet is a biennial plant, unique in its content of iodine, iron, cadmium, magnesium, molybdenum, and other metals [25,26]. It contains numerous minerals, antioxidants, vitamins A, C, B1, PP, B2, and betanin necessary for the human body [27–30]. Beet juice is used as a natural food coloring agent [31,32]. It also has an increased content of dietary fiber, which has a positive effect on the functional state of the digestive system, maintaining normal cholesterol levels and reducing the risk of cardiovascular diseases [33–37]. Beet varieties are numerous in terms of maturation, characterized by resistance to pests and diseases [38,39]. Humus loamy and sandy loam soils are preferred for its cultivation. When growing on humus-poor soils, which may be due to long-term crops and irrational crop rotation, a large amount of fertilizers is required. Studies show that the addition of sapropel suspension to the soil on which beet is grown significantly increases the yield of vegetables. As it turns out, the organic substances and trace elements contained in sapropel contribute to more efficient absorption of nutrients by beet roots. This leads to an increase in the content of vitamins and minerals in the plant, making it more useful for humans [40]. In addition, sapropel helps improve the structure of the soil and its fertility, creating optimal conditions for the development of the beet root system. This factor turns out to be extremely important when growing beet in regions where soil quality is a problem. Therefore, a number of researchers focus on adding various fertilizers to the soil [41,42].

Currently, one of the innovative directions aimed at improving the quality and productivity of agricultural crops is being actively developed. These are studies on the use of liquid fertilizers at the stage of pre-sowing seed treatment [43–46].

We propose using the extract obtained from sapropel from local lakes for the pre-sowing treatment of beet seeds (*Beta vulgaris* L.) of the Bordo 237 variety. This is one of the beet varieties that is widely used for cultivation by both professional farmers and gardeners. Important qualities of this beet variety are resistance to many diseases, good storage performance, and taste [47,48]. This variety is widely cultivated in the North Kazakhstan region.

Thus, the aim of this work is to study the effect of the use of sapropel extract on biometric indicators and yield of table beet (*Beta vulgaris* L.) under the environmental conditions of the North Kazakhstan region. It is assumed that the use of sapropel suspension is a promising method for optimizing the yield and quality characteristics of beets. Our research is aimed at analyzing the effects of the sapropel product on the morphobiological parameters of beet and yield, as well as determining the optimal concentrations to maximize the effectiveness of this approach. To identify the most effective concentration of sapropel extract, experiments were conducted in a variety testing laboratory. Studies have been conducted on the effect of the obtained extract on the germination energy and germination of beet seeds of the Bordo 237 variety. Based on statistical analysis, the optimal concentration of sapropel suspension for use at the stage of pre-sowing treatment of beet seeds was revealed. Field studies conducted in 2023 confirm the effectiveness of the sapropel suspension on biometric indicators and beet yields.

## 2. Materials and Methods

### *2.1. Obtaining a Sapropel Product*

To obtain a sapropel product, we took sapropel from Lake Penkovskoye [49]. A sufficient volume of sapropel deposits at depths of 1.5–2 m was selected by the Petersen dredger. The analysis to study the chemical composition was carried out in certified laboratories. This choice was justified by the complex chemical composition of the sediments, including the richness of organic substances, the presence of necessary macro- and microelements, as well as optimal physicochemical parameters. The content of organic matter was 38.1%, and the content of humus was 36.94%. There was a sufficient amount of phosphorus (15.48 mg/kg), potassium (928.34 mg/kg), magnesium (210.4 mg/kg), zinc (0.36 mg/kg), etc.

To obtain a solution of the sapropel product, a method was used for extracting organic and inorganic compounds from bottom sediments in water and aqueous alcohol solutions, removing solid particles, and concentrating and combining aqueous and aqueous alcohol extracts. The solvents were distilled water and ethyl alcohol (96%). Sieves of various diameters and a centrifuge were used to obtain a homogeneous mass from sapropel. After that, the sample was treated with distilled water and a solution of ethyl alcohol. Next, the solution was brought to a boiling point by lowering the pressure with a vacuum pump and evaporated in a rotary evaporator at a temperature of no more than 390 °C in order to preserve organic compounds.

The resulting extract was named “SAPROLIN” [50]. From the final solution obtained with a concentration of 2.98 g/L, a series of solutions were prepared with the addition of distilled water with different concentrations (0.4, 0.8, 1.2, 1.6, 2.0 g/L). A patent has been obtained for the method of obtaining sapropel extract for pre-sowing seed treatment developed by us [1].

### *2.2. Laboratory Study*

Laboratory studies to identify the optimal concentration of sapropel extract, which affects the energy and germination rate of beet seeds (*Beta vulgaris* L.) of the Bordo 237 variety during pre-sowing treatment, were carried out in accordance with GOST 12038-84 “Seeds of agricultural crops” [51]. The germination of beet seeds was determined by germination of seeds under laboratory conditions. At the beginning of the experiment, samples of 100 seeds each were taken from the seeds of the experimental culture for each variant of the experiment. After that, the seeds were laid out on two or three layers of filter paper moistened with various concentrations of sapropel extract (0.4, 0.8, 1.2, 1.6, 2.0 g/L) in Petri dishes. In the control version, the filter paper was moistened with water. Then Petri dishes with seeds were placed in a thermostat for germination at a constant temperature of $20 \pm 2$ °C.

The thermostat was used to germinate seeds at optimal temperatures while maintaining the necessary humidity. This was necessary to create conditions in automatic mode to determine the germination and germination energy of seeds.

Germination energy—the percentage of normally germinated seeds—was determined on the 4th day. Seed germination was determined by counting the number of normally germinated seeds on the 10th day.

### *2.3. Field Studies*

The field experiment was initiated in order to study the effect of pre-sowing seed treatment with the obtained sapropel extract on field germination, yield, and biometric indicators of table beet of the Bordo 237 variety. The study was conducted on the territory of the agrobiological station of the M. Kozybaev NKU in the field season of 2023, in accordance with the generally accepted methodology “Methodology of field experience” [52]. The agrobiological station is located on the western border of the city of Petropavlovsk (Republic of Kazakhstan, North Kazakhstan region, in the zone of temperate latitudes of Eurasia, 54.844536° N, 69.082864° E). The climate of the research site is sharply continental, which is expressed by a high amplitude of summer and winter temperatures and insufficient humidity [53,54]. The soil on which the experiment was conducted was characterized by the following agrochemical parameters: organic matter—4.25%; pH—6.7; hydrolyzable nitrogen—1.96 mg per 100 g of soil; mobile phosphorus—35.49 mg/kg, mobile potassium—287.05 mg/kg.

The work was carried out in fourfold repetition. The crops were sown on plots of 4 $m^2$ in size. The placement of plots was carried out by the method of randomized repetitions in order to eliminate possible distortions in the results of the experiment. Due to the fact that the Bordo 237 beet variety is characterized by fairly good germination and yield, we purposefully used seeds produced in 2019 with lower-quality indicators.

The prepared crop seeds were soaked in sapropel extract for 6 h before sowing to evenly distribute the substance, then sown into the soil. The seeding rate was 120 seeds per plot. The width of the aisles was 30 cm and the sowing depth was 6–8 cm. The volume of the working fluid for the pre-sowing treatment of beet seeds was 5 mL. The concentration of the solution was 1.6 g/L (Figure 1).

**Figure 1.** Field experiment at the stage of vegetation.

The scheme of the experiment was as follows:

Group 1. Control without fertilizers, background + dry seeds.

Group 2. Background + pre-sowing treatment with water (soaking for 6 h) at a dose of 5 mL/120 seeds.

Group 3. Background + pre-sowing seed treatment (soaking for 6 h) with a sapropel product (SAPROLIN) in a dose of 5 mL/120 seeds.

Group 4. Background + dry seeds + foliar treatment at Stage 3 of the leaf.

After harvesting, the root crops were counted in each variant of the experiment. Each root crop was weighed and, the length (without root) and diameter were determined. The average crop yield in each variant of the experiment was calculated.

*2.4. Statistical Analysis*

The following methods were used to process the results of the study: quantile–quantile graph, analysis of variance (ANOVA), and a posteriori Tukey–Kramer test.

The QQ graph (quantile–quantile ) is an analysis tool used to assess the correspondence of a dataset to a theoretical distribution. In the study, we used this method to check whether the beet mass indicators in the experimental groups correspond to the normal distribution [55,56].

The analysis of variance (ANOVA) was used to identify a statistically significant dependence in the samples. ANOVA is one of the most common methods of statistical analysis [57–61]. The procedure of variance analysis consists of determining the ratio of systematic (intergroup) variance to random (intragroup) variance in the measured data. In this study, according to the experimental scheme, four groups were identified [62].

Based on the experimental scheme, there was a control group in the study, so we used the Tukey–Kramer criterion as a posteriori criterion. A posteriori test was performed after an analysis of variance to determine which mean values of the groups participating in the experiment differed statistically significantly from each other [63–65].

The applied methods of statistical analysis were selected by us based on the specifics and conditions of the conducted research.

## 3. Results

### 3.1. Laboratory Tests to Identify the Optimal Concentration of Sapropel Product

At the first stage, laboratory tests were carried out on the variable use of organomineral fertilizer, beet seeds for germination, and germination energy. Five concentrations of sapropel extract were used (0.4, 0.8, 1.2, 1.6, 2.0 g/L). The results of the laboratory experiment are presented in Table 1.

**Table 1.** The results of a laboratory experiment to identify the energy of germination and germination of beet seeds.

| Sapropel Extract Concentration, g/L | Germination Energy, % | Seed Germination, % |
|---|---|---|
| 0 | 21 | 33 |
| 0.4 | 26 | 40 |
| 0.8 | 22 | 38 |
| 1.2 | 29 | 37 |
| 1.6 | 40 | 50 |
| 2.0 | 33 | 46 |

Based on the data shown in Table 1, it can be seen that the maximum indicators of germination and seed germination energy are noted when using a concentration of 1.6 g/L. For this concentration, the maximum values of germination energy and seed germination are 40% and 50%, respectively.

To confirm the results of laboratory experience, a polynomial regression model was constructed in the range of the series of concentrations used [66]. The polynomial trend made it possible to visually illustrate the relationship between the concentrations used and the indicators of germination energy and seed germination (Figure 2).

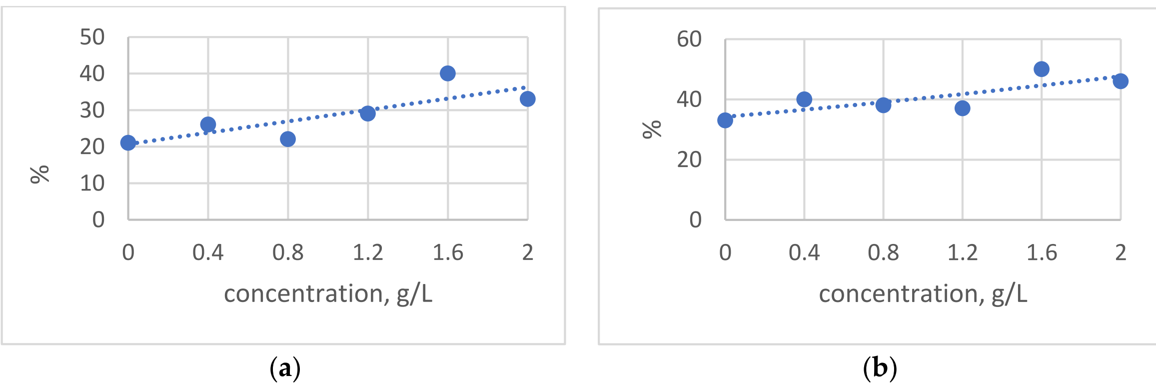


**Figure 2.** The polynomial trend of determining the optimal concentration of the effect of sapropel extract "SAPROLIN" on (**a**) the germination energy of beet seeds of the Bordo 237 variety; (**b**) the germination of beet seeds of the Bordo 237 variety.

Thus, based on a laboratory study, the optimal concentration of 1.6 g/L was revealed, which showed the greatest effect, which was subsequently applied in field tests.

*3.2. The Results of the Field Experiment*

At the end of the field experiment and harvest, the biometric indicators of beet were studied—the mass index, diameter, and length of the root crop (without root). The average values of these indicators were calculated and it was found that the maximum values belong to the third group from the experiment scheme, which included soaking seeds with sapropel extract. The average root crop weight in this group was 273.8 ± 265.3 g (n = 174), the average diameter was 7.3 ± 3.0 cm, and the average length of the root crops was 7.2 ± 2.5 cm. The minimum values of root crop were noted in the first group of the experiment scheme, which included the results of the control, represented by planting dry seeds. In this group, the average weight was 214.9 ± 415.5 g (n = 103), the diameter was 5.4 ± 2.0 cm, and the root crop length was 5.9 ± 1.7 cm. Intermediate data were obtained in the second and fourth groups of the experiment scheme. In these two groups, the values were as follows: in the second group, the average weight was 217.7 ± 147.0 g (n), the average diameter was 6.6 ± 2.1 cm, and the average length of the root crop was 6.7 ± 1.8 cm. In the fourth group, the values were as follows: root crop weight of 206.7 ± 196.3 g (n = 140), diameter of 6.4 ± 2.4 cm, and root crop length of 6.8 ± 2.2 cm.

At the next stage of the study, based on the results of processing data characterizing crop yield in various experimental variants, a table reflecting the reproductive indicators of beet was prepared (Table 2).

**Table 2.** Reproductive indicators of beet.

| Indicator | Total by Group 1 * | Total by Group 2 | Total by Group 3 | Total by Group 4 |
|---|---|---|---|---|
| Number of seeds, pcs. | 480 | 480 | 480 | 480 |
| Seed germination, % | 21.5 | 29.8 | 36.3 | 29.2 |
| Number of beet pcs. (n) | 103 | 143 | 174 | 140 |
| Average weight of 1 beet from the number of germinated seeds, gr. | 214.9 | 217.7 | 273.8 | 206.7 |
| Average weight of 1 beet from the number of planted (120 seeds in one repeat, i.e., 480 seeds of each variation), gr. | 46.1 | 64.9 | 99.3 | 60.3 |
| Total weight, grams | 22,134.2 | 31,128.6 | 47,640.5 | 28,936.8 |
| Beet crop yield, kg/m$^2$ | 1.4 | 1.9 | 3.0 | 1.8 |
| **Ratio to yield control** | **1** | **1.41** | **2.15** | **1.31** |
| **Ratio to control by the average weight of 1 beet from the number of germinated seeds** | **1** | **1.01** | **1.27** | **0.96** |

* The group variants used in the experimental scheme are given in Section 2.3.

The analysis of Table 2 revealed that the maximum values for all studied indicators—the total weight, number of beets, and average weight of root crops from sprouted and planted seeds—are noted in Group 3. The best indicators of germination and yield are also noted in the group whose seeds were treated with sapropel extract before sowing. At the same time, the minimum values of these indicators are in Group 1 of the field experiment, represented by the use of dry seeds. The indicators in Groups 2 and 4, according to the results of the experiment, are characterized by average values. Group 2, characterized by pre-soaking of seeds with water, has a slight separation compared with the group, which is represented by seeds without pretreatment before planting but with foliar treatment at Stage 3 of the leaf.

According to various sources, the average yield of beet of the Bordo 237 variety ranges from 2 to 7 kg/m$^2$ [67–69]. However, as a result of the initial poor seed quality and unfavorable weather conditions (due to the dry summer of 2023 in North Kazakhstan region, as well as the lack of irrigation in the experiment), the average yield in the control plots was 1.4 kg/m$^2$. Pre-sowing treatment of seeds with sapropel extract solution showed the highest yield of 3.0 kg/m$^2$, which, in turn, is 2.15 times, or 53%, higher than the control. Also, in the group using the extract, the highest indicator of 1.27 ratio to control by the average weight of the root crops from the number of germinated seeds was noted in comparison with other groups of the experiment.

The data obtained confirm the effectiveness of using sapropel extract in pre-sowing seed treatment, which affected the biometric parameters of table beet.

The main indicator characterizing the yield is the mass of root crops. To verify the obtained data on the mass of beet according to the normal distribution for each plot of each group, according to the experimental scheme, a "quantile–quantile" (QQ) graph was used (Figure 3).

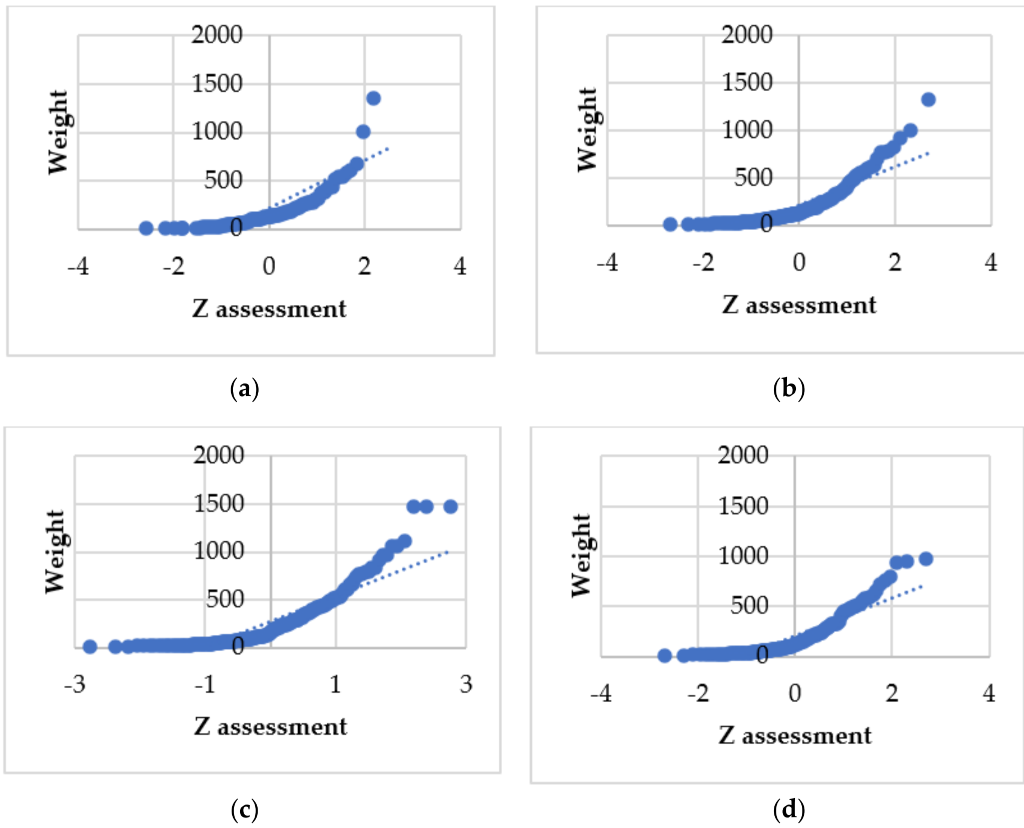


**Figure 3.** Checking the distribution for "quantile–quantile" normality: (**a**) control; (**b**) pre-sowing seed treatment with water; (**c**) pre-sowing seed treatment with sapropel extract solution; (**d**) foliar top dressing of seeds with sapropel extract in the phase of the 3rd leaf.

On the constructed graphs, we see that the points deviate slightly from the straight diagonal line, in particular, the exponent is clearly traced. This is a clear indication that the dataset is normally distributed. Although the QQ graph is not a formal statistical test, it allows us to visually check whether the dataset is normally distributed. This confirms the objectivity of the results obtained when weighing beet. This allows the yield results to be subjected to further statistical analysis.

To identify a statistically significant relationship between the average values of the total weight of root crops and the group characterizing the experimental conditions, a single-factor analysis of variance ANOVA was used (Table 3).

**Table 3.** The results of a single-factor analysis of ANOVA.

| Groups * | Count of Seeds, pcs | Sum of Root Crop Weight, g | Average Weight of the Root Crop, g | Dispersion |
|---|---|---|---|---|
| 1 | 480 | 22,134.22 | 46.11 | 40,146.48 |
| 2 | 480 | 31,128.64 | 64.85 | 25,533.57 |
| 3 | 480 | 47,640.49 | 99.25 | 49,891.84 |
| 4 | 480 | 28,936.79 | 60.28 | 22,028.00 |

* According to the scheme of the experiment given in Section 2.3.

According to the results of the analysis, it was found that the value of F is 7.09, and the critical value of F is 2.6. Since the value of F is greater than F-critical, we rejected the null hypothesis that the sum of the root crops does not depend on the experimental conditions of the four groups. This means that there is a dependence and a significant difference between the four variations. Also, the obtained *p*-value (0.000097) is less than the significance level, which allows us to reject the null hypothesis and conclude that one of the average values of the groups differs from the others.

The presented experimental groups have a significant impact on the variable of interest to us (the sum weight of the root crops). However, this does not show the reliability of the differences between the groups. To find out which groups differ from each other, the a posteriori Tukey–Kramer test was conducted. A comparative analysis of the absolute average values of the parameter between each group participating in the experiment revealed that in all groups, the difference in the absolute average was greater than the critical value of Q (Table 4).

**Table 4.** A posteriori Tukey–Kramer test.

| Comparison * | Abs. Mean Diff | Q Critical Value | Significant |
|---|---|---|---|
| 1 vs. 2 | 14,612.907 | 33.01589 | yes |
| 1 vs. 3 | 9745.359 | 33.01589 | yes |
| 1 vs. 4 | 18,118.477 | 33.01589 | yes |
| 2 vs. 3 | 24,358.266 | 33.01589 | yes |
| 2 vs. 4 | 3505.570 | 33.01589 | yes |
| 3 vs. 4 | 27,863.836 | 33.01589 | yes |

* The compared variants of the groups used in the experimental scheme are given in Section 2.3.

This allowed us to conclude that the average values between all groups are statistically significant and that sapropel extract affects beet yield indicators.

## 4. Discussion

The necessary features of the use of organomineral fertilizers, including sapropel fertilizers, are their environmental friendliness and economic benefits [70–75]. Fertilizers provide plants with all the necessary chemical elements and substances and, also, make them more accessible [76–81].

The North Kazakhstan region is an agricultural region, the economy of which is aimed at growing grain and vegetable crops. The vegetable crop considered in the article, beet of the Bordo 237 variety, is widely distributed and is part of a large number of dishes for the population of many countries [82,83]. In Kazakhstan, beet is a crop that is harvested and used in winter as a component of dishes and a source of vitamins and minerals [84–86]. The peculiarities of this crop are its resistance to the climatic features of the region and diseases. But in order to obtain a full-fledged harvest, additional organomineral fertilizers must be applied [87–90]. Due to the above factors, under the environmental conditions of the North Kazakhstan region, various ways to increase the yield are being investigated. One of them is the use of sapropel from local lakes [49]. At the same time, taking into account the necessary positive ecological and economic requirements for the use of fertilizers, we have developed an innovative liquid fertilizer by extracting sapropel from a local lake [50]. This fertilizer, or sapropel product, was used at the stage of pre-sowing seed treatment, unlike other already known methods of using sapropel-based fertilizers [91,92].

During the laboratory study, the optimal concentration of the sapropel product was obtained at 1.6 g/L, which showed the greatest effectiveness in the pre-sowing treatment of beet seeds. The effectiveness of the sapropel product was confirmed by the indicators of the germination energy and germination of beet seeds of 40% and 50%, respectively, discussed in Section 3.1 of the article.

The conducted field experiment confirmed the effectiveness of using the obtained suspension of sapropel extract during pre-sowing seed treatment. After harvesting, the biometric indicators of fruits and beet yields were studied in groups with different experimental conditions specified in Section 2.3.

According to the results of the measurements, it was revealed that the average weight of the root crop in the variation of pre-sowing seed treatment with sapropel extract solution was 27% higher than the average weight of the root crop from the germinated control seeds. It was also 26 and 32% higher than the average weight of the beet from the sum of the planted seeds in other variations This, in turn, proves the effectiveness of sapropel extract not only on germination and summary yield but also on the average weight of beets.

Based on the data obtained from the results of field research, a combined schedule of field germination and beet yield has been prepared (Figure 4).

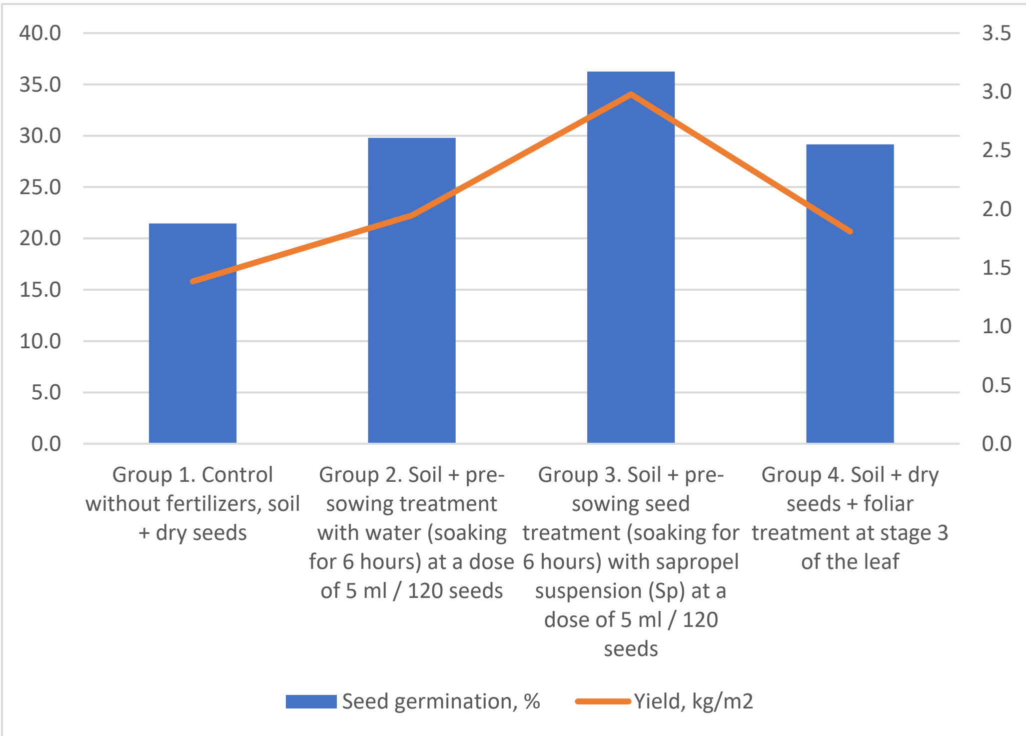


**Figure 4.** Combined schedule of yield and germination of beet varieties of Bordo 237.

According to the results of the graph analysis, it was revealed that seeds that were not soaked exhibited the minimum values of germination and yield parameters, which were 21.5% ± 7.2 and 1.4 ± 1.4 kg/m$^2$, respectively. The maximum values were recorded for seeds soaked in the suspension where field germination was 36.3% ± 10.6, and the yield reached 3.0 ± 1.3 kg/m$^2$. The average values for the second and fourth groups were almost the same. Field germination rates were 29.8% ± 11.9 and 29.2% ± 10.6, and yield rates were 1.9 ± 1.3 and 1.8 ± 0.8 kg/m$^2$, respectively.

The yield index in the group using sapropel extract as a pre-sowing seed treatment, despite the poor seed quality and climatic features of the field season, exceeded the control values by 2.15 times.

Thus, it was found that optimal values of both field germination and yield are achieved by soaking seeds in sapropel extract [93].

This result testifies to the high efficiency using an innovative organomineral fertilizer obtained on the basis of bottom sediments of lakes in the North Kazakhstan region, even with low seed quality and unfavorable climatic conditions of the field season [94]. This, in turn, may reduce the use of mineral fertilizers and make the technology of plant production more environmentally friendly [95–97].

## 5. Conclusions

Laboratory and field studies conducted to evaluate the effectiveness of the organomineral fertilizer based on sapropel in the pre-sowing treatment of beet seeds of the Bordo 237 variety revealed the positive effects of this sapropel product. The indicators of germination energy and germination of seeds allowed us to identify the optimal concentration of sapropel extract for use. After the pre-sowing treatment of seeds with a solution of sapropel extract, there was an improvement in both qualitative and quantitative characteristics of the harvest of beet of this variety.

The results of statistical processing of the field experiment data confirmed a significant difference between the experimental and control groups. Thus, experimental observations confirm the conclusion that this fertilizer is highly effective not only for the Bordo 237 variety beet but, possibly, for other crops also. The study of the use of sapropel suspension is planned to continue on other crops, including cereals, to identify a greater range of fertilizer effectiveness.

The effectiveness of the application of the innovative fertilizer obtained in the pre-sowing treatment of seeds, within the framework of the study, opens up the possibility of its use in agricultural production. The economic efficiency can be pre-calculated by using the amount of fertilizer per 1 $m^2$. If we consider that from 1 kg of sapropel, 500 mL of SAPROLINE is obtained with a concentration of 2.98 g/L, which is diluted with distilled water to a concentration of 1.6 g/L to a volume of 931 mL. Therefore, the consumption of fertilizer (sapropel) is 1.34 g/$m^2$. At the same time, according to the literary sources, traditional mineral fertilizers are introduced per the following standards: 15–20 g/$m^2$ of ammonium nitrate or 20–30 g/$m^2$ of ammonium sulfate, 30–40 g/$m^2$ of superphosphate and 10–15 g/$m^2$ of potassium chloride. The rate of application of organic fertilizers is as follows: manure—4–5 kg/$m^2$, humus—2–3 kg/$m^2$, or compost—3–4 kg/$m^2$ [98]. The resulting extract makes it possible to optimize the process of cultivating crops (minimizing the cost of increasing profitability, increasing yields, and improving the quality of the products). This can further contribute to the promotion of sustainable agricultural practices, as well as environmental and food security, which will lead to economic growth, with minimal environmental impact, and can improve the health indicators of the region's population.

The research results will make it possible to implement the principle of organic farming, which will contribute to the restoration and preservation of soil fertility and will solve the problem of regeneration of degraded agricultural lands. In addition, the extraction of bottom sediments from the lakes of the region, in order to obtain organomineral fertilizers, contributes to lake purification from excessive bottom sediments. This makes them suitable for fisheries and leads to the improvement of the ecological systems and the situation in the region. All these principles are aimed at the realization of environmental safety and sustainability.

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