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Posted Date: 1 April 2024

doi: 10.20944/preprints202404.0022.v1

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Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 1 April 2024 doi:10.20944/preprints202404.0022.v1

Article

Influence of Organic Humic Fertilizer «Tumat» on the Productivity of Sugar Beet

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Abstract: The production of sugar beet in the Republic of Kazakhstan is insufficient to meet the domestic sugar needs of the population. This shortfall is attributed to the natural and climatic conditions, the high cost of production, and the low use of mineral fertilizers. The objective of the study is to investigate the impact of the organic humic fertilizer "Tumat" on the growth, development, yield, and sugar content of sugar beet in the conditions of irrigated light chestnut soils in Southeast Kazakhstan. The research employed widely accepted methods of field experiments and laboratory studies from the Commonwealth of Independent States. Scientific research confirms the effectiveness of using the organic humic fertilizer "Tumat" for cultivating sugar beets. This fertilizer is highly bioavailable and contains a balanced mix of essential macronutrients and micronutrients, polyunsaturated fatty acids, and other biologically active substances. Foliar feeding of sugar beets enriches the soil with exchangeable potassium, mobile phosphorus, and easily hydrolyzable nitrogen during the plant's vegetative period. Using "Tumat" fertilizer improves seed germination, stimulates growth and development, accelerates the ripening of sugar beets, and enhances tuber yield and sugar content. "Tumat," an organic humic fertilizer, is recommended as an environmentally safe and effective agricultural product that boosts the productivity and quality of sugar beets, as well as soil fertility.

Keywords: light chestnut soils; organic humic fertilizer; sugar beets; yield; sugar content

1. Introduction

The total global sugar production exceeds 131 million tons, with 98 million tons from sugarcane (74.8%) and 33 million tons from sugar beet (25.2%). The leading producers of sugarcane are Brazil (27.7 million tons), India (19.9 million tons), China (9.7 million tons), and the USA (2.2 million tons). For sugar beet, the top producers include the USA (4.6 million tons), Germany (4.3 million tons), France (4.2 million tons), Russia (2.3 million tons), Poland (2.0 million tons), Turkey, and Ukraine (1.9 million tons). The average yield of tubers worldwide is 34.3 tons/ha, while in highly developed agricultural countries like France, the USA, Germany, and Italy, yields range from 50 to 60 tons/ha. The average yield of sugar beets in Russia is 17.8 tons/ha, reaching up to 30 tons/ha in the Krasnodar Krai, Kursk, and Belgorod regions, and some farms achieve yields of 40-50 tons/ha [1]. Sugar beet is one of the primary industrial crops that yields carbohydrate-rich tubers. The tubers of sugar beet contain 16-20% sucrose. With a high yield of beet roots (40-50 tons/ha), the sugar harvest can reach 7-8 tons/ha or more.

A crucial component of the food security of any country is ensuring the population's access to sugar through domestic production [2].

In 2004, Kazakhstan had 22.3 thousand hectares dedicated to sugar beet farming. By 2022, this area had decreased by more than half due to the unstable nature of sugar beet cultivation areas, which can be attributed to climatic conditions and the high cost of production. Despite this reduction in

 doi:10.20944/preprints202404.0022.v1

farming area, sugar beet yield in Kazakhstan significantly increased, from 19.74 to 34.14 tons per hectare between 2004 and 2022, marking a 2.5-fold increase. The highest sugar beet yield was recorded in the Zhetysu region, reaching 40.97 tons per hectare, followed by the Almaty region with 27.89 tons per hectare, and the Zhambyl region with 27.63 tons per hectare. However, the current production levels of sugar beet are not sufficient to meet the domestic sugar needs of the country. Presently, 52% of sugar in Kazakhstan is produced from imported raw sugar, 42% of white sugar is directly imported, and only 5% is produced from local sugar beet [2,3].

Addressing the challenges of efficient development in the sugar industry can be achieved by improving the quality of sugar beet seeds and root crops, diversifying production to expand the range of products, and increasing the resource potential [4]. This includes achieving financial stability for agricultural producers and sugar factories, enhancing the profitability of sugar beet production, expanding the cultivation areas for sugar beets, increasing sugar beet yields through the adoption of modern cultivation technologies, and boosting the gross harvests of factory sugar beets [5].

Sugar beet is considered one of the most demanding crops in terms of soil fertility and is highly responsive to mineral nutrition. Optimal results in sugar beet cultivation can only be achieved with high agricultural standards in all fields of crop rotation [6]. One widely used element in modern sugar beet cultivation worldwide is the application of foliar fertilization with complex fertilizers containing macro- and micronutrients in a biologically active form. Foliar fertilization enhances crop productivity, improves water management, enhances the physicochemical properties of the soil, and activates microbial activity, contributing to overall soil fertility improvement.

To realize the potential of sugar beets in the zonal adaptive-landscape farming system, the introduction of new innovative chemical agents, including humic fertilizers with a broad spectrum of action, is necessary [7–9]. These fertilizers contain humic acids, fulvic acids, salts of these acids (humates and fulvates), as well as humins-stable compounds of humic and fulvic acids with soil minerals. The application of humic preparations contributes to quality improvement, ensures the ecological cleanliness of products, enhances the efficiency of mineral and organic fertilizers, leading to reduced production costs [10].

The salts of humic and fulvic acids enhance the absorption of oxygen in plant cells, stimulate the formation of the root system, increase the permeability of the cell membrane, activate enzymes, improve plant respiration, and enhance the uptake of nitrogen, phosphorus, potassium, iron, and plant resistance to a wide range of adverse factors (pesticides, frost, drought, increased soil salinity) [11,12].

Humic preparations contribute to the increase in soil biological activity, which is influenced by the hydrothermal regime of the soil, pH value, organic matter and nutrient availability, microbial population, and enzyme pool [12]. Soil biological activity can be assessed by the intensity of carbon dioxide (CO_2) emission, enzyme activity, microbial population, their various groups, and other indicators [11].

The application of humic fertilizers to the soil leads to increased microbiological activity both during the year of application and in subsequent periods. There is an overall increase in the microbial population and specific groups. Humic fertilizers have the most significant impact on nitrogen-fixing, ammonifying, and nitrifying bacteria, cellulose-degrading and oil-acid bacteria, as well as soil microfungi [13].

Research has shown that humic preparations influence the microbial population in the soil not only when directly applied to the soil but also when used in the treatment of growing plants. In a field experiment on chernozem soil, treating maize seeds with lignohumate before sowing and treating the growing plants stimulated the growth and development of microscopic fungi by 54.8% and bacteria by 39.0%, and for soybeans, the growth was 146.0% for microscopic fungi and 25.4% for bacteria [14].

The combined impact of the humic preparation «Bio-Don» on the soil and wheat plants during the tillering and shooting stages provides maximum stimulation of the soil microflora, fungi, and cellulose-degrading actinomycetes by 150% [15]. The stress-protective role of humic preparations for the microbial community in the rhizosphere has also been observed. When wheat is exposed to humic preparations, the activity of invertase increases during the shooting phase. Humic preparations enhance the mobilization of phosphorus and increase grain yield, attributed to the enhancement of soil biological activity.

In crop production, humic fertilizers are employed as growth stimulators, leading to increased grain yields by 20-30%, vegetables and potatoes by 25-50%, and fruit-berry crops by 30-40%. The application of humic fertilizers also reduces the growth, development, and ripening periods of crops by 3-12 days, enhances resistance to diseases, weeds, pests, frost, drought, and other adverse factors. Studies have shown that the use of «Biogumat» fertilizer increases wheat seed germination energy and viability by an average of 2.5%. It also boosts plant vegetative mass by 21%, plant height by 23%, and chlorophyll content in wheat seedling tissues by 14%. The anti-stress effect of humic fertilizers has been identified, indicating an increase in the proliferative activity of cells in the primary cortex of wheat embryo roots and stems [16].

Collaborative efforts between scientists from Kazakhstan and Uzbekistan have led to field trials of the organic humic fertilizer «Tumat» in of the Republic of Uzbekistan, covering an area of 80,681 hectares. The results of these scientific studies have been published in both international and national publications, as well as in materials from international conferences. The impact of the organic humic fertilizer «Tumat» on the productivity of cereals, legumes, vegetables, industrial crops, and fruit-berry crops has been thoroughly investigated [17–22].

In the Republic of Kazakhstan, production trials of the organic humic fertilizer «Tumat» have been conducted for the cultivation of cereals, legumes, and other crops. Studies on the microflora of light chestnut soil during the cultivation of soybeans and safflower have shown the positive influence of the organic fertilizer «Tumat» on the content of ammonifiers and actinomycetes, which are activators of soil processes. It was found that actinomycetes of the genus Streptomyces (20 to 30%) predominate, and their presence can serve as an indicator of the influx of slowly decomposable organic matter into the soil [23].

The research indicates that the organic fertilizer «Tumat» has a positive impact on the properties of ordinary chestnut soil, as well as on the growth, development, and productivity of soybeans. There is a tendency to increase the content of total humus and nitrate nitrogen ($N\text{-}NO_3$), the mobility of phosphorus (P_2O_5), and exchangeable potassium (K_2O). Foliar feeding of soybean plants with the «Tumat» fertilizer increases the number of large nodules on the main root (17.1 pieces/plant) and the mass of nodules (1.20 g/plant) compared to the control. The organic humic fertilizer, by influencing the diversity of soil microorganisms, contributes to the increase in symbiotic nitrogen fixation (11.9 ± 1.7) × 106 CFU/g of soil (CFU - colony-forming units). Double foliar feeding ensures the production of 35.2 quintals/hectare of soybeans, an increase of 11.0 quintals/hectare compared to the control (45.4%), and also increases the protein content (34.81%) and fat content (30.14%) [24]. The effectiveness of foliar feeding with the organic fertilizer «Tumat» is also confirmed in the cultivation of soybeans and winter wheat in the conditions of light chestnut soils of the Semirechye region [25,26].

The application of the organic humic fertilizer «Tumat» in rice-swamp soil increases the content of total humus and nitrogen, the mobility of phosphorus and potassium; influences the length of the panicle and grain filling, providing an increase in rice grain yield by 1.3 tons/hectare (36.1%) compared to the control, which yielded 3.6 tons/hectare [27,28].

The combined application of mineral fertilizers ($N_{100}P_{100}K_{100}$) and the organic humic fertilizer «Tumat» ensures the highest potato yield at 39.3 tons/hectare, with an increase of 71.2%. In the variant using the organic humic fertilizer «Tumat» without mineral fertilizers, the potato yield is 26 tons/hectare, showing a yield increase of 13.4% compared to the control [29].

This article presents the findings of scientific research conducted between 2021 and 2023 under the scientific and technical program "Scientific and Technological Support for the Conservation and Reproduction of the Fertility of Agricultural Lands," with the program code O.0946, №0112PK01718. The research focused on the impact of the organic humic fertilizer "Tumat" on the fertility of irrigated light chestnut soils and the productivity of sugar beet in the Semirechye region of the Republic of Kazakhstan.

 doi:10.20944/preprints202404.0022.v1

2. Materials and Methods

Objects of research. Field scientific studies were conducted from 2021 to 2023 at the experimental fields of the "Kaynar Koks" Peasant Farm, located in the Koksu district of the Zhetysu region, Republic of Kazakhstan (44°52'13.5"N 78°11'11.3"E).

The Zhetysu region is characterized by different vertical climate zones, vegetation, and consequently, soil cover. Depending on the altitude, various vertical natural zones create different conditions for soil-forming processes. The phenomenon of vertical zoning is associated with the diversity of the region's soil cover. In the dry, hot, sharply continental Balkhash-Alakol depression and the PriBalkhash desert plain, northern light grey soils are formed, *which are the subjects of our scientific research*.

The climate of the Koksu district is continental. With average temperatures in January ranging from -9 to -7°C and in July from 22-24°C. In some areas, winter temperatures can drop to -35°C. The annual amount of atmospheric precipitation in the plains is 150-250 mm, and in mountainous areas, it ranges from 400-550 mm.

Culture. Sugar beet was cultivated during field research, hybrid «Viorica KWS». Originator**:** KWS SAAT SE, Germany.

The hybrid was tested at the Jambyl Complex State Variety Testing Management in Kazakhstan. The average yield of root crops was 81.6 t/ha, and the sugar yield was 12,91 t/ha.

Organic humic fertilizer "Tumat" is produced from leonardite brown coal with the addition of sapropel, fish meal and cottonseed cake. A patent for the invention "Method of producing organic humic fertilizer" was obtained and an international application was filed.

Each component of the «Tumat» fertilizer is unique in its chemical composition, containing a rich spectrum of biologically active substances necessary for plants in proportions balanced by nature.

The main component of the «Tumat» fertilizer is *leonardite*, a natural mineraloid, with a content of humic acids ranging from 65-85%, which is significantly higher compared to other natural sources: black peat - 10-40%, sapropel - 10-20%, brown coal - 10-30%, manure - 5-15%, compost - 2-5%, soils - 1-5%, silt - 1-5%, coal - 0-1% [30,31].

The fertilizer «Tumat» includes *sapropel* – a unique product of natural origin, representing fine-structured colloidal deposits from freshwater reservoirs. Sapropel contains water-soluble, easily and difficultly hydrolyzable substances, humic acids (HA), humatomelanic acids (HMA), and fulvic acids (FA) an expanded composition of macro- and microelements in the form of metal-organic complexes. Such a variety of biologically active substances contribute to the activation of humification processes of brown coal leonardite, improve the soil microbiota, and consequently enhance soil fertility [32,33].

In the production of the fertilizer «Tumat» *fish meal* was used, containing nutrients in a form easily assimilated by plants and soil. Fish meal includes a variety of macro- and microelements: nitrogen, phosphorus, potassium, calcium, magnesium, iron, zinc, sodium, as well as animal fats and biologically active substances. This makes the fertilizer easily absorbable by plants, improves soil structure, promotes a healthy root system, accelerates flowering and fruiting, and facilitates the rapid growth of shoots. The addition of fish meal to the soil enhances cellular metabolism processes and replenishes nitrogen and phosphorus losses during the growing season. It is believed that fish bone meal contains more phosphorus, while fish meal from soft parts contains more nitrogen [34].

Another key component of the "Tumat" fertilizer is *cottonseed cake* (kunzhara) - a by-product of cottonseed oil production. According to State Standard (StSt) 68-74 "Cottonseed Cake," it is produced by pressing cotton seeds to extract the oil, containing 36-38% crude protein and about 5-7% fats, with fiber content ranging from 12-25%. The protein in cottonseed meal includes a significant amount of essential amino acids, with the total amino acids making up 30% of its composition, including 11.4% of essential ones, among which methionine is 0.23% and lysine is 1.31%. The meal also contains an ample supply of nutrients: calcium (0.28%), potassium (1.65%), phosphorus (0.94%), magnesium (0.54%), sodium (0.44%), iron (22.8%), copper (0.00145%), zinc (0.00272%), manganese (0.00222%), cobalt (0.000017%), and iodine (0.000043%). The high content of biologically active substances (proteins, vitamins A, E, D, and B, fiber, nutrients, amino acids, and fatty acids) in cottonseed meal scientifically supports its inclusion in the "Tumat" fertilizer formulation [35].

Research methods. In the course of scientific research, the generally accepted methods of field experience and laboratory research of the Commonwealth of Independent States were used.

Field research. The study on the impact of the organic humic fertilizer "Tumat" on the growth, development, and productivity of sugar beet was conducted through field trials following the methodology of F.A. Yudin [36].

The field experiment was conducted between 2021 and 2023 on a mineral basis ($N_{100}P_{135}$), utilizing ammonium nitrate (N 34%, NH_4NO_3) and monoammonium phosphate (N 11%, P_2O_5 46%, $NH_4H_2PO_4$). Mineral fertilizers were applied to the soil using a cultivator three times before the vegetative irrigation sessions.

A comparative study was conducted on the impact of single and double foliar feeding of sugar beet with the organic humic fertilizer "Tumat" against a mineral background ($N_{100}P_{135}$). The foliar feeding was carried out using a trailed sprayer during the 2-3 and 5-6 true leaf stages. To prepare the working solution, 1 liter of "Tumat" liquid organic humic fertilizer was mixed with 200 liters of water. The application rate of the working solution was 200 liters per hectare.

The field experiment layout is presented in Table 1, detailing the experiment variants and the timing of the sugar beet foliar feeding according to the developmental stages.

Table 1. - Field Experiment Scheme.

#	Option	Development Phase
1	Control without the use of "Tumat"	-
2	Single application of "Tumat" foliar fertilizer	2-3 pairs of true leaves
3	Double foliar feeding with "Tumat"	2-3 and 5-6 pairs of true leaves

The accounting plot area is 120 square meters (10 meters wide and 12 meters long). The experiment was repeated three times. Sugar beet is a moderately thermophilic crop. Therefore, sugar beet planting was carried out in the first ten days of May. The sowing rate was 15 kg/ha.

The statistical analysis of the obtained results was carried out using the methodology of B.A. Dospexov [37], MS Excel was also used in the program.

The soil sample chemical analysis was conducted at the accredited laboratory of the U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry. Analytical methods described in the manual for general soil analysis were used to analyze the soil composition [38]. Determination of organic matter (humus) was carried out according to State Standard (StSt) 26213-91, readily hydrolyzable nitrogen by the Tyurin-Kononova method, mobile forms of phosphorus and potassium by the Machigin method in the Central Research Institute for Agrochemical Service in Agriculture (CRIASA) modification State Standard 26205-91, pH in water by State Standard 26423-85. Total forms of nitrogen by Kjeldahl, phosphorus by Ginzburg-Scheglova, potassium by Smith.

Chemical Analysis of Organic Humic Fertilizer «Tumat»**:** The chemical analysis of the organic humic fertilizer «Tumat» was conducted in an accredited laboratory Almaty Technological University using standard methods: N (nitrogen) – State Standard 28743-93, P (phosphorus) - State Standard 26717-85, K (potassium), Ca (calcium), Mg (magnesium), Fe (iron), Cu (copper), Ni (nickel), Mn (manganese), Zn (zinc) - State Standard 53218-2008, SiO_2 (silicon dioxide) - State Standard 25542.1-2019, Cr (chromium) – State Standard 30418-96, Fatty acid composition – State Standard R 53218-2008. The fatty acid composition of the «Tumat» fertilizer was determined using the «Chromaluks-4000M» chromatograph.

3. Results

The chemical composition of the organic humic fertilizer «Tumat». The chemical analysis of the organic humic fertilizer "Tumat" revealed the following element contents per 100 g of the product: nitrogen (N) - 1.309 g, phosphorus (P) - 1.416 g, potassium (K) - 3.619 g, calcium (Ca) - 1.48 g, magnesium (Mg)

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- 0.47 g, zinc (Zn) - 3.018 g, iron (Fe) - 0.793 g, copper (Cu) - 0.746 g, manganese (Mn) - 0.161 g, nickel (Ni) - 0.123 g, and silicon dioxide (SiO2) - 1.039 g (Table 2).

Table 2. Chemical composition of the organic humic fertilizer «Tumat».

Macro- and Micronutrients	Quantity, g/100 g
Nitrogen (N)	1,309 ± 0,008
Phosphorus (P)	1,416 ± 0,005
Potassium (K)	3,619 ± 0,003
Calcium (Ca)	1,48 ± 0,030
Magnesium (Mg)	0,47 ± 0,002
Zinc (Zn)	3,018 ± 0,005
Silicon Dioxide (SiO_2)	1,039 ± 0,0002
Iron (Fe)	0,793 ± 0,008
Copper (Cu)	0,746 ± 0,003
Manganese (Mn)	0,161 ± 0,002
Nickel (Ni)	0,123 ± 0,001

Tumat» fertilizer, unlike many humic fertilizers, contains amorphous silicon dioxide in the amount of 1.039 g/100 g (Table 2). The role of silicon (Si) compounds is significant for both soil (contributing to structure formation through organomineral complexes) and plants (strengthening the epidermis walls).

Fatty acid composition of the organic humic fertilizer «Tumat». The fatty acids of cottonseed cake also serve another crucial function for the production of the «Tumat» fertilizer - a stabilizing function, ensuring the stability of dispersed systems. This stability is expressed in maintaining the initial degree of dispersion and the uniform distribution of particles of the dispersed phase in the dispersion medium over time. Therefore, it was important to study the fatty acid composition of the organic humic fertilizer «Tumat».

The total fat content in the fertilizer is approximately 1%. Chemically, these are fatty acids of various structures and degrees of saturation (Table 3). An increase in the length of the hydrocarbon radical of fatty acids leads to an increased tendency of solution components to micelle formation, consequently enhancing the stability of the surfactant suspension (surface-active agents) [39]. The content of unsaturated fatty acids with a hydrocarbon radical length of more than 10 is 13.25% (positions 5, 7, 9, 11-15), which is sufficient to ensure suspension stability.

Table 3. Fatty acid composition of organic humic fertilizer «Tumat».

№	Fatty acid	Formula	Concentration, mass %
1	Butyric acid	$C_4H_8O_2$	4,462824
2	Caprylic acid	$C_9H_{18}O_2$	0,008199
3	Carboxylic acid	$C_{10}H_{22}O_2$	0,011995
4	Myristic acid	$C_{14}H_{28}O_2$	0,118669
5	Pentadecanoic acid	$C_{15}H_{28}O_2$	0,057663
6	Pentadecanoic acid	$C_{15}H_{30}O_2$	0,002508
7	Palmitoleic acid	$C_{16}H_{30}O_2$	0,009594
8	Palmitic acid	$C_{16}H_{32}O_2$	0,027633
9	Heptadecenoic acid	$C_{17}H_{32}O_2$	0,000703
10	Heptadecanoic acid	$C_{17}H_{34}O_2$	0,012893
11	Gamma-linolenic acid	$C_{18}H_{30}O_2$	0,034491
12	Linoleic acid	$C_{18}H_{32}O_2$	0,008817
13	Eicosapentaenoic acid (EPA, Omega-3)	$C_{20}H_{30}O_2$	0,442533
14	Arachidonic acid	$C_{20}H_{32}O_2$	0,145895
15	Nervonic acid	$C_{24}H_{46}O_2$	0,009489

The stabilizers derived from cottonseed cake do not contain synthetic components, are biodegradable, and environmentally friendly, making them promising for companies aiming for sustainable and environmentally responsible multi-fertilizer production. It is worth noting that polyunsaturated fatty acids (PUFAs) in the cake possess the properties of surfactants (surface-active agents), capable of evenly distributing the oil phase (organic components) in the aqueous phase and creating stable suspensions. The latter is one of the key indicators for the practical use of liquid fertilizers when applied by spraying [39].

Thus, the «Tumat» humic fertilizer, thanks to its rich composition of organic, mineral, stimulating, and biologically active substances, creates various independent mechanisms of influence on plants and soil, resulting in a synergistic effect. This statement is supported by the results of phenological observations and yield accounting for sugar beets in the conditions of irrigated light chestnut soils.

Influence of organic humic fertilizer «Tumat» on the growth, development, and productivity of sugar beets in light chestnut soils. The soil is one of the essential resources for agriculture, as the fertility of the soil affects the yield and quality of agricultural crops. The foothill soils of Kazakhstan are marked by a low organic matter content, which diminishes their productivity and resilience against biotic and abiotic factors.

The analysis of the initial agrochemical condition of irrigated light chestnut soil in the upper 0-20 cm layer (Table 4) indicates that the soil is characterized by low content of organic humus (0.81%), readily hydrolyzable nitrogen (34.8 mg/kg), and exchangeable potassium (K_2O 188.4 mg/kg), but high content of available phosphorus (P_2O_5 49.4 mg/kg). Therefore, to increase organic matter and available forms of macroelements in the soil, it is necessary to use new, more effective fertilizers.

Table 4. Initial State of the Chemical Composition of the Soil on the Investigated Experimental Plots.

Depth, cm	Humus, %	Gross forms, %			Mobile forms, mg/kg		
		N	P_2O_5	K_2O	Readily hydrolysable N	P_2O_5	K_2O
0-20	0,81±0,03	0,15±0,04	0,14±0,01	1,9±0,02	34,8±1,63	49,3±4,69	188,4±11,14
20-40	0,61±0,04	0,09±0,01	0,13±0,01	1,85±0,02	32,8±1,28	37,3±4,44	163,2±14,45

To reduce costs for mineral fertilizers and mitigate their negative impact on soil properties, we conducted a field experiment to study the influence of the organic humic fertilizer «Tumat» enriched with a complex of mineral elements, on the growth and development, yield, and sugar content of sugar beets.

The composition of absorbed bases is dominated by calcium (Ca 74-75%, 9.0-8.8 mg.ekv/100 g), followed by magnesium (Mg 20.1-20.4%, 2.4 mg.ekv/100 g). A small amount of absorbed bases includes sodium (Na 3.69-3.93%, 0.44-0.45 mg.ekv/100 g) and potassium (K 0.77-0.84%, 0.09-0.10 mg.ekv/100 g), respectively.

The examined experimental soil plots are characterized by a loamy and medium loamy granulometric composition (Table 5). The fraction of fine sand (0.25-0.05 mm) predominates at 53.65%. The physical clay (<0.01) in the upper 0-20 cm layer is 32.2%, and in the lower layer, it is 23.4%.

Table 5. Granulometric composition of the soil of the examined experimental plots.

Depth, cm	Fraction content in percentage of absolute dry soil						
	Fraction sizes in millimeters						
	Sand		Dust			Silt	The sum of fractions
	1-0,25	**0,25-0,05**	**0,05-0,01**	**0,01-0,005**	**0,005-0,001**	**<0,001**	**<0,01**
0-20	1,129	53,654	12,919	10,497	13,323	8,478	32,2
20-40	1,311	68,019	7,264	7,264	0,807	15,335	23,4

 doi:10.20944/preprints202404.0022.v1

The agrochemical characteristics of irrigated light gray soil at the end of the growing season are presented in Table 6. In the control group without the use of "Tumat" fertilizer, a decrease in humus content, available phosphorus, and exchangeable potassium is observed compared to the initial data (Table 4), while the content of easily hydrolyzable nitrogen increases. By the end of the growing season, the mobility of phosphorus decreases, and exchangeable potassium is actively used to improve the key indicator of sugar beet - its sugar content. It is important to note that the control group without "Tumat" fertilizer corresponds to the mineral background ($N_{100}P_{135}$) with three top dressings N_{50}, $N_{50}P_{65}$, and P_{70} for cultivation. Ammonium nitrate, added to the top dressing, contributed to crop formation and partially leached into the lower soil layers during irrigation. The use of ammonium phosphate did not lead to an increase in soil phosphorus content, as it was partially retained by the soil.

Table 6. Agrochemical properties of the soil in the experimental plot at the end of the growing season.

Variants	Depth, cm	Humus, %	Mobile forms, mg/kg		
			Light hydrolyzable N	P_2O_5	K_2O
Control	0-20	0,59±0,05	39,2±0,01	34,6±0,66	175,0±5,10
	20-40	0,53±0,05	35,4±0,93	32,6±2,40	170,0±10,00
One-time treatment with «Tumat»	0-20	0,72±0,08	42,0±0,01	41,3±6,35	200,0±10,00
	20-40	0,69±0,03	36,4±7,40	35,6±2,33	185,0±5,00
Two-time treatment with «Tumat»	0-20	0,80±0,12	43,4±4,20	43,6±3,17	210,0±10,00
	20-40	0,65±0,03	42,0±3,23	38,0±5,56	185,0±5,00

Our research has revealed that applying the organic humic fertilizer "Tumat" towards the end of sugar beet growth significantly enhances soil quality. This includes increases in total humus, easily hydrolyzable nitrogen, available phosphorus, and exchangeable potassium levels compared to the baseline. The humic and fulvic acids present in "Tumat" interact with soil minerals, promoting the formation of humic acids. This fertilizer enriches the soil with essential macro and microelements, particularly potassium, phosphorus, and nitrogen, which are crucial nutrients for sugar beets during their vegetative growth phase (Table 6).

Sugar beet is a moderately heat-loving crop. Therefore, sugar beet sowing was carried out in the first decade of May. Shoots emerged on the 8th-10th day at a temperature of 10-11°C. According to the conducted counts, it was established that the average number of sugar beet shoots ranged from 10.0 to 11.6 per 1/m², depending on the studied variants (Table 7). The formation of the highest plant density was noted in variants where the organic fertilizer «Tumat» was applied with one- and two-time treatments, with the indicator being 3.7-12.5% higher compared to the control (9.51 thousand shoots/ha).

Table 7. Phenological observations of sugar beet.

Variants	Seedlings, units per 1/m²	Plant density, thousand units/ha	Plant height by growth stages, cm		
			6-8th pair of leaves	Leaf closure	Technical maturity
Control	10,0±1,52	9,51±1,63	16,8±0,46	29,9±1,19	33,7±1,31
One-time treatment with «Tumat»	10,6±1,20	9,87±1,95	16,7±0,53	31,3±1,31	37,6±1,07
Two-time treatment with «Tumat»	11,6±0,66	10,7±2,01	19,4±0,75	32,2±1,24	39,5±1,30

The growth of sugar beet throughout all development stages was similar across the studied variants, and by the time of technical maturity, it reached 39.5 cm in variant 3 with double fertilization treatment using "Tumat," which is 17.2% higher compared to the control indicator.

 doi:10.20944/preprints202404.0022.v1

The productivity of sugar beet is closely linked to the root vegetable's weight. The maximum weight of the root vegetable before harvesting sugar beets, achieved with the use of the "Tumat" fertilizer, ranged from 8.5 to 9.2 kg/m². Meanwhile, the minimum weight of the root vegetable was recorded in the control variant, amounting to 7.0 kg/m².

It has been established that the yield of sugar beets when using the organic fertilizer «Tumat» with one and two-time treatment shows a maximum increase of 10.5-15.2% compared to the control, in quantitative terms ranging from 4.9 to 7.1 t/ha (Table 8). The sugar content in the roots is 0.4-0.7% higher, and the sugar yield is 0.92-1.41 t/ha (13.6-20.8 %) more compared to the control variant without treatment.

Table 8. Sugar beet yield and productivity.

Variants	Sugar beet yield, t/ha	Crop yield improvement		Sugar content, %	Sugar yield, t/ha
		t/ha	%		
Control	46,6	-	-	14,5	6,75
One-time treatment with «Tumat»	51,5	4,9	10,5	14,9	7,67
Two-time treatment with «Tumat»	53,7	7,1	15,2	15,2	8,16
$SSD_{0,5}$ t/ha	2,39				
P, % Experiment error	1,63				

Therefore, the organic humic fertilizer "Tumat" stimulates soil activity, enhances germination, promotes growth and development of plants, and also accelerates their maturation. The use of single or double foliar feeding for sugar beets increases the yield of tubers and their sugar content.

Statistical analysis of the collected data is crucial as it allows for the analysis, interpretation, and making informed conclusions based on the gathered information. This key process in research helps identify patterns, trends, and relationships among various variables. Thanks to statistical processing, informed decisions can be made in science and many other fields, improving the efficiency and accuracy of predictions.

Smallest significant difference, a statistical term that is used to define the smallest difference between two values at which the differences between them are considered statistically significant. According to our scientific research, the smallest significant difference in the yield data of sugar beet is 2.39 t/ha. The error of the experiment (P) is 1.63% (Table 8).

Statistical data processing was carried out using the MS Excel analysis package. The descriptive statistics of the obtained data are presented in the Table 9. Invoice n = 9 indicates the processing of experimental data from 2021 to 2023, with each year's data being repeated three times.

Table 9. Descriptive Data Statistics.

Indicators	Easily hydrolysable nitrogen, mg/kg	P_2O_5, mg/kg	K_2O, mg/kg	Sugar beet yield, t/ha	Sugar content, %	Sugar yield, t/ha
Average	39,73	37,63	187,5	50,63	14,86	7,52
Standard error	0,54	0,67	2,18	1,48	0,46	0,22
Median	39,4	38,5	192,5	50,9	14,9	7,67
Mode	37,3	33,6	172,5	44,6	14,5	6,75
Standard Deviation	2,84	3,52	11,37	7,69	2,40	1,16
Variance	8,09	12,42	129,34	59,24	5,78	1,35
Interval	9,6	13,5	32,0	29,5	10,0	4,88
Minimum	34,9	30,9	168,1	34,1	9,5	4,55
Maximum	44,5	44,4	200,1	63,6	19,5	9,43
Invoice (n)	27	27	27	27	27	27

The data indicates that the average yield of sugar beet reaches 50.63 tons per hectare, with an average sugar content of 14.86% and an average sugar production of 7.52 tons per hectare. The report also includes variability and data distribution metrics, such as standard deviation and variance, allowing for an assessment of data dispersion around the mean value.

To determine the relationship between two or more variables, the statistical tool MS Excel was used. Correlation measures the degree to which two variables change together. The correlation value can be between -1 and 1, where -1 indicates complete inverse correlation, 0 indicates no correlation, and 1 indicates complete direct correlation.

As indicated in Table 10, the strongest direct correlation between the yield of sugar beet and macronutrients is observed with easily hydrolysable nitrogen at 0.50, indicating a moderate relationship. There is a weak direct correlation between the yield and both available phosphorus and exchangeable potassium, with values of 0.37 and 0.40, respectively.

Table 10. Correlation Coefficient.

Indicators	Sugar beet harvest	Sugar yield
Easily hydrolysable nitrogen	0,50	0,44
Mobile phosphorus	0,37	0,47
Exchangeable potassium	0,40	0,54

The sugar output is primarily influenced by the soil content of exchangeable potassium (0.54), followed by available phosphorus (0.47) and easily hydrolysable nitrogen (0.44).

4. Discussion

The use of humic substances in spraying vegetating plants directly influences them through the foliage. Low-molecular-weight humic compounds penetrate through the leaf blades [40]. The intake of high-molecular-weight substances through cell membranes is problematic due to the large size of these molecules. However, experiments have shown that the presence of humic substances increases the permeability of cell membranes [41].

The permeability of cell membranes facilitates the increased intake of nitrogen, phosphorus, potassium, iron, and enhances plant resistance to a wide range of adverse factors such as pesticides, frosts, droughts, and high soil salinity. Additionally, it has been proven that humic substances boost photosynthesis and respiration rates, and strengthen protein and phosphorus metabolism in plants [40].

The second way humic substances affect plants is by enhancing soil biological activity [42]. Adding humic fertilizers and substances to the soil boosts microbial activity, leading to increased consumption of organic and mineral substrates. This process enhances the mineralization of organic matter and the breakdown of soil minerals. As a result, there's a release of mineral nutrients that plants actively absorb. It's important to note that plants, through their root exudates, contribute organic acids to the soil. These acids help activate microflora, decompose mineral substrates, and release nutrients, creating a "rhizosphere effect" [43–45].

Structure and chemical composition of humic acids are not identical and never repeat, especially if they come from different sources. This explains their differences in properties and their effects on living organisms (plants, animals, and humans). The unique properties of leonardite are precisely related to the structure and mass of humic acids. The molecular weight of humic acid molecules extracted from leonardite is over 2500 atomic units, for comparison, the molecular mass of humic acids from sapropel is up to 1000 atomic units, and from peat, it ranges from 500 to 2500 atomic units [12].

From a chemical perspective, leonardite is a complex mixture of high-molecular-weight natural organic compounds formed during the decomposition of dead plants and their subsequent humification (the biochemical transformation of the products of organic residue decomposition into humus with the participation of microorganisms, water, and oxygen). Humic substances are biologically active compounds. They activate biochemical processes in the organisms of animals and

 doi:10.20944/preprints202404.0022.v1

in the cells of plants. This circumstance determines the high demand for humates in domestic and international markets. Humic preparations enriched with potassium and phosphorus, i.e., the basic elements determining soil fertility, are particularly valuable for plants [30,31].

It has been scientifically proven that soil fertility largely depends on the content of humic acids and their ability to influence plant growth by enriching the product with various macro- and microelements. The humic acids in fertilizer intensify the synthesis of nucleic acids. This is important for strengthening plants, as all forms of nucleic acids participate in protein synthesis [10].

The application of leonardite-based fertilizers affects the water-physical properties of the soil: capillary and field moisture capacity of light soils increases, and water permeability of heavy soils improves. Soil structure and density also improve. At the same time, there is an increase in soil microbiological activity, leading to higher crop yields for agricultural crops [20,24].

Based on the nature of the impact of humic acids on soil and plants, three types of effects are distinguished [12,32]: physical impact – accompanied by the modification of soil structure, chemical impact – accompanied by changes in the binding properties of the soil, biological impact – accompanied by the stimulation of plant growth and microbial activity.

Humic fertilizers influence the growth, development, and productivity of agricultural crops and enhance soil fertility. In the Russian Federation, the use of humic fertilizers, particularly the treatment of corn and soy seeds and plants with the humic substance "Lingohumat," stimulates the growth and development of microscopic fungi and bacteria [14]. The application of the humic substance "Bio-Don" to soil and wheat plants during the tillering and stem elongation stages significantly enhances the stimulation of soil microflora, fungi, and cellulose-decomposing actinomycetes. This boost in soil biological activity intensifies the processes of phosphorus mobilization and increases grain yield [15]. Using the "BioHumate" humic fertilizer enhances the germination energy and seed germination rates of wheat, as well as the vegetative mass, plant height, and yield [16].

The application of the organic humic fertilizer "Tumat" in the Republic of Uzbekistan, specifically for pre-sowing seed treatment and foliar feeding of rice, cotton, tomatoes, winter wheat, and soybeans in the Andijan region, enhances germination, promotes growth and development of plants, and increases their yield [17–19,21,22].

Field research conducted in the Republic of Kazakhstan has confirmed the positive effects on soil, growth, development, and crop yield. Research on the microflora of light chestnut soil used for cultivating soy and safflower has shown a positive impact of the organic fertilizer "Tumat" on the levels of ammonifiers and actinomycetes, which are activators of soil processes [23]. Treating ordinary sierozem soil with organic humic fertilizer enhances the organic matter and nitrate nitrogen content, phosphorus mobility, and exchangeable potassium, leading to increased symbiotic nitrogen fixation. Applying the "Tumat" fertilizer as a foliar feed twice to soy plants increases the number of nodules on the main root, boosts grain yield, and raises the protein and fat content [24].

During the scientific and technical program, we conducted from 2021 to 2023, we also carried out field studies involving the cultivation of soybeans, winter wheat, rice, and potatoes. Pre-sowing treatment of soybean seeds with Tumat organic fertilizer solution on light sierozem soils increased their germination by 10-20%. Both single and double foliar feeding of soy plants enhanced their growth and development, increased yields by up to 21-25%, and contributed to a higher count of nodular bacteria [25]. Treating seeds and performing one or two foliar feedings of winter wheat with the "Tumat" fertilizer solution on light sierozem soils increased plant survival, ear grain number, the weight of 1000 seeds, and the yield of winter wheat by 11-15%. The use of "Tumat" fertilizer also affects the quality of winter wheat grain, increasing the protein and gluten content in the grain while reducing the starch content and lowering the gluten index [26]. Preparing rice paddy soil before sowing rice stimulates an increase in the content of organic matter and nitrogen, the mobility of phosphorus and exchangeable potassium, affects the length of the panicle and grain filling, and ensures a grain yield increase of 1.3 tons per hectare (36.1%) compared to the control without treatment [27,28]. Using the organic humic fertilizer "Tumat" on light chestnut soils without mineral fertilizers increases the weight of tubers and potato yield up to 26 tons per hectare, ensuring a yield increase of 13.4% compared to the control group [29].

5. Conclusions

Scientific research confirms the effectiveness of using the organic humic fertilizer "Tumat" for cultivating sugar beets in the conditions of the irrigated light chestnut soils of the Republic of Kazakhstan. It has been scientifically established that the organic humic fertilizer "Tumat" represents a new generation of fertilizers, featuring high bioavailability. It contains a balanced complex of essential macro- and micro-nutrients, polyunsaturated fatty acids, and other biologically active substances.

Tumat organic humic fertilizer is a highly dispersed aqueous suspension of humic substances derived from leonardite brown coal, enriched with organomineral complexes from sapropel and fish meal, and stabilized with fatty acids from cottonseed cake.

Applying fertilizer to sugar beet crops once or twice outside of their root zone impacts their nutrition, enriches the soil with exchangeable potassium, available phosphorus, and easily hydrolyzable nitrogen during the plant's growth period.

Using the organic humic fertilizer "Tumat" enhances seed germination, stimulates growth and development, and accelerates the ripening of sugar beets. Both single and double foliar applications of this fertilizer contribute to increased tuber yield and sugar content in sugar beets.

"Tumat" is recommended as an environmentally safe and effective agricultural solution that not only boosts the productivity and quality of sugar beets but also improves the fertility of soil resources.

The findings from our research could benefit agricultural producers, agronomists, and ecologists focused on advancing organic farming, enhancing soil fertility, improving the physical and biological properties of soils, increasing the yield of agricultural crops, and improving their quality indicators.

6. Patents

Patent for utility model KZ № 8251, Date: 14.07.2023, Title: Method of producing organic humic fertilizer, Inventors: G.Kaisanova, B.Suleimenov, S.Tanirbergenov, M.Ibrayeva, was obtained.

Author Contributions: Conceptualization, B.S., M.S.; methodology, B.S., G.K., M.S.; validation, B.S.; G.K., M.S.; formal analysis, S.T.; M.S.; investigation, B.S.; G.K.; S.T.; M.S.; resources, B.S.; G.K.; S.T.; M.S.; data curation, B.S.; writing-original draft preparation, B.S.; M.S.; writing-review and editing, B.S.; M.S.; visualization, B.S.; M.S.; supervision, B.S.; project administration, B.S.; funding acquisition, B.S., G.K. All authors have read and agreed to the published version of the manuscript.

Funding: This study was financed by the State Institution Ministry of Agriculture of the Republic of Kazakhstan under budget program No. 267 Improving the Accessibility of Knowledge and Scientific Research. Program code O.0946, No.0112RK01718.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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