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Influence of Fertilizers and Bioactive Substances on Sugar Sorghum Yield in Southern Kazakhstan

Kalmakhan Mambetov[1], Alikhan Bozhbanov[2], Inkar Dzhakupova[3*], Roza Abildaeva[1], Roza Mamykova[4]

[1] Department of Biology and Geography, M. Auezov South Kazakhstan University, Shymkent 160100, Republic of Kazakhstan
[2] Department of Biodiversity and Biological Resources, Al-Farabi Kazakh National University, Almaty 050040, Republic of Kazakhstan
[3] Department of Chemistry, Chemical Technology and Ecology, Almaty Technological University, Almaty 050012, Republic of Kazakhstan
[4] Department of Biology, South Kazakhstan State Pedagogical Institute, Shymkent 160012, Republic of Kazakhstan

Corresponding Author Email: i_dzhakupova@outlook.com

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ABSTRACT

This study aimed to determine the effects of biologically active substances and nitrogen-phosphorus fertilizers on the yield of sugar sorghum (Sorghum bicolor L.) grown in southern Kazakhstan. A three-year field experiment was conducted using a factorial design with the sorghum variety 'Kazakhstanskoe 20'. Three fertilizer treatments (control, $N_{30}P_{30}$, $N_{60}P_{60}$, $N_{90}P_{90}$ kg/ha) were combined with three seed treatments (Celeste Top, Gumi 20, Potassium Humate). Sorghum was harvested at the wax ripeness stage. Analysis of variance was used to analyze the data. Fertilizer dose, seed treatments, and their interaction significantly increased sorghum green mass yield compared to the control. The highest yields (18.0-19.3 t/ha) resulted from combining $N_{90}P_{90}$ fertilization with seed treatments. Celeste Top and Gumi 20 increased yields by 1.6-4.1 t/ha across fertilizer doses, while Potassium Humate had the greatest effect (increase of 2.7-5.4 t/ha). The integrated use of biologically active seed treatments and moderate to high doses of nitrogen-phosphorus fertilizers can substantially increase the productivity of sugar sorghum grown in southern Kazakhstan. These findings provide agronomic strategies to improve sorghum yields under arid conditions.

1. INTRODUCTION

In recent decades, periods of drought, which are unfavorable for the cultivation of traditional fodder crops, are increasingly observed in the region of southern Kazakhstan. Therefore, there is an active introduction of crops that are more resistant to moisture deficit in the soil, in particular: sorghum-Sudanese hybrid, sugar sorghum, millet, Sudanese grass, amaranth, chumiza.

For the first time, in the laboratory of sorghum selection and seed production of the Scientific and Production Center of Agriculture and Plant Breeding of the Republic of Kazakhstan under the leadership of Omarova and Makarov [1] promising varieties of fodder sorghum and selection material of early ripening food sorghum were obtained.

Sugar sorghum grain is used in many types of economic and business activities. In particular, in the agro-industrial complex, it is used in feed additives for animals, as a basic additive for the production of compound feed, as well as a raw material in the starch, molasses and alcohol industries.

This crop is also used in the food industry. Cereals are prepared from sugar sorghum grains, and in the countries of Central Asia, sorghum is considered among grain crops for further processing and production of bakery products. It is important to note that sugar sorghum ranks third in the world as a food crop after wheat and rice. It is interesting that sorghum is also used for snow retention and protection of crops from droughts, and in the context of row crops, it is a good precursor for spring crops during crop rotation.

The growth and development of sugar sorghum, which has high drought resistance, is of great value for the arid regions of the Republic of Kazakhstan [2]. Crops are concentrated in Central Asia, the North Caucasus and Transcaucasia, southern Ukraine, Moldova, the Lower Volga, and the Don.

That is why research directions aimed at increasing the yield of sugar sorghum and developing methods and technologies of cultivation in general, based on the determination of sowing methods and seed sowing rates, selection of varieties, application of biofertilizers, herbicides for plant protection and nutrition, remain important. And the conducting of scientific field experiments allows us to develop an adaptive technology for growing sugar sorghum for the specific conditions of the South Kazakhstan zone.

Baiseit and Konkarova [3] consider the features of increasing productivity and productivity indicators of the same multifunctional agricultural crop as sugar sorghum – spring rapeseed. The authors note that this culture needs protection and nutrition during the period of growth, development of biologically active substances that will increase the quantitative and qualitative indicators of the obtained agricultural products. Such positive changes occur due to positive changes in the process of metabolism, while influencing the chemical composition of plants and accumulating proteins, fats, carbohydrates and other life-sustaining nutrients. After all, so-called biofertilizers contain effective, fast-acting components that can increase the level of ecological and economic efficiency as a result of working with various agricultural crops, including rapeseed and sugar sorghum.

Abdrakov et al. [4] study the action of synthesized available products, which include dimethyl terephthalic ether acids and dimethylaminoethanol, namely their physical and chemical composition, quantitative and qualitative indicators of similarity. It is important to study the energy impact of these substances on the growth of such crops as wheat and sugar sorghum. In particular, the authors consider a number of technological techniques for cleaning methods and the selection of necessary substances from the aqueous phase without the use of solvents of organic origin. In other words, the so-called biostimulant is used for the growth and development of crops characterized by a high level of productivity. The above-mentioned technologies make it possible to open the way to the synthesis and production of economically and technologically effective substances, which play an important role for the diversity and systematicity of research, expand and deepen biochemical knowledge, the structure of culture at the cellular level.

Kunypiyaeva et al. [5] are conducting scientific research in the areas of selection experiments of sorghum crops, namely Sudanese grass, grain sorghum, sugar sorghum for further production of green mass in the territory of the Republic of Kazakhstan in the conditions of the southern and southeastern regions. Scientists studied the characteristics of germination energy and laboratory seed germination of Silosne 88, Pomarancheve 160, Stavropolske 36, Kazakhstan 20 varieties. In this case, phenological observations regarding the conditions of growth and development of the varieties were important. According to the results of the screening of sugar sorghum varieties for the yield of green mass, the highest results were characterized by the varieties Orange 160, Kazakhstan 20 in the southern regions of Kazakhstan.

While previous studies have examined fertilization practices for sorghum, this is the first to systematically test different combinations of biologically active seed treatments and mineral fertilizers under arid conditions in southern Kazakhstan. The results will provide novel agronomic strategies to increase sorghum productivity in this region and other drought-prone areas.

The central hypothesis was that an integrated management approach using biologically active seed treatments and optimized fertilizer doses would significantly increase the yield of sugar sorghum compared to standard practices.

The objective of this study was to determine the effects of biologically active substances and nitrogen-phosphorus fertilizers on the productivity of sugar sorghum grown in southern Kazakhstan. Specifically, the research aimed to: evaluate different doses of fertilizers in combination with seed treatments; and identify optimal agronomic practices to improve sorghum yields.

2. LITERATURE REVIEW

2.1 Cultivation practices and yield of sugar sorghum

Recently, more and more attention has been paid to the issues of biological farming. Biotechnologies have been developed for the production and use of biological products based on symbiotic and associative nitrogen-fixing microorganisms, as well as microorganisms producing phytohormones, vitamins, organic acids, antibiotics and other biologically active substances. Many scientists [1, 3-16] argued that this helped to improve the mineral nutrition of plants, increase their resistance to various stresses and phytopathogens, as well as to ameliorate yields and quality of crop production while maintaining soil fertility.

According to Kostikov and Bogapov [17], in the conditions of Northern Kazakhstan, the sowing dates, seeding rates and harvesting dates were studied. The research established that among the studied varieties of sweet sorghum, early-ripening hybrids were more productive, providing a yield of green mass at the level of 108-143 c/ha (centner on hectare). The optimal sowing time for sweet sorghum is the time when the temperature in the soil at the seed placement depth warms up to +20°C. The optimal seeding rate for varieties of sugar sorghum is 250 thousand units. seeds/ha. The highest yield of green mass and dry matter was obtained during harvesting in the phase of wax ripeness of grain – 146-183 c/ha.

According to studies of the Food Security Department of the Food and Agriculture Organization of the United Nations [2], over a number of years, an important biological property of sorghum has been revealed – it tolerates permanent crops for many years without a decrease in yield. The introduction of permanent crops of sorghum has certain advantages compared to cultivation in crop rotation. This primarily concerns the placement of sorghum crops on slopes, eroded and saline lands, often found in the south of our country, where other crops drastically reduce productivity. Long-term practice shows that sorghum does not give such a high yield, which is inherent in its potential. This is due to the fact that it is sown on random, clogged, worse predecessors.

2.2 Nutritional value and use as animal feed

Sorghum grain contains 12-15% protein, 3.4-4.4% fat, 70-80% starch (BEV), 2.4-4.8% fiber. Sorghum grain is equal to, and even surpasses, barley in terms of fodder qualities. However, in the conditions of the region, the productivity potential of this crop is far from being fully realized. To solve the problem of increasing the yield of sorghum, it is necessary to work on the development of methods and cultivation technology in general, based, among other things, on determining the methods of sowing and seeding rates, selection of varieties, the use of fertilizers and herbicides to protect crops from weeds [18].

According to Golubev et al. [19], sweet sorghum easily tolerates summer drought, and after a long period without precipitation, it is able to continue growth and development without any loss in biomass. In addition, sweet sorghum during the growing season economically consumes soil moisture for the formation of vegetative and generative organs. Unlike maize, sorghum is an acceptable silage crop, especially in dry conditions. This ensures uninterrupted in-line production of feed with a high content of feed units and digestible protein during the critical autumn-winter period of feeding farm animals.

Sugar sorghum is characterized by high indicators of nutritional value. For example, if sorghum grains are added to food additives in the field of pig farming, the quality of meat products will be much higher than when using conventional balanced feed. Comparing compare sorghum and spring barley, which are used in animal rations, it is estimated that 1 hectare of sugar sorghum can produce almost half as much pork as 1 hectare of barley.

From the point of view of forage crops, sorghum contains the highest protein content, which is 12-15%, and starch is estimated at 70%, fats – 3.5-4.5%. At the same time, 1 centner of grain contains from 118 to 130 feed units, and the energy indicators of the sorghum yield are 18.3 mJ/kg.

Sugar sorghum has the property of regrowth, which is observed 1.5 months after the optimal phase, usually in spring. Due to this property, for agricultural enterprises that do not have enough equipment, the technique of using this culture is extremely important in the context of ensuring effective indicators. Future annual pastures can also be planned using sorghum. However, after the leaves and stems are fully matured, the plant loses its primary properties. Thus, 100 kg of sorghum silage can contain 20-24 fodder units per unit with protein values of 1.31-1.67 kg.

2.3 Research on sugar sorghum in Kazakhstan

Within Kazakhstan specifically, studies have evaluated sorghum varieties, productivity, and response to cultivation practices. Omarova and Makarov [1] developed new sorghum hybrids and varieties in Kazakhstan. Others have tested planting methods, seed treatments, and fertilization, finding benefits from wider row spacing, seed inoculants, and nitrogen fertilization [5]. However, there remains a need for comprehensive studies optimizing integrated crop management techniques to maximize sorghum yields in Kazakhstan [15].

According to the research of Nokerbekova et al. [16], in the conditions of chestnut soils of the South-East of Kazakhstan, the application of nitrogen fertilizers in the early phases of growth and development of sugar sorghum plants contributed to the accumulation of sugar in sorghum plants throughout the growing season with its maximum content in the milky-wax phase grain ripeness. At the same time, the tendency to increase the content of both sugar and juice quality indicators remained in connection with the fertilization with nitrogen fertilizer against both backgrounds of soil availability with mobile phosphorus, depending on the biological characteristics of sugar sorghum varieties.

According to the results of experimental research by Nokerbekova et al. [16], when sowing sugar sorghum, a special temperature regime must be observed in the soil, which is +14-16°C. Subject to an increase in temperature in the soil to +25-28°C, paprostes begins to germinate on the 5-6th day after sowing.

In recent years, due to the lack of sugar in Kazakhstan, interest in sugar sorghum has noticeably increased. The high sugar content in the stems makes it possible to obtain molasses, syrup, which can replace beet sugar in the manufacture of various products. Along with varieties, studies show that high yields of grain and green mass are determined by cultivation technology, of which timing, sowing methods, seeding rates, mineral nutrition, and moisture availability are the determining agrotechnical methods.

2.4 Gaps in current literature

While previous studies have examined various cultivation factors independently, there is limited research on interactions between management practices and their combined effects on productivity. Additional research on optimized, integrated crop management packages is needed, especially from the arid regions of southern Kazakhstan. This study aims to address these gaps by evaluating combinations of seed treatments and mineral fertilization strategies for improving sorghum yields.

3. MATERIALS AND METHODS

The main studies, in particular the experiment, were conducted in the period from 2018 to 2020 on the basis of the educational and research institute of the Research Institute "Ecology and Biotechnology" and the Regional Testing Laboratory "Structural and Biochemical Materials" of an engineering profile at M. Auezov South Kazakhstan University. The site where the tests were carried out is located in the foothill-steppe zone and, according to soil and climatic parameters, is typical for these conditions within the region of South Kazakhstan.

The variety of sugar sorghum "Kazakhstan-20" was the object of detailed study during the research. In the course of the experiment, the following research methods were used: observation, multivariate field experiment, method of controlled (laboratory) experiment. The method of field two-factor research included a method of comparing similar land plots with subsequent comparison their qualitative and quantitative characteristics [20], as well as the "Methodology for conducting an agrotechnical field experiment" [21]. The variety was bred at the Kazakh Research Institute of Agriculture and Crop Production LLP. Created by crossing sugar sorghum that is not damaged by birds. The plant is 130-175 cm high, with high bushiness, vigorously develops in the initial period of growth, resistant to lodging, suitable for mechanized harvesting of green mass and seeds.

The variety is aligned with the stem. The main stem has 7 aerial nodes, 9 leaves. The leaf is green, lanceolate. Leaf blade and vein without pubescence. The leaf sheath is light green with slight pubescence. Panicle with a shortened stem 25-30 cm long. Leg length 30-35 cm. Distance from the bell of the upper leaf to the first branch of the panicle 5-8 cm. Spikelet rhomboid, spinous, glumes 6-7 cm, black and white, smooth. The grain is ovoid, brown, almost completely covered with a film. The shell is brown-yellow, the endosperm is white. The content of crude protein in absolutely dry matter of green mass is 5.8-6.2%, fiber 24.4-24.6%, sugar content in stem juice. The variety has good seed productivity, the yield of green mass is 800-870 q/ha. The vegetative period from germination to the 1st cutting is 78-95 days, from sowing to the full ripeness of the grain is 115-120 days. The variety is drought-resistant, responsive to moisture and high agro background. Recommended for cultivation in Zhambyl, Pavlodar, South Kazakhstan regions.

According to factor A, four backgrounds of mineral nutrition of sorghum plants were studied in the following variants: 1. Control – without fertilizers; 2. $N_{30}P_{30}$; 3. $N_{60}P_{60}$; 4. $N_{90}P_{90}$.

By factor B – the effectiveness of three different biologically active substances was studied: Celeste Top, "Gumi 20" and Potassium Humate, used in pre-sowing preparation of seeds.

The mineral nutrition backgrounds (factor A) were applied to the soil for each plot. The biologically active seed treatments (factor B) were applied to the sorghum seeds 24 hours prior to planting. This resulted in 12 treatment combinations from the factorial combination of A×B.

Celeste Top is a biopolymer of natural origin, the basis of the active substance is poly-beta-hydroxybutyric acid, obtained by isolating Pseudomonas aureofaciens and Bacillus megaterium from soil bacteria [22]. The principle of Potassium Humate is based on the push of the plant's natural defense reactions. At the same time, increased resistance to extreme temperatures, pesticide stress, soil pollution with chemicals, drought, salinity, frost and other stresses increases.

Gumi 20 contains phytohormones and trace elements in an active biological form, as well as fulvo and humic compounds up to 2000 mg/l. The preparation also contains rhizospheric microorganisms and phytopathogens.

Potassium humate – an effective growth stimulant combines the properties of an anti-stress adaptogen, increases productivity and environmental cleanliness of the crop. Based on humic acids and phytohormones with a high content of sodium and potassium humates – 80%, thereby providing energy for germination.

The field experiment was repeated over three growing seasons (2018-2020) to provide replication. The biologically active substances Celeste Top, Gumi 20, and Potassium Humate were obtained from commercial sources (company, city, country). They were prepared according to manufacturer specifications and applied to sorghum seeds at a rate of 30/60/90 ml/kg seed 24 hours prior to planting.

Data were analyzed by two-way ANOVA to determine the effects of mineral nutrition, seed treatments, and their interaction on sorghum yields. Normality and homogeneity of variance were checked prior to analysis. Means were separated by Tukey's HSD test at the 5% significance level.

4. RESULTS

External conditions affect growth both directly and indirectly. The latter is due to the fact that the growth rate depends on the intensity of all other physiological processes, air and root nutrition, water supply, intensity of metabolic and energy processes. In this regard, the influence of external conditions can affect the intensity of growth through a change in any of these processes. At the same time, it is not always possible to establish the causes of this or that influence with sufficient accuracy, since in a natural setting the influence of individual factors is closely interconnected. The growing season of sugar sorghum is characterized not only by the growth and development of agricultural crops, and the level of yield with appropriate quality indicators.

Sweet sorghum easily tolerates summer drought, and after a long period without precipitation, it is able to continue growth and development without any loss in biomass. In addition, sweet sorghum during the growing season economically consumes soil moisture for the formation of vegetative and generative organs. Unlike maize, sorghum is an acceptable silage crop, especially in dry conditions. This ensures uninterrupted in-line production of feed with a high content of feed units and digestible protein during the critical autumn-winter period of feeding farm animals [19].

The average long-term annual precipitation is 262 mm. Their extremely uneven distribution over the seasons is characteristic. The largest amount falls in spring and winter – 41.4 and 37.2%, the smallest in summer – 3.8%. In some years, there is no precipitation during the summer period. Autumn accounts for 17.6% of the annual precipitation rate [23].

Most of the precipitation falls in the form of rain. The snow cover is unstable, varies from 10 to 35 cm and can last up to 43 days. Winters are short, unstable and relatively cold. The average air temperature in January is minus 3.4°C. The indicators of the average daily temperature regime were 0°C within 45-65 days. The depth of soil freezing is 20 cm, but in cold winters freezing up to 60 cm is noted. Relative air humidity in the winter months is 81%. Spring is short, characterized by an intensive increase in air temperature and maximum precipitation. Stable average daily air temperatures above 0°C are usually established in mid-February. However, fluctuations can be 15-25 days in one direction or another. Sometimes the onset of spring is celebrated at the end of March or dragged on until the last days of April. The average air temperature for the spring period is +14°C, with fluctuations from +12 to +20°C. The average monthly temperature in April is +15.1°C. Relative humidity is 60%, in May it drops to 50%.

Summer is dry and hot with a stable average daily air temperature of +25.1°C, but on some days it can even reach +45°C in the shade. Atmospheric precipitation is practically absent. The average air temperature in July is +26.9°C, and the average monthly relative humidity in June-July drops to 46-47%, but may drop to 26%. During this period, the winds of the northern and northwestern directions dominate. The thermal resources of summer make up 80-85% of the total annual indicator. Autumn is warm, with an average air temperature of +11.7°C. The first autumn frosts occur in early or mid-October. The average monthly air temperature is +18.5°C, in November it drops sharply to +4.6-5.1°C. Relative humidity in September is 56%, by November it rises to 74%.

Table 1. Indicators of duration of development and growth of plants taking into account different temperature regimes (in 2017-2020 research years)

Years Research	Average Monthly Air t °C for Rapeseed Vegetation		Increase in Air Temperature by t °C	∑ Active t for the Vegetative Period of Rapeseed, t °C	Duration of the Growing Season of Sorghum, in Days
	During the Years of Research	Over Many Years Data			
2018	23.7		4.9	∑ 3205	114
2019	24.2		5.4	∑ 3315	116
2020	24.0	18.8	5.6	∑ 3270	110
Average	23.8		5.0	∑ 3263	115

The winter-spring period provides the maximum partial leaching of salts harmful to plants from the arable soil layer, which creates a moisture reserve in the soil, and in areas with a close occurrence of desalinated or weakly mineralized groundwater, it contributes to an increase in the thickness of the desalinated upper layer of groundwater – the "fresh cushion", created by autumn-winter leaching irrigation against the background of drainage. Indicators of the temperature regime for favorable ecosystem conditions for the growth of sugar sorghum were determined according to the values of the average monthly air temperature (t °C) during the growing season of sorghum in 2018-2020 (Table 1).

According to the analysis of data from Table 1, the indicators of the average monthly air temperature during the growth period of sugar sorghum fluctuated within the 23.3°C and 24.2°C with a norm of 18.8°C.

Seasonal conditions during field research have the following characteristics: the growing season in 2018 (precipitation during this period fell from 28 to 25 mm, which is 5.5-6.6 mm lower than the average annual data), was characterized as dry.

In 2019, a large amount of precipitation fell in April 139 mm, which is 13.5-30.3 mm higher than the long-term average, in August there was no precipitation -0.0 mm (the total precipitation was 187.7 mm, which is 30.0 mm above the long-term average), the average temperature in July reached +30.66°C, while July 2019 (+30.63°C) turned out to be one of the warmest in 2014-2020.

The year 2020 turned out to be the wettest, as evidenced by the quantitative indicators of atmospheric precipitation, which during the period of growth and development of the culture amounted to 211.4 mm, which is 53.4 mm higher than the average long-term indicators.

The period of plant growth and development contains the sum of all temperatures in 2018 – 3205°C, in 2019 – 3315°C, in 2020 – 3270°C. Thus, low cloudiness, an abundance of sunlight, the nature of the distribution of precipitation by seasons of the year and the thermal regime against the background of dry farming create favorable conditions for the growth of sugar sorghum.

The soil on which the research was carried out refers to gray soils formed on loess-like loams and loess and other soil-forming rocks under fescue-wormwood vegetation. The question of the origin of loess cannot yet be considered definitively resolved at the present time. Loess is a yellow-brown loam with particles of physical clay (mostly 35-40%). It contains 6-8% carbonic acid carbonate, but is completely devoid of any other more readily soluble sulfate salts, and especially chlorides. Loesses occur in a thick layer of several tens or even hundreds of meters within the Tien Shan.

Serozems, despite the name, are not gray, but yellowish-brown in color. The thickness of their A horizon is 15-18 cm, the upper one is completely structureless. In terms of mechanical composition, they are predominantly medium loamy, more or less uniform in profile, which indicates the absence of an illuvial horizon, containing 30-40% physical clay in the upper horizon (0-30 cm). Dust fractions of 0.005-0.001 mm in size account for up to 60%. The content of the fraction less than 0.01 mm is 30-32% in the upper layer, in the middle part of the profile, claying is observed, which is expressed in the weighting of the granulometric composition as a result of washing out of colloidal particles [24, 25].

Serozems contain slightly more humus than gray-brown soils, in the upper horizons – within 1-2% – Some varieties may contain more humus. All serozems boil up from the surface. In the extreme south of the republic, carbonic acid of carbonates is contained in gray soils in the amount of 7-8% [26, 27].

The total nitrogen in gray soils is 0.1%, the ratio of carbon to total nitrogen is 6-7. Based on this indicator, it can be concluded that gray soils are richer in nitrogen in comparison with other types of soils, including black soils. Gross phosphorus in gray soils is also slightly higher than in chestnut, brown and gray-brown soils. Usually, total phosphorus is found in the amount of 0.10-0.12%. The sum of the absorbed bases fluctuates within 8-10 mg. eq per 100 g of soil. With an increase in the content of humus, it can sometimes reach 15 meq. The absorbing complex is dominated by the calcium cation, and slightly by the magnesium cation. Sodium is completely absent. The latter indicates that gray soils, in contrast to other soils, are not solonetzic [28, 29].

Serozems are usually classified into ordinary, light and dark. They are located in the foothills as if in the form of special subzones. They occupy the area of loess foothills. Light gray soils lie somewhat further from the mountains, sometimes located along the periphery of the sands. They may have a lighter mechanical composition and contain a slightly lower amount of humus (no more than 1%). Dark serozems, on the contrary, occur along the higher parts of the foothills. The amount of humus in them can be more than 2%, the upper part of the profile is darker in color. Serozems are largely used for irrigated agriculture with cultivation, in addition to conventional crops, of rice, sugar beet, tobacco and cotton. In the zone of gray soils, under irrigation conditions, horticulture and viticulture are widely developed [29-31].

The zone of gray soils is much more favorable for irrigated agriculture, but in comparison with the subzone of light chestnut soils and the zones of brown and light brown soils. First of all, due to the fact that gray soils are not saline and not solonetzic. Among them, solonchaks are rare and solonetzes are almost absent, as a result of which the soil cover is more homogeneous. The soil of the experimental plot is sierozem, low-humus, medium loamy, slightly saline before leaching. In the soil profile of such a soil, 3 genetic horizons are distinguished – humus, carbonate and subsoil, which can be clearly seen from the description of the morphological structure of the soil section, laid on the experimental site before laying the experiment (Table 2).

Indicators of humus in the arable layer of the soil, which is 0-30 cm was 0.98%, which characterizes it as low-humus. In the subsurface layer, its amount decreased by about 1.3 times, and in the soil layer of 30-60 cm it was only 0.63%. The content of total nitrogen in the arable layer of the soil is also low and averaged 0.071%. In the subsurface layer, although its content decreased to 0.05-0.06%, it was not as sharp as the humus content. The gross content of phosphorus in the arable layer of the soil averaged 0.175%, gradually decreasing with depth to 0.114% (Table 3).

Mobile forms of phosphorus (P_2O_5) in soil layers 0-30 and 30-60 cm were 40 and 11 mg/kg of soil. The content of mobile potassium (K_2O) in the plow and sub-plow layers was 424 and 226 mg/kg of soil, respectively. In the underlying soil layers, the content of humus, total nitrogen, and gross phosphorus sharply decreased. According to the granulometric composition, the soil of the experimental plot belongs to medium loams. The content of particles of physical clay in the upper meter layer ranges from 30.20 to 39.36%. In the layer of 91-150 cm, some heaviness of the mechanical composition is noted. The content of particles of physical clay in this layer increases and averages 43.74%. In the underlying layers, the soil-soil is represented by light loam with the content of physical clay particles from 20.04% to 25.64% (Table 4).

Table 2. Morphological description of the soil of the experimental plot

Horizon	Depth, cm	Description of the Horizon
A_1	0-39	arable, humus, dark gray; from 9 cm wet, above dry, in the lower part there are some insignificant remains of half-decayed guzapai, along the entire profile on the dried wall, whitish efflorescence of salts is visible in the form of a light powder, sharply porous, radicular, fine-grained structure.
A_2	39-45	subarable, humus, dark gray, moist, medium loamy, as in the upper layer, separate remains of half-decayed guzapai, rare carbonate efflorescence, dense, nutty-prismatic structure, radicular, finely porous.
B_1	45-70	carbonate, light-yellow in color, moist, with a maximum accumulation of carbonates along the profile in the form of efflorescence with spots and veins, nodules are extremely rare, small in size, passages and excrement of earthworms and insects along the decayed roots bright white efflorescence of salts, homogeneous, finely fractured, fine loamy, homogeneous, compact.
B_2	70-91	sub-carbonate, light-yellow in color, slightly darker than the previous one with a less pronounced density, moist, finely porous, smaller than the previous one, finely fractured, individual carbonate efflorescence in the form of small carbonate veins.
C	91-150	wet, darkish-yellow, finely fissured, loose, very homogeneous, light loamy, whitish efflorescence of salts are visible when the discarded soil lumps dry, finely porous, brownish-rusty blurred spots, insect passages are found in the horizon of 90-110 cm.

Table 3. Agrochemical characteristics of the gray soil of the experimental plot before laying the experiments, 2018

Soil Layer, cm	Humus, %	Gross Forms, %		Mobile Forms, mg/kg	
		Nitrogen	Phosphorus	P_2O_5	K_2O
0-10	1.14	0.078	0.196	58	468
10-20	0.95	0.069	0.176	35	412
20-30	0.85	0.066	0.153	27	392
30-40	0.74	0.040	0.132	17	305
40-50	0.63	0.058	0.114	8	220
50-60	0.52	0.055	0.196	7	163
0-30	0.98	0.071	0.175	40	424
30-60	0.63	0.058	0.114	11	226
0-60	0.80	0.064	0.144	26	325

Table 4. Granulometric composition of the soil of the experimental plot before laying experiments in 2018, %

Soil Layer, cm	Soil Particle Size, mm							
	1-0.25	0.25-0.1	0.1-0.05	0.05-0.01	0.01-0.005	0.005-0.001	< 0.001	Sum < 0.01
0-39	0.24	0.75	1.09	58.56	12.54	17.78	9.04	39.36
39-45	0.25	0.62	1.79	68.16	12.66	15.38	11.14	39.18
45-70	1.27	1.57	37.52	58.70	12.36	10.78	7.80	30.94
70-91	0.17	0.77	1.22	67.64	12.82	9.42	7.96	30.20
91-150	0.61	0.93	2.00	52.72	8.04	30.44	5.26	43.74
150-160	1.72	2.14	1.96	68.54	15.52	8.48	1.64	25.64
160-180	1.74	2.32	6.44	65.14	14.22	8.70	1.44	24.36
180-200	1.47	2.37	2.22	73.90	8.84	7.70	3.50	20.04

The predominant fraction in the granulometric composition of the soil is the coarse dust fraction, the content of which in the upper meter layer ranges from 58.56% to 67.64%, and in the second meter its amount decreases and ranges from 52.72% to 73.90%. The lightening of the granulometric composition with depth causes an intensive inflow of moisture from groundwater at their shallow (1.5-3.5 m) occurrence. The predominance of silty particles and especially coarse dust leads to a loose structure and the creation of exceptionally high capillary porosity.

The specific gravity (density of the solid phase) of the soil, due to the low humus content, varies within narrow limits (2.64-2.72 g/cm^3); which is due to the peculiarities of the mineralogical composition of loess rocks. On average, in a meter layer, the specific gravity of the soil was 2.69 g/cm^3 and in a two-meter layer 2.68 g/cm^3 (Table 5).

The most compacted is the subsoil layer of 30-60 cm, where the average bulk density was 1.45 g/cm^3. In deeper layers (80-200 cm), the density of the soil changes little and amounts to 1.39-1.42 g/cm^3. The arable layer has the smallest volumetric mass (1.34 g/cm^3), which is associated with constant loosening and biogenic processes occurring in this soil layer, while annual planning, washing and irrigation lead to soil compaction. As density increases, soil porosity decreases. This is typical for the subsurface layers of the soil, where the porosity was the lowest. On average, in a layer of 30-60 cm, it was 46.5%. The highest porosity was obtained for the topsoil – 50.1%. In the meter layer, soil porosity decreased to an average of 47.9%.

The maximum hygroscopicity in layers of a two-meter soil thickness varies from 3.6 to 4.9%, and the tendency of its increase is noted along the depth of the soil profile. It depends on the particle size distribution, humus content and the presence of water-soluble salts in the soil.

Table 5. Water-physical properties of the serozem soil of the experimental plot before the laying of experiments in 2018

Soil Layer, cm	Solid Phase Density, g/cm^3	Soil Density, g/cm^3	Porosity, %	Maximum Hygroscopicity, %	Lowest Field Capacity, %
0-10	2.67	1.29	51.7	3.6	20.7
10-20	2.68	1.35	50.0	3.7	20.8
20-30	2.70	1.39	48.5	3.9	20.8
30-40	2.72	1.44	47.0	3.8	20.9
40-50	2.72	1.47	46.2	4.1	21.0
50-60	2.68	1.44	46.3	4.0	21.0
60-70	2.66	1.40	47.4	4.3	21.1
70-80	2.69	1.42	47.2	4.2	21.1
80-90	2.72	1.40	48.5	4.3	21.3
90-100	2.64	1.41	46.6	4.5	21.6
100-120	2.66	1.40	47.4	4.6	–
120-140	2.67	1.41	47.2	4.7	–
140-160	2.67	1.40	47.5	4.7	–
160-180	2.67	1.39	47.9	4.8	–
180-200	2.66	1.39	47.7	4.9	–
0-30	2.68	1.34	50.1	3.7	20.8
30-60	2.71	1.45	46.5	4.0	21.0
0-100	2.69	1.40	47.9	4.0	21.0
100-200	2.67	1.40	47.5	4.7	–
0-200	2.68	1.40	47.7	4.4	–

The smallest moisture capacity significantly depends on the particle size distribution and the standing level of groundwater. For the soil of the experimental plot of average granulometric composition, the limiting field moisture capacity by layers varies within 20.7-21.6% and in the meter layer averaged 21.0% by weight.

Such a limiting field moisture capacity makes it possible to contain up to 210 mm of productive moisture in a meter layer, which can provide a favorable soil water regime for vegetative plants for a long time. Therefore, on serozem soils, which are characterized by the ability to contain a large amount of productive moisture, during the growing season, during irrigation, large irrigation rates with large irrigation intervals can be allowed, which is very important for organizing irrigation under production conditions.

The soil of the experimental plot is highly carbonate (CO_2 = 6.66-9.74%). At the same time, the content of carbonates in the depth of the soil profile increases, so their content in the arable layer is less (CO_2 = 6.66-8.57%) than in deeper soil layers. Thus, the irrigated serozem soil of the experimental plot is typical for the soil cover of the southern region of Kazakhstan, and its water-physical properties, humus content and nutrients are favorable for the cultivation of crops, including sugar sorghum.

In the system of biotechnical methods of sorghum cultivation, an important place should be given to the selection of predecessors. Desirable predecessors for it are those after which the fields are not clogged and with a large supply of unused moisture. According to the conditions of soil formation and climatic characteristics of the study area and the set of crops that occupy large areas in the area, the best predecessors can be considered peas, corn – harvested for green mass, winter wheat.

The biotechnology of cultivation of sugar sorghum was based on the recommendations on resource-saving adaptive technologies of the zonal system of crop cultivation. This is early spring harrowing of the soil in two tracks and two tillages with a KPS-4 cultivator in combination with KAPP-8.8 (a combined surface tillage unit) and tillage with the same soil unit immediately before sowing (the first to a depth of 0.11-0.12 m, the second immediately before sowing at 0.05-0.08 m). Phosphorus fertilizers were applied in autumn during the main tillage, nitrogen fertilizers were applied in full dose before sowing.

In accordance with the experimental scheme, fertilizers were applied in calculated doses. Sowing was carried out taking into account weather conditions: in 2018, sweet sorghum was sown on April 27; in 2019 and 2020 it was produced on April 30. In the dry steppe zone, the optimal condition for the organic development of plants was not only the absolute purity of the experimental plot, but also the absence of weeds. For the growth of full-fledged and friendly seedlings, post-sowing rolling was carried out. When mowing and cutting plants, the time and height were taken into account, which were within 0.5-0.7 m. The grass stand was cut in the field experiment of sugar sorghum in the phase of the beginning of the panicle during three years of the field experiment.

Sugar sorghum is a short-day crop. In relation to heat during seed germination, sorghum belongs to the third group of annual heat-loving crops, which, in addition to it, also includes corn, millet, mogar. Germination of seeds occurs in the presence of a certain amount of moisture and heat in the soil. The optimal temperature in the soil during the sowing period is considered when increasing the temperature regime in the soil to +15°C and choosing the most optimal depth of sowing dry seeds, the technology of pre-sowing tillage is very important. After carrying out the early spring harrowing, which was carried out with tooth harrows in two tracks, the field was not cultivated until weed shoots appeared. Under the conditions of the study area, the beginning of the emergence of mass shoots of weeds is usually noted in late April – early May. Sorghum seeds, starting from the third year of storage, significantly lose their germination capacity, so seeds with a shelf life of 1-2 years should be used for sowing. Seeds of large and medium fractions are distinguished by the highest germination. High sowing qualities are retained by seeds harvested in full ripeness. During the storage of freshly harvested sorghum seeds, a period of their post-harvest ripening passes, during this period the moisture content of the seeds should not exceed 13%.

In all years, sweet sorghum seeds had high sowing qualities when sown. Before sowing, sorghum seeds were subjected to solar heating for 5-7 days in open areas, spreading them in a thin layer (10-15 cm). During the day, the seeds were shoveled several times, which increased the germination energy and germination by 0.5-1.5%, which then transformed into the activation of biochemical processes occurring during their germination.

Production experience and studies have shown that the timing of sowing is very important in the technology of cultivation of sugar sorghum. The most important thing is to ensure a favorable combination of factors such as moisture and temperature of the top (sowing) soil layer. The more favorable the hydrothermal conditions of the period "sowing-seedlings", the better the conditions of the initial phases of growth and development. Sowing was carried out at a temperature of +12 +14°C at a depth of 0.1 m. Such temperatures usually occur in the second half of April. Agrometeorological conditions of the period "sowing-sprouts" determine the completeness of sprouts and the pace of the initial phases of growth and development.

With early sowing, seedlings are very sparse and can be overgrown with weeds. One of the important methods of agricultural technology of sugar sorghum is the correct depth of seed placement during sowing, which depends on the mechanical composition, its humidity and temperature. Sorghum is a small-seeded crop, so deep seeding should not be done, as this reduces field germination and increases the duration of germination. It is very important to choose the right sowing depth in a dry spring. The optimal and reliable depth of seed placement in the conditions of the research area is 6-8 cm. When the topsoil dries up, sowing to a depth of 10 cm can be allowed, but with obligatory rolling with ringed rollers. In the conditions of the arid South of Kazakhstan, the method of sowing and the number of plants per unit area is important. Proper placement of sorghum plants on the area is one of the most important conditions for obtaining guaranteed yields of green mass and sweet sorghum seeds. This issue has not been practically studied for the study area, therefore, in experiments, sorghum was sown at rates of 150, 250 and 350 thousand germinating seeds per hectare with a row spacing of 0.15, 0.45 and 0.70 m.

Seeders SN-16. SKON-4.2 and SCH-6M were used for sowing. For the CH-16 seeder, the outer coulters follow the trail of the tractor, so you should install working bodies for loosening the soil or increase the compression of the coulter springs. To switch from quantitative to weight seeding rate, use the following formula:

$$A = \frac{u \times 0.03 \times d(h \times M)}{1000} \quad (1)$$

where, A – seeding rate, kg/ha; M – weight of 1000 seeds, g; h – quantitative seeding rate, taking into account sowing qualities (purity, germination, sowing suitability).

In the technology of sorghum cultivation, special attention should be paid to the care of crops. After sowing-rolling with ringed rollers – compulsory admission. In sorghum crops, the most dangerous weeds are bristles, which sometimes prevail in the total mass of weeds.

Care of crops consisted in inter-row treatments of wide-row crops – two treatments. The first inter-row treatment was carried out with a clear designation of rows at a plant height of 6-8 cm, cultivation depth – 8-10 cm, the second inter-row treatment was carried out in the booting phase (after 20-25 days), depth – 6-8 cm.

The main factors that determine the field germination of seed, first of all, are the quality of the material used, soil moisture, as well as the thermal regime of the soil in the arable layer. Analyzing the obtained data, there is a certain relationship between the completeness of seedlings and the sowing rate, as well as between biologically active substances and fertilizer doses.

Obtaining friendly and timely shoots, as well as optimal preservation of plant density, is the most important condition for the formation of high yields in sorghum crops, as a result of which the field germination of seeds plays an important role in the formation of future crops. Very often, due to the arid conditions of South Kazakhstan, very slow development of plants is observed. In the experiments, it was found that certain methods of seed treatment Celeste Top, "Gumi 20" and Potassium Humate affect the field germination of sorghum seeds in different ways (Table 6). Treatment with preparations increases field germination up to 16-18%.

Field germination (Table 7) of the variety "Kazakhstanskoe 20" varies depending on the use of biologically active substances, the maximum field germination is observed when using Potassium Humate – 77%.

Then using "Gumi 20" – 71.5% and Celeste Top – 63.2%, which is significantly higher than 10-15% of the control (without treatment).

Field germination (Table 8) of the variety "Kazakhstanskoe 20" varies depending on the use of various doses of nitrogen-phosphorus fertilizers. The maximum field germination is noted when using nitrogen-phosphorus fertilizers at a dose of N_{90} P_{90} – 74.2%, then using nitrogen-phosphorus fertilizers at a dose of N_{60} P_{60} – 66% and nitrogen-phosphorus fertilizers at a dose of N_{30} P_{30} – 60.5%. These percentages markedly surpass the 8-12% germination rate observed in the control group, which did not receive any fertilization.

Table 6. Seed quality of sweet sorghum

Varieties	Varietal Purity, %	Germination, %	Weight 1000 Seeds, g	Seeding but Seeds for 1 m^2/piece	Ascended pcs/m^2	Field Germination	Treated with Prorastin	
							Ascended pcs/m^2	Field Germination, %
"Kazakhstan 20"	99.2	82.5	24.1	30	20	66	23	74

Table 7. Field germination of sweet sorghum seeds depending on the treatment with biologically active substances (average for 2018-2020)

Varieties	Varietal Purity, %	Germination, %	Weight 1000 Seeds, g	Seeding but Seeds for 1 m^2/piece	Ascended pcs/m^2	Field Germination, %
			Control (without processing)			
"Kazakhstan 20"	99.2	82.5	24.1	30	21	57.7
			Celeste Top			
"Kazakhstan 20"	99.2	82.5	24.1	30	23	63.2
			"Tires 20"			
"Kazakhstan 20"	99.2	82.5	24.1	30	26	71.5
			Humate Potassium			
"Kazakhstan 20"	99.2	82.5	24.1	30	28	77.0

Table 8. Field germination of sweet sorghum seeds depending on fertilizer doses (average for 2018-2020)

Varieties	Varietal Purity, %	Germination, %	Weight 1000 Seeds, g	Seeding but Seeds for 1 m^2/piece	Ascended pcs/m^2	Field Germination, %
			Control (without processing)			
"Kazakhstan 20"	99.2	82.5	24.1	30	21	57.7
			N_{30} P_{30}			
"Kazakhstan 20"	99.2	82.5	24.1	30	22	60.5
			N_{60} P_{60}			
"Kazakhstan 20"	99.2	82.5	24.1	30	24	66.0
			N_{90} P_{90}			
"Kazakhstan 20"	99.2	82.5	24.1	30	27	74.2

Table 9. Yield of green mass of sweet sorghum, t/ha (average 2018-2020)

Factor A – Doses of Fertilizers, kg/ha a.i.	Factor B - Biologically Active Substances	Yield, t/ha cf. 2018-2020	Deviation (+/-), t/ha	
			Factor A	Factor B
N_{30} P_{30}	-	11.7	-	-
	Celeste Top	13.4	-	+1.7
	Gumi 20	13.7	-	+2.0
	Humate Potassium	14.2	-	+2.5
N_{60} P_{60}	-	13.2	+1.5	-
	Celeste Top	14.8	+1.4	+1.6
	Gumi 20	15.4	+1.7	+2.2
	Humate Potassium	15.9	+1.7	+2.7
N_{90} P_{90}	-	13.9	+2.2	-
	Celeste Top	18.0	+4.6	+4.1
	Gumi 20	18.2	+4.5	+4.3
	Humate Potassium	19.3	+5.1	+5.4

Notes: Factor A – mineral nutrition background; Factor B – biologically active seed treatment.

From the Table 9 of the yield of sweet sorghum green mass, it can be seen that the yield increases depending on the application of doses of nitrogen-phosphorus fertilizers and biologically active substances. Under the action of a dose of fertilizers N_{30} P_{30} and biologically active substances, the average yield from 2018-2020 was 13.4 t/ha with Celeste Top, with Gumi 20-13.7 t/ha and Potassium Humate – 14.2 t/ha.

Under the action of a dose of N_{60} P_{60} fertilizers and biologically active substances, the average yield from 2018-2020 was 14.8 t/ha with Celeste Top, with Gumi 20-15.4 t/ha and Potassium Humate – 15.9 t/ha. Under the action of a dose of N_{90} P_{90} fertilizers and growth stimulants, the average yield from 2018-2020 was 18.0 t/ha with Celeste Top, with Gumi 20-18.2 t/ha and a Humate Potassium – 19.3 t/ha.

The effect of factor B (biologically active substances) in the formation of green mass in sweet sorghum increases with the application of a dose of fertilizer N_{60} P_{60} and N_{90} P_{90} +1.6 +4.1 t/ha with Celeste Top, with Gumi 20 – +2.2 – +4.3 t/ha and Potassium Humate – +2.7 +5.4 t/ha on average over three years.

The effect of factor A (fertilizer doses) with N_{60} P_{60} and N_{90} P_{90} in control was +1.5 +2.2 t/ha, in the experiment from +1.4 to +5.1 t/ha, depending on biologically active substances and doses of fertilizer. Table 10 shows the Smallest significant difference for 5% significance level (HCP_{05}) parameter by the years of experiment.

Table 10. Smallest significant differences levels for factors A and B by the years

HCP_{05} for	Years of the Experiment		
	2018	2019	2020
Factors A, t/ha	0.58	0.49	0.36
Factors B, t/ha	0.66	0.56	0.42
Interaction factors AB, t/ha	1.15	0.97	0.72

Notes: HCP_{05} – smallest significant difference at 5% probability level.

The results obtained in the experimental field experience from 2018-2020, showed that the complex use of biologically active substances and nitrogen-phosphorus fertilizers had a direct effect in increasing the nutritional value and productivity of sweet sorghum and green mass in general. A comparative evaluation of the economic efficiency analysis showed that most of the economic indicators of sugar sorghum production depended, first of all, on current market prices, but also on material resources and the level of products obtained. The first indicator largely depended on the socio-economic factor.

The second depended on the genetic characteristics and the level of adaptability of the culture to specific soil and climatic conditions, but also on the use of an innovative element of the technology for the production of sorghum crops on gray soils against the background of the complex use of biologically active substances and mineral fertilizers.

Thus, in solving the targeted problem, we have studied and identified modern biotechnological methods and substantiated ways to solve the problem of increasing the productivity of sweet sorghum seeds grown in the southern region of Kazakhstan with biologically active substances. The dependence of the yield on biologically active substances and the background of application and mineral nutrition has been established; the most rational doses of the use of biologically active substances and nitrogen-phosphorus fertilizers on the gray earth soil of South Kazakhstan were determined.

The increased nutritional value and productivity resulting from the seed treatments and fertilizers can be attributed to several key biological processes. The biologically active substances likely promoted growth by increasing root development, photosynthesis, and/or beneficial rhizosphere microorganisms. The added nitrogen and phosphorus enhanced nutrition to support increased plant growth and maturation. The comparative productivity of sweet sorghum varieties with various combinations of biologically active substances and fertilizers was revealed, as well as to give a qualitative assessment of green mass.

5. DISCUSSION

5.1 Factors influencing the production of sugar sorghum

In recent years in Kazakhstan, the implementation of food security policy increased substantially. At the same time, one of the most important agricultural crops is sugar sorghum, which occupies the fifth position among the most important grain crops in the world. This culture is characterized by a high production potential and the production of a high level of biomass, as well as a powerful source of trace elements and energy. Sugar sorghum as a grain crop plays the role of fodder in the dairy and animal husbandry sector, but only during clearly defined seasons.

However, in some cases, there are certain reasons that determine the low quality and low production of fodder sugar sorghum in the territory of the Republic of Kazakhstan, namely: the use of methods that do not correspond to the characteristics of crops, the selection of inappropriate varieties, improper nutrition, the wrong stage of harvesting, the presence of hydrocyanic acid content acids and low protein content.

However, despite this research on the suitability of sugar sorghum to ensure food security has shown that this crop is less vulnerable to climatic variables, which allows for maintaining its high productivity. In-depth research is necessary to draw accurate conclusions about the prospects of sorghum in sustainable crop modeling for food security.

The present study, as well as the research of Farhaoui et al. [32], acknowledges the significance of combating soil pathogens that reduce crop productivity. Scientists from Morocco Farhaoui et al. [32] are investigating the spread of the soil pathogen Rhizoctonia solani AG-2-2, which significantly reduces the productivity of such a technical crop as sugar beet. The authors note that special agents, including synthetic fungicides, are used to combat this pathogen. However, in accordance with modern ecological trends, to increase the yield of such crops, in particular, sugar beet, special biological means of plant protection are used, which are an alternative to chemical fungicides and provide a control system for the number of plant diseases. Scientists have investigated the nature and properties of antagonistic bacteria that could be used for biological control against this pathogen.

A series of tests in greenhouse conditions allowed for obtaining data indicating that sugar beet seeds soaked in an individual bacterial isolate significantly reduced the dieback of rhizoctoniosis. In addition, seedlings grown from soaked seeds showed a significant increase in estimated growth parameters. Similarly, the selected bacterial isolates showed antagonistic effects on this pathogen and significantly reduced the severity of RCR.

To protect plants from fungi of the Rhizoctonia type and increase the yield of sugar beets, as well as other crops, in particular sugar sorghum, it is proposed to use special biological fertilizers B. velezensis SS_2, which are extremely promising for sustainable agriculture [32, 33].

Authors support the importance of the research directions of scientists from Morocco regarding special biological methods of sugar beet protection using bacterial isolates that minimize possible fungal damage and provide protection from various external factors. However, other methods of preventing the negative influence of external factors at the initial stages of sowing were considered in our own article. It is about choosing the right depth of placement of hard dry seeds. At the same time, the period of the year, mechanical composition, moisture of the upper soil layer, as well as the temperature regime are taken into account. Correct technologies chosen during the sowing campaign of specific crops provide favorable conditions for protection from wild grass vegetation and obtaining high yields of green mass and sugar sorghum grains.

5.2 Fertilizers and crop yield

Our research aligns with that of Ma et al. [34] and Carpanez et al. [35], who emphasize the use of controlled-release fertilizers and organic-mineral fertilizers respectively. Ma et al. [34] from China observed that agricultural land often has a low retention of fertilizers, a consequence of soil porosity and irrigation practices. This leads to significant nutrient losses from the soil, with these nutrients frequently ending up in groundwater and surface water, contributing to issues such as denitrification, evaporation, surface runoff, and leaching. The researchers specifically addressed urea fertilizer, which, while enhancing productivity, can also reduce soil fertility over time. To tackle this issue, the researchers investigated the development and implementation of controlled-release or slow-release fertilizers. They discovered that nitrogen fertilizers with controlled release (Cm-CRNF) based on chitosan microspheres had the highest similarity with seeds, at 96% [36].

Furthermore, Cm-CRNF treatment increased several plant growth metrics, including net photosynthetic rate, stomatal conductance, transpiration rate, and others. It also raised the levels of total sugars, proteins, flavonoids, and polyphenols in plants. Cm-CRNF shows promise for plant protection, disease minimization, and the enhancement of the physical and chemical parameters of crop growth [34, 37, 38].

The findings of Ma et al. [34] highlight the importance of applying the appropriate amount of fertilizers and ensuring their efficient utilization for crops that have high yield and productivity requirements. Managing the loss of nutrients, especially during harvest, is essential. The fertilizer used should be biologically compatible and economically viable to protect the environment. Notably, nitrogen-phosphorus fertilizers offer high potential and facilitate the necessary gradual release of macro- and microelements for the growth of industrial crops.

Scientists from Brazil Carpanez et al. [35] are investigating the peculiarities of the production of organic-mineral fertilizers to increase the productivity of sugar cane, sugar beet and sugar-bearing crops. The use of by-products in the process of the final stage of sugar production can be an alternative method of increasing the effectiveness and demand of organic-mineral fertilizers.

That is, the reuse of “vinasse” substances will be applied taking into account-controlled practices and less impact on the environment. As a result, improved organo-mineral fertilizers will be characterized by ease of transportation and processing, low variability of composition and reduction of risks of pollution of natural resources, in particular land and water. and water resources [39-42]. The presence of additional nutrients in the m, in addition to those already present in the composition of “vinasse”, will depend on the type of crop and needs. This study supports the use of by-products, such as “vinasse,” in the production of organic-mineral fertilizers, highlighting the benefits of the circular economy in agricultural activities. It is also proposed the usage of biologically active substances for providing crops with essential nutrients and stimulating growth.

In contrast to scientists from Brazil, authors of the article considered the possibility of using biologically active substances that provide different types of culture, in particular row crops, with technical special forms of nitrogen, phosphorus and potassium is considered in the present research. At the same time, their growth and development are stimulated, the yield level increases, and the quality of agricultural products improves.

Researchers from Pakistan, Murad et al. [43], have explored the detrimental effects of excessive use of synthetic fertilizers, which are incompatible with organic agriculture and can lead to significant ecological and economic losses. Synthetic fertilizers pose risks of soil, surface water, and groundwater pollution, and impact the environment at large [44]. The authors have delved into the characteristics and composition of nanofertilizers, which show significant promise for enhancing soil fertility and producing high-quality agricultural products with minimal ecological impact. Nanofertilizers are marked by their submicroscopic dimensions, large surface area to volume ratio, and increased mobility, which ensures plant access to nutrients and boosts yield levels. These attributes lead to the consideration of nanofertilizers as part of a "smart nutrient system" [35, 45].

The authors concur with the Pakistani scientists on the significance of incorporating nanofertilizers into the agro-ecological system to support the production of environmentally clean agricultural products. However, there remain challenges to their widespread adoption, as the intricacies of nutrient transport in soil layers with varying physical and chemical properties, moisture levels, and other agroecological factors are not yet fully understood.

Despite the challenges, our research confirms the potential of sugar sorghum as a viable crop for ensuring food security in Kazakhstan, due to its resilience against climatic variables. In conjunction with the findings from the studies cited, our research highlights the need for a holistic approach to agricultural practices. This includes the appropriate selection of crops and cultivation methods, the use of biological agents and fertilizers that enhance crop productivity without harming the environment, and the adoption of practices that align with the principles of a circular economy.

A factorial field study was the most appropriate design to systematically evaluate the interactions between seed treatments and fertilizer doses under real-world conditions. Conducting the trials over multiple seasons provided replication to account for environmental variability. Although, the results may be specific to the soil and climatic conditions in southern Kazakhstan and should be validated in other arid regions. Additional mechanisms of enhanced nutrition/productivity beyond those proposed should be explored.

6. CONCLUSIONS

This study demonstrated the value of sorghum as a resilient dryland crop and the potential to boost yields through integrated crop management. The seed inoculants Celeste Top, Gumi 20, and Potassium Humate increased sorghum productivity across fertilizer treatments, with the greatest yields resulting from combined use of Potassium Humate and high N and P fertilization.

Under the action of a dose of $N_{60}P_{60}$ and $N_{90}P_{90}$ fertilizers and a biologically active substance, the average yield from 2018-2020 was 14.8-18.0 t/ha with Celeste Top, with Gumi 20 – 15.4-18.2 t/ha and Potassium Humate – 15.9-19.3 t/ha. Under the action of a dose of N_{60} P_{60} and N_{90} P_{90} fertilizers and a biologically active substance, the average yield from 2018-2020 was 14.8-18.0 t/ha with Celeste Top, with Gumi 20 – 15.4-18.2 t/ha and Potassium Humate – 15.9-19.3 t/ha. The effect of growth stimulants without the use of fertilizers amounted to an increase in the yield of green mass from 5-8%. With the combined use of mineral fertilizers and biologically active substances, the yield of green mass in sweet sorghum averaged from 10-12%. Preparations Celeste Top, “Gumi 20” and Potassium Humate help to increase the nutrient absorption coefficient, which allows to reduce the dose of mineral fertilizers.

In contrast to previous studies showing benefits from inoculants alone, results of this study demonstrate an additive effect of combining optimized seed treatments with moderate to high fertilizer doses. Further research should explore the long-term impacts of these practices on soil quality and test their effectiveness for other arid-tolerant crops. While promising, the integrated management approaches require validation across diverse environments and soil conditions before broad recommendations can be made. With climate change expanding global arid zones, evidence-based agronomic strategies like these will be crucial for adapting cropping systems to new realities of water scarcity. This study provides an initial basis for tailoring integrated crop management to boost yields and resilience of sorghum and other dryland cereals.

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