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GRAIN SORGHUM PRODUCTIVITY RESPONSE TO SEEDING RATES AND MINERAL FERTILIZERS IN SOUTH AND SOUTHEAST KAZAKHSTAN

I.A. TAUTENOV¹, G.T. KUNYPIYAEVA^{2*}, S.ZH. BEKZHANOV¹, L.A. TOKHETOVA¹, and
 R.K. ZHAPAYEV²

¹Korkyt Ata Kyzylorda University, Kyzylorda, Kazakhstan

²Kazakh Scientific Research Institute of Agriculture and Crop Production, Almaty, Kazakhstan

*Corresponding author's email: kunypiyaeva_gulya@mail.ru

Email addresses of co-authors: ibadulla_t@mail.ru, ser.bekzhanov@mail.ru, lauramarat_777@mail.ru, r.zhapayev@mail.ru

SUMMARY

This study aimed to assess the impact of mineral fertilizer's doses, seeding rates, sowing dates, and cultivation technologies (conventional and no-till) on the yield of grain sorghum (*Sorghum bicolor* L.). The research took place in 2024–2025 under moisture-deficit conditions of the Almaty and Kyzylorda regions, Kazakhstan. The mineral nutrition established became a determining factor in the formation of grain yield in sorghum. By applying mineral fertilizers at the rate of N₁₀₀P₆₀ in the Almaty Region, the grain yield reached 6.17 t/ha, while without fertilizers, it did not exceed 2.3–3.97 t/ha, providing an increase of 2.2 t/ha. In the Kyzylorda Region, by applying mineral fertilizer (N₁₂₀P₆₀), the grain yield reached 4.18 t/ha, while without fertilizers, it only reached 1.81–2.75 t/ha, providing an increase of 1.43 t/ha. The optimal seeding rate (180,000 plants/ha) showed the highest productivity, while the increased planting density (300,000 plants/ha) obtained a 0.3–0.6 t/ha decrease in grain yield. Sowing time also has a significant impact, and the maximum yield (3.92–4.18 t/ha) occurred when sowing in the third 10-day period of May, depending on the nutrient levels.

Keywords: Sorghum (*S. bicolor* L.), climate change, drought stress conditions, mineral fertilizers, seeding rate, sowing time, grain yield

Key findings: The establishment of mineral nutrition, along with optimum seeding rate and sowing time, has been successful as a key factor in determining yield in grain sorghum (*S. bicolor* L.). The proven agrotechnology can significantly improve grain sorghum productivity under moisture-deficit conditions.

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INTRODUCTION

Climate change and extreme weather conditions have an increased pressure on agriculture, especially in regions where farming community earning is directly dependent on natural conditions. Under such circumstances, the development of climate-resilient crop cultivars, especially to abiotic stress conditions, is particularly important. Sorghum is one of such crops, characterized by high drought tolerance and ability to produce optimum grain yield under adverse climatic conditions (Mekonen and Berlie, 2021).

In this regard, sorghum (*Sorghum bicolor* [L.] Moench) occupies a leading position among the world's cereal crops, after wheat, corn, rice, and barley (Luna *et al.*, 2018). Sorghum is a C4 crop that is highly adaptable to various soil and climatic conditions, including arid and hot regions, and can be grown as an annual and short-stemmed plant (Shukla *et al.*, 2017). Moreover, in the face of increasing climate change, sorghum remains a key crop for ensuring agricultural sustainability in arid regions.

According to the United States Department of Agriculture (USDA) data, global sorghum production in 2024/25 reached approximately 63.68 million tons, reflecting the growing importance of sorghum as a drought-tolerant crop under climate change conditions (USDA, 2024–2025). Such an increase details the stabilization and gradual increase in sorghum production. The sorghum average grain yield remains relatively low and varies between 1.4–1.6 t/ha globally. However, under intensive farming conditions, it can reach 3–5 t/ha and even more. In countries with highly developed agriculture, the sorghum grain yield even rose to 6–12 t/ha.

In 2025, the sorghum crop area in Kazakhstan amounted to over 19,000 hectares, including about 875 hectares in the Almaty Region and 215 hectares in the Kyzylorda Region. The gross grain yield amounted to over 17,600 tons, including 1,520 tons in the Almaty Region and 426 tons in the Kyzylorda Region (KAZSTAT, 2025). In Kazakhstan, the arid zones, especially the southern and southeastern regions, have become the main

regions for sorghum cultivation. The crop is notable for its ability to withstand prolonged periods of drought, effectively utilize summer precipitation, and quickly restore growth after unfavorable conditions. Several studies conducted between 2011 and 2017 have identified promising sorghum genotypes, along with the effects of fertilizers on yield and sugar accumulation, and developed the agro-technology for their cultivation under irrigated conditions (Zhapayev *et al.*, 2015; Zhapayev *et al.*, 2022).

Sorghum can grow effectively on low-yielding and saline soils, including in crop rotation with rice, helping to stabilize the salt regime of soils (Tautenov *et al.*, 2016a, 2016b; Tautenov *et al.*, 2025). Thus, to further expand the sorghum crop, the introduction of resource-saving technologies and improved cultivation systems can play an essential role in adapting agriculture to climate change in Kazakhstan. The presented study aimed to examine the effects of mineral fertilizer application, seeding rates, and sowing times on sorghum, depending on soil nutrient availability in the southern and southeastern regions of Kazakhstan.

MATERIALS AND METHODS

Experimental design

The promising research regarding the effects of mineral fertilizers, seeding rates, sowing times, and cultivation technologies (conventional and no-till) on the sorghum (*Sorghum bicolor* L.) commenced in 2024 until 2025 at the Kazakh Research Institute of Agriculture and Plant Growing, Almaty, Kazakhstan. Field studies conducted were part of a rice crop rotation at the Y. Zhakhayev Kazakh Research Institute of Rice Growing. The field experiment, observations, and grain sorghum yield accounting, as well as calculations of the LSD and the share of participation of each factor, continued in accordance with the method of Dospekhov (1985). The field experiments conducted were in triplicate, with plots systematically placed.

The study based on the agrochemical properties of the experimental plot revealed low total humus content (1.47%–1.26%) and a decrease in its content down the profile. The soil pH of the arable layer was high, with a pH of 8.4. Low organic matter content in the soil results in low levels of mobile and exchangeable forms of plant nutrients, which easily decompose, float, and form crust on the surface. Thus, the content of readily available nitrogen does not exceed 52.5 mg/kg of soil, available phosphorus is 66 mg/kg of soil, and exchangeable potassium is 260 mg/kg of soil in the arable layer of this area.

Meteorological conditions

The analysis of air temperatures in the Almaty Region, Kazakhstan, showed both crop seasons (2024 and 2025) exceeded the long-term average. The average annual temperature in 2024 was 10.9 °C; in 2025, it was 12.8 °C, which were 1.3 °C and 3.2 °C higher than the long-term norm, respectively (Table 1). The most significant deviations were evident in the winter and spring periods: in January, the temperature was -1.2 °C and -2.6 °C compared with the norm of -5.9 °C, and in March, it was 5.4 °C and 6.2 °C, compared with 2.8 °C. The summer months also showed features of higher temperatures, especially in July (25.0 °C–27.7 °C), than the norm (23.7 °C). Precipitation had an uneven distribution. In 2024, the annual total precipitation was

770.1 mm, exceeding the long-term average by 94.5 mm, with the maximum in March (135.5 mm) and May (121.2 mm). In contrast, 2025 emerged with a significant precipitation deficit of only 450.8 mm, 224.8 mm below the average. The summer months were particularly dry: July saw only 9.6 mm of precipitation compared with the average of 56.9 mm, and June appeared with 17.1 mm versus an average of 59.9 mm.

In the Almaty Region, the meteorological conditions in 2024 were remarkable, with increased humidity and relatively warm temperatures, while 2025 had characteristics of higher temperatures and a significant precipitation deficit, especially during the growing seasons. These contrasting weather conditions have a significant impact on the growth, development, and productivity of various crops.

The Kyzylorda Region location is to the east of the Aral Sea in the lower reaches of the Syr Darya River. The region's climate had the quality of being sharply continental. The month of June revealed a very hot weather; the average monthly air temperature was 29.3 °C with the norm being 26.7 °C (Table 2). Heavy precipitation in May (43 mm) contributed a slight increase in soil moisture in the experimental plot. Subsequently, the precipitation during the growing season was nonsignificant and did not affect the growth of grain sorghum.

Table 1. Weather conditions for 2024 and 2025 at the Almalybak weather station.

Month	Average air temperature per month (°C)			Total precipitation per month (mm)		
	2024	2025	Long-term	2024	2025	Long-term
January	-1.2	-2.6	-5.9	38.8	33.6	41.3
February	-4.0	-1.5	-5.3	43.6	17.1	44.6
March	5.4	6.2	2.8	135.5	76.8	64.7
April	12.8	15.7	10.9	111.3	57.2	110.6
May	17.6	20.8	16.3	121.2	80.4	98.0
June	24.5	25.6	21.2	19.7	17.1	59.9
July	25.0	27.7	23.7	85.2	9.6	56.9
August	25.9	24.9	22.9	25.1	17.9	34.8
September	15.1	18.9	20.9	14.3	47.0	25.9
October	12.0	11.0	10.3	71.8	10.9	43.6
November	1.5	5.7	2.0	58.1	31.5	47.0
December	-3.3	0.7	-4.4	45.5	51.7	46.1
Average	10.9	12.8	9.6	770.1	450.8	675.6

Table 2. Meteorological data for 2024–2025 at the Kyzylorda weather station.

Months	Air temperature (°C)			Atmospheric precipitation (mm)		
	2024	2025	Wed	2024	2025	Wed
January	-4.1	-3.2	-6.8	19	16	18
February	-2.8	-1.8	-4.5	4	24	14
March	5.4	6.5	4.0	54	19	15
April	17.6	18.6	14.0	3	7	20
May	20.6	24.9	21.1	43	2	19
June	29.3	28.3	26.7	2	6	8
July	28.0	30.3	28.3	6	0	5
August	26.7	26.9	26.2	4	3	3
September	18.4	19.3	19.0	1	7	3
October	11.5	11.5	10.6	13	0	9
November	3.5	4.8	1.7	16	3	16
December	-4.0	-2.0	-4.9	13	18	16
Average	12.5	13.3	11.3	178	105	146

Meteorological conditions revealed that 2025 was abnormally hot, and characteristically, the average monthly air temperature for all 12 months was higher than the long-term average. In May, the average monthly air temperature was 24.9 °C, 3.8 °C above normal. Average daily air temperatures in June and July were higher than long-term values by 1.6 °C and 2.0 °C, respectively. In August and September, these figures were at the long-term average level. During the growing season from May 20 to August 31, the sum of active temperatures (above 10° C) was 2911 °C, which is 103 °C higher than the previous year. Light precipitation in September (10 mm) did not interfere with the harvesting of grain sorghum.

Sorghum agricultural technology

In the Almaty Region before sowing, the sorghum seeds received treatments with Dividend Star against smut diseases at the rate of 0.5 l/t 1–2 days before sowing. Ammophos application to the sorghum was at the rate of 60 kg active ingredient (a.i.) per hectare. Field trials had schedules during the optimal sowing period of May 1–5. Sowing of grain sorghum cultivars Tagamdyk 2017 and ICSV 112 used a VenceTudo-7500 direct seeding drill (Brazil) with the simultaneous application of 60 kg a.i. of Ammophos to the rows. The sorghum crops' treatment with herbicide 'Ballerina' continued at the end of the tillering phase at the rate of

0.4 l/ha against weeds. Fertilizing with ammonium nitrate in the booting phase was at the rates of 60 and 100 kg a.i. per hectare.

In the Kyzylorda Region (Kazakhstan Research Institute of Rice Growing), rice was the predecessor crop to grain sorghum through both years of the study. The agricultural practices for the rice field experiment followed the recommendations for spring fieldwork for rice crop rotation. Sowing primarily transpired in May, when soil temperature consistently warmed to 18 °C–20 °C at the seed placement depth. According to mineral fertilizer application, nitrogen fertilizers' application comprised urea (carbamide) with a nitrogen content of 46% and phosphorus fertilizers applied as double granulated superphosphate (with a phosphorus content of 40%).

RESULTS AND DISCUSSION

Productivity of grain sorghum

Water scarcity may affect more than two billion people and could become a more serious problem in urban areas in the future (Nellemann *et al.*, 2009). In this regard, grain sorghum (*S. bicolor* L.), being a drought-tolerant crop, could become adaptable to various environmental conditions, especially under water-deficit conditions, as it is very useful in regions with uneven rainfall distribution and high air temperature (Almeida-

Filho *et al.*, 2014; Griebel *et al.*, 2019). Numerous studies have demonstrated the highest efficiency of mineral fertilizer application in various crops. With the highest green mass yield, the yield increase was successful with nitrogen application at the rate of 90 kg/ha (Rakhimbekov and Karakalchev, 1991).

In traditional seeding without fertilizer application, the grain yield considerably rose with an enhancement in the seeding rate in both sorghum cultivars, i.e., Tagamdyk 2017 (3.14–3.6 t/ha) and ICSV-112 (3.87–3.97 t/ha) (Table 3). The application of mineral fertilizers contributed a significant increase in grain yield. With the $N_{60}P_{60}$ dose, the grain yield elevated to 3.57–4.66 t/ha in the cultivar Tagamdyk 2017 and 4.01–5.28 t/ha in the cultivar ICSV-112. However, the highest grain yield obtained with the dose $N_{100}P_{60}$, where the grain yield reached 4.07–4.73 and 4.86–6.17 t/ha, respectively, with the maximum yield of 6.17 t/ha observed was in the cultivar ICSV 112 at the seeding rate of 420,000 plants/ha. In the evaluation of maize hybrids, the row spacing of 45 cm and the number of plant populations of 300,000 plants/ha were the most ideal combination to achieve the highest grain yield (Szemerits *et al.*, 2024). Based on the results, 600,000 plants per ha had attained the highest seed yield and biological yield and the optimum one hundred seed weight (Soleymani *et al.*, 2012).

With direct seeding without fertilizers, the grain yield was lower than the traditional technology, which amounted to 2.3–3.17 t/ha (Tagamdyk 2017) and 2.82–3.54 t/ha (ICSV 112). The mineral fertilizers' application also had a positive effect; with a dose of $N_{60}P_{60}$, the grain yield increased to 3.24–4.16 and 3.53–4.33 t/ha, respectively (Table 3). With an increase in the fertilizer dose to $N_{100}P_{60}$, a further increase in grain yield reached 4.45–4.72 t/ha in the sorghum cultivar Tagamdyk 2017 and 4.28–5.05 t/ha in the cultivar ICSV 112. The grain sorghum cultivated with traditional plowing produced the grain yield of 1.51 t/ha, while no-till recorded with the grain yield of 1.44 t/ha (Melnichuk *et al.*, 2019).

The application of mineral fertilizers significantly increased the sorghum grain yield regardless of the sowing methods, with the greatest effect achieved at the dose of $N_{100}P_{60}$. Conventional seeding generally provided higher yields than direct seeding; however, with optimal fertilizer application, the variations between the cultivation technologies become smaller. Furthermore, an increased seeding rate of 420,000 plants/ha in most cases promotes yield growth, especially with adequate mineral nutrition. Fertilizer applications up to 138/69 kg N/P_2O_5 ha⁻¹ emerged to be the fertilizer rate leading to the highest grain yield in grain sorghum (Mrubata *et al.*, 2024). Additionally, the highest grain yield appeared with the plant population of 600,000 plants per hectare in sorghum (Melnichuk *et al.*, 2019).

In the Kyzylorda Region during 2024 and 2025, the study established that with no fertilizers, the grain yield enhanced with late sowing dates; however, grain yield decreased with an enhancement in the seeding rate. Thus, during the first sowing date, the grain yield was 1.81 to 2.12 t/ha; during the second date, 2.01 to 2.36 t/ha, while during the third date, the grain yield was 2.28 to 2.56 t/ha (Table 4). By sowing sorghum seeds in the last 10 days of May (20 °C–22 °C of warming in the soil at a seeding depth), the highest productivity (3.92 t/ha) resulted in sorghum (Vasilchenko *et al.*, 2022).

Moreover, the maximum yield values obtained had a minimum seeding rate of 180,000 plants/ha. Grain sorghum productivity gained robust influence from agronomic factors, such as plant density and mineral nutrition. The application of mineral fertilizers ($N_{60}P_{60}$) contributed a significant increase in grain yield in all the variants of sorghum. During the first sowing period, grain yield was 2.54 to 2.85 t/ha; during the second period, 2.77 to 3.07 t/ha, while in the third sowing period, the grain yield was 2.84 to 3.33 t/ha (Table 4). Similar to the control, a slight decrease in grain yield was prominent with an increase in the seeding rate. Past studies revealed optimal seeding rates (120,000 to

Table 3. Grain yield of grain sorghum based on seeding rates and nitrogen fertilizer rates under irrigated conditions in the Almaty Region (average for 2024–2025).

Fertilizer doses a.i. (kg ha ⁻¹)	Tagamdyk 2017 (st)			ICSV 112		
	seeding rate (000 plants ha ⁻¹)			seeding rate (000 plants ha ⁻¹)		
	150	280	420	150	280	420
Traditional sowing						
Without fertilizers	3.14	3.43	3.60	3.87	3.97	3.96
N ₆₀ P ₆₀	3.57	4.28	4.66	4.01	4.19	5.28
N ₁₀₀ P ₆₀	4.07	4.57	4.73	4.86	4.27	6.17
Direct seeding						
Without fertilizers	2.30	3.17	3.06	2.82	3.54	3.24
N ₆₀ P ₆₀	3.24	3.94	4.16	3.53	4.15	4.33
N ₁₀₀ P ₆₀	4.45	4.08	4.72	4.28	3.81	5.05
LSD _{0.05}	A = B = C = 1.104; D = 0.9014; AB = AC = BC = 1.9122; AD = BD = CD = 1.5613; ABCD = 4.6840					

Table 4. Grain yield of grain sorghum based on seeding rates and nitrogen fertilizer rates under irrigated conditions in the Kyzylorda Region for 2024.

Fertilizer doses a.i. (kg ha ⁻¹)	1 term (01-10.05)			2nd term (11-20.05)			3rd term (May 21–31)		
	Seeding rate (000 plants ha ⁻¹)			Seeding rate (000 plants ha ⁻¹)			Seeding rate (000 plants ha ⁻¹)		
	180	240	300	180	240	300	180	240	300
Without fertilizers	2.12	1.90	1.81	2.36	2.22	2.01	2.56	2.35	2.28
N ₆₀ P ₆₀	2.85	2.61	2.54	3.07	2.95	2.77	3.33	3.09	2.84
N ₁₂₀ P ₆₀	3.17	2.88	2.73	3.49	3.23	3.00	3.78	3.36	3.21
LSD _{0.05}	A = B = C = 0.0471; AB = AC = BC = 0.0815; ABC = 0.1412								

180,000 plants ha⁻¹) under semi-arid conditions, while the excessive plant density leads to increased interplant competition and reduced panicle size and grain weight (Maman *et al.*, 2003; Baumhardt and Howell, 2006).

The highest grain yield appeared with the higher dose of fertilizer (N₁₂₀P₆₀). This variant yielded grain yields up to 3.17 t/ha during the first sowing period, 3.49 t/ha in the second sowing, and up to 3.78 t/ha during the third sowing (Table 4). The maximum grain yield (3.78 t/ha) recorded emerged during the third sowing period with an enhanced seeding rate (180,000 plants/ha). The sorghum contribution as a forage crop has significantly enhanced the cost of production; therefore, the selection criteria of breeding programs may include biomass production and quality, as well as grain yield (Hassan *et al.*, 2015).

During 2025, the studies confirmed increased mineral fertilizer rates considerably enhanced grain yield, with the most favorable conditions occurring during the third sowing

period (May 21–31) along with a moderate seeding rate (180,000 plants/ha) (Table 5). Increased plant density (300,000 plants/ha) in all variants was in parallel with a decrease in grain yield, necessitating to optimizing the seeding rate based on mineral fertilizer nutrition and sowing time. Over two years, the average grain yield was at par with the seeding rates of 210,000 (7.98 t/ha) and 300,000 seeds/ha (8.29 t/ha), differing only by 0.31 t/ha (Szemerits *et al.*, 2025). Excessive plant density often leads to increased competition for moisture and nutrients, resulting in a lower grain yield (Li *et al.*, 2017). Thus, the study has established that increasing fertilizer rates has a significant positive impact on grain yield, and a late sowing date (the last 10 days of May) provided better results.

The results of a multivariate analysis of variance for grain yield in the Almaty Region showed fertilizer rate was the dominant factor, accounting for 54.0% and even more than half of the total effect (Figure 1). The second most

Table 5. Grain yield of grain sorghum based on seeding rates and nitrogen fertilizer rates under irrigated conditions in the Kyzylorda Region for 2025.

Fertilizer doses a.i. (kg ha ⁻¹)	1 term (01-10.05)			2nd term (11-20.05)			3rd term (May 21-31)		
	Seeding rate (000 plants ha ⁻¹)			Seeding rate (000 plants ha ⁻¹)			Seeding rate (000 plants ha ⁻¹)		
	180	240	300	180	240	300	180	240	300
Without fertilizers	2.54	2.33	2.24	2.68	2.56	2.32	2.75	2.51	2.42
N ₆₀ P ₆₀	3.08	2.95	2.82	3.25	3.04	2.77	3.92	3.53	3.18
N ₁₂₀ P ₆₀	3.56	3.23	3.05	3.79	3.48	2.98	4.18	3.89	3.56
LSD _{0.05}	A = B = C = 0.0468; AB = AC = BC = 0.0811; ABC = 0.1405								

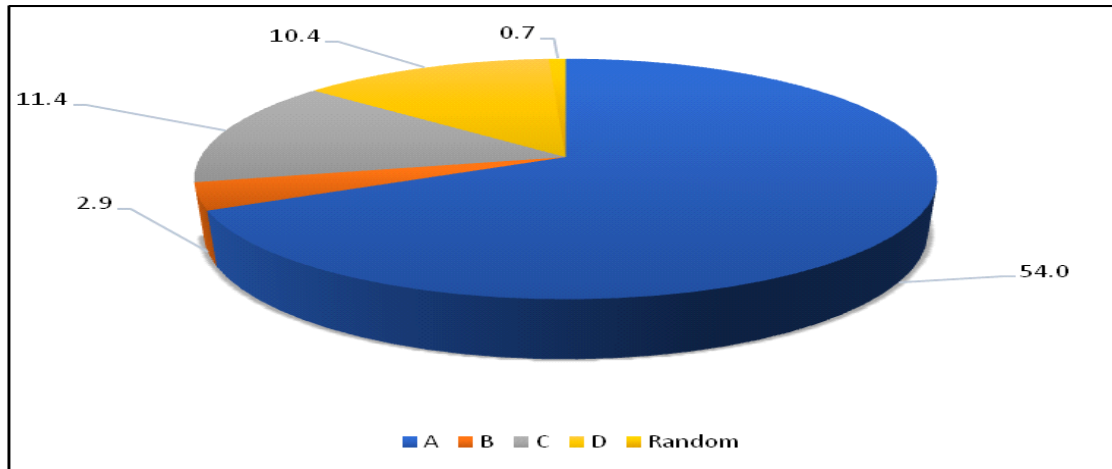


Figure 1. The share of factors in the formation of grain yield of grain sorghum in the conditions of the Almaty Region, where A is the fertilizer rate, B is the variety, C is the seeding rate, and D is the technology.

significant important factors were the seeding rate and cultivation technology, with shares of 11.4% and 10.4%, respectively. The crop contribution share to the formation of grain yield was dependent on the cultivars and environmental conditions of the crop seasons (Kunypiyaeva *et al.*, 2023).

The multivariate analysis for grain yield in the Kyzylorda Region revealed fertilizer rate dominated in both crop seasons (2024 and 2025), accounting for 70.4% and 64.6%, respectively (Figure 2). Combining mineral fertilizer has a potential of improving grain yield, from 500 to 5000 kg ha⁻¹ in sorghum, depending on the soil type and rainfall received (Kugedera and Kokerai, 2024). The most favorable combination of technological factors, which ensured a maximum yield of 9.22 t/ha, emerged as represented by sowing sorghum at

the distance of 70 cm between rows and using a fertilization level of N₁₂₀P₆₀K₆₀ (Oprea *et al.*, 2017).

CONCLUSIONS

The results established that mineral fertilizers showed the greater influence on grain yield in grain sorghum (*S. bicolor* L.) cultivated in the Almaty and Kyzylorda regions, Kazakhstan. However, the highest grain yield obtained was at N₁₀₀P₆₀ (Almaty) and N₁₂₀P₆₀ (Kyzylorda with late sowing). The seeding rate (180,000 plants/ha) was optimal, while the higher plant density (420,000 plants/ha) could also enhance the grain yield only under sufficient mineral nutrition; however, it generally led to reduced yield.

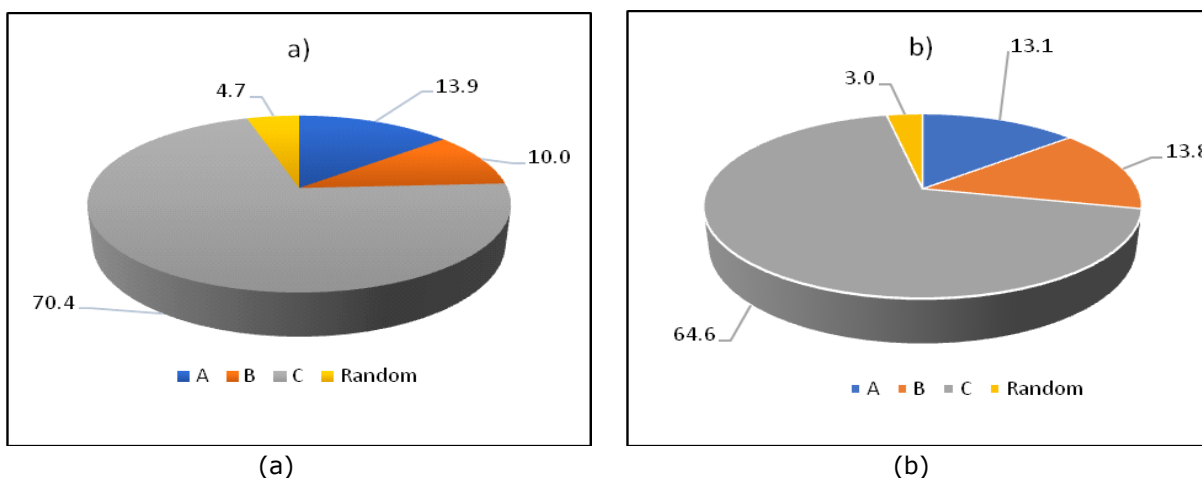


Figure 2. The share of factors in the formation of grain sorghum yield in the Kyzylorda Region: a) 2024, b) 2025, where A is the sowing date, B is the seeding rate, and C is the fertilizer rate.

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