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The Impact of Sowing Timing and Nutrition on Soybean Yields on the Absheron Peninsula in the Context of Climate Change

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Abstract. *The climate changes that have occurred over the past decades, as well as other plants, affect the yield of soybean grains. The study mainly examines the change in qualitative and quantitative indicators of soybean yield and development depending on the timing of sowing and the use of various fertilizer options. It was found that sowing in the third decade of April contributed to the production of mass seedlings, and at the stage of plant development, with a 60 x 10 cm sowing scheme, the results were different from the rest. On the irrigated gray-brown soils where the experiments were conducted, optimal conditions for seed swelling were created against the background of the use of* $N_{60}P_{40+15}$ *tons manure in cultivation, which, compared with the option without fertilizers, promotes the appearance of mass shoots and formation 3-4 days later than the ripening phase. According to the results of the study, it was noted that high yields of soybean grains are achieved against the background of the application of an optimal sowing scheme using manure* $N_{60}P_{40+15}$ *tons. The yield in this variant was 32.0 c/ha higher. This option should be considered significant in all directions.*

Keywords: *soybeans, yield, fertilizer, climate change, gray-brown soils*

Introduction

Agricultural production is one of the priorities of the Azerbaijani economy. The conditions of the relief and climate of the country are not the same for the development of individual branches of agriculture. In Azerbaijan, vast plains covering large areas, relatively gentle mountain slopes and wide river valleys are quite suitable for the development of crop production and settlements.

To fully meet the needs of the population for food and agricultural products, it is necessary to develop crop production. Soybeans, grown since ancient times, are considered one of the world's plants with a high protein and fat content. This plant is widely used in medicine, the food industry, for technical purposes and as a feed. It can be said that it has no equal in the world in terms of the high content of valuable nutrients and the possibilities of multi-purpose use. For this reason, soybeans are grown on all continents of the globe and its production is growing every year (Kumudini, 2010). Rich soil and climatic conditions, as well as historical traditions and a strategic geographical and economic position create favorable conditions for the cultivation of agricultural plants with high comparative advantages, and the development of meat and dairy farming.

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However, in the context of modern climate change, there are some difficulties (Mammadov, 2020; IPCC, 2021).

Ensuring food security is of great importance due to the global climate change currently taking place, the reduction of arable land, population growth and the frequency of natural disasters. Therefore, increasing food supply has become a priority development program in the world, including in our country (Mammadov & Abdullayev, 2021; IPCC, 2021). Research work is already underway in this area (Nasirova & Hajiyeva, 2024).

Soybeans play an important role in ensuring food security and in creating a strong feed base for animal breeding and poultry farming. Unlike other leguminous plants, soybeans stand out for their high quality and amount of protein in the green mass and seeds. The protein content in soybean grains is 30–53%, in the green mass up to 20%, as well as 20–30% fat and the same amount of carbohydrates. No plant synthesizes as much fat and protein as soy in 100 days. Soy protein is similar in acid composition to animal proteins. In addition, it is used as a green fertilizer (Mammadov, 2020; Havlin et al., 2014). From what has been noted, it becomes clear that in the context of climate change, it is necessary to expand soybean acreage and implement measures to increase its yield (Nasirova, 2023; IPCC, 2021).

Compared to other agricultural crops, the nutritional needs of soybeans are high. The conducted studies show that in conditions of optimal provision of mineral nutrition and water supply, soybeans increase their ability to absorb sunlight and normalize the photosynthesis process. As a result, the biological development of the plant improves, yields increase and quality indicators increase (Havlin et al., 2014; Xu et al., 2026).

Studies show that the optimal rate of nitrogen fertilizers leads to an increase in the amount of chlorophyll, the intensity of photosynthesis, an increase in soybean biomass and an increase in its yield (Xu et al., 2026).

Despite the fact that the management strategy for early sowing of soybeans to increase its yield is considered effective, logistics issues, lack of equipment, environmental conditions, and labor difficulties can lead to a delay in sowing. However, if early sowing is possible, there is a risk of spring frosts, insects at the beginning of the season and diseases of seedlings, rains that can damage plants, which can lead to suboptimal plant density (Mourtzinis et al., 2017).

The main objective of the article is to determine the optimal sowing timing and nutritional conditions for soybeans in order to increase their yield in the face of climate change. The influence of extreme climatic factors, such as excessive precipitation in some regions, drought and partial drought in others, has led to weakened development of agricultural plants (Reynolds & Ortiz, 2010; Ciríaco da Silva et al., 2010; IPCC, 2021).

Thus, favorable soil and climatic conditions are considered one of the most important factors for the development and growth of agricultural crops, as well as the production of products with high yields and quality, and observations made during the research years confirm the above.

Materials and Methods

Considering the above, in 2018–2020, 3-factor (3 x 3) field experiments were conducted at the Absheron subsidiary experimental farm of the Scientific Research Institute of Agriculture to obtain a crop using the Biyson soybean variety with an area of 48 m^2 per bed, arranged according to the following scheme.

Factor A: timing of sowing
1. 2nd decade of April
2. 3rd decade of April
3. The 1st decade of May
Factor B: sowing scheme (plant density)
1. 60 × 5 cm (333 thousand piece/ha)
2. 60 × 10 cm (167 thousand piece/ha)
3. 60 × 15 cm (111 thousand piece/ha)
Factor C: nutritional conditions
1. without fertilizers
2. $N_{60}P_{40}$+15 tons of manure
3. $N_{60}P_{40}K_{40}$.

The yield of soybeans largely depends on whether mineral fertilizers remain in a form that can be absorbed by plants or, conversely, turn into a form that is difficult to digest, on the acid-alkali pH of the soil and its carbonate content. For this purpose, taking into account the above, the pH and carbonate content of the soils of the experimental area were determined.

Over the years of research, it was found that the pH of the soil at a depth of 0–20 cm ranges from 8.35–8.45; at a depth of 20–40 cm – 8.60–8.86; 40–60 cm – 8.79–8.82 and the pH increases accordingly to the depth.

During the experiments, the method of B. A. Dospekhov was used (Dospekhov, 1985). The studies were conducted on gray-brown soils. On the samples taken, total humus was determined using the I.V. Tyurin method, total keldal nitrogen, mobile phosphorus, and 1% ammonium carbonate $(NH_4)_2CO_3$ were determined using a pH meter (Khadzhimammadov, 2016; Jafarov, 2014). For each variant, the grain yield in each repeated bed was calculated.

During the study, in each of the experiments, the agrochemical properties of the soil were determined in detail depending on the depth (Table 1).

Table 1
The main agrochemical parameters of soils at different depths in the field of research

Years	Depth, cm	Total humus, %	$CaCO_3$ %	Total nitrogen (N), %	Mobile phosphorus (P_2O_5) 1 kg soil	Exchangeable potassium El (K_2O) g, mg	pH
2018	0–20	1,35	13,05	0,093	11,5	305	8,40
	20–40	0,76	17,55	0,059	6,8	185	8,60
	40–60	0,55	20,20	0,043	3,4	114	8,81
2019	0–20	1,31	12,65	0,090	12,1	289	8,35
	20–40	0,82	16,80	0,063	7,3	176	8,86
	40–60	0,60	20,10	0,047	2,9	110	8,79
2020	0–20	1,37	14,10	0,093	10,8	295	8,45
	20–40	0,79	16,95	0,058	5,5	186	18,65
	40–60	0,58	19,25	0,044	3,1	115	8,82

The amount of humus and biogenic elements in these soils is very low genetically. The climate at the research area is semi-desert and dry-steppe with mild winters. Under the conditions of modern climate change, tangible changes in the hydrothermal regime are taking place in this territory.

Table 2 shows that there are changes in the current climatic indicators of the territory compared to the average long-term information. In each year of the studied years, the average temperature is high compared to the average long-term temperature. With an average long-term temperature of 15.7 ^{0}C, in 2018 it was 16.0 ^{0}C, in 2019 it was 15.9 ^{0}C, and in 2020 it was close to the long-term average temperature of 15.7 ^{0}C.

It is known that an increase in temperature leads to a decrease in soil moisture and an acceleration of mineralization. Especially in the warm season, during droughts, it has a negative impact on microbiological processes. During a very warm and dry period, microbiological processes can be said to stop.

Table 2
Agrometeorological indicators for 2018–2020, obtained during a study by the National Hydrometeorological Department of Ministry of Ecology and Natural Resources of the Republic of Azerbaijan

Years	Months												
	January	February	March	April	May	June	July	August	September	October	November	December	Average
Average monthly air temperature, 0 ^{0}C													
2018	4,7	6,4	8,2	12,5	20,6	24,4	29,6	26,0	22,9	17,9	11,0	7,9	16,0
2019	6,5	5,8	8,0	12,1	20,3	27,0	26,6	26,0	21,4	18,3	10,8	8,7	15,9
2020	6.0	7,4	9,7	11,3	18,6	25,6	27,3	24,8	23,2	17,8	11,1	6,4	15,8
Long-term	5,3	5,5	8,3	12,6	19,7	25,0	27,4	27,5	22,9	16,2	10,4	7,2	15,7
The amount of precipitation, mm													Sum
2018	33,7	62,1	24,2	11,0	4,6	1,6	2,7	0,3	0,0	8,5	33,9	49,5	232,1
2019	26,8	37,6	43,7	15,3	7,7	0,4	0,0	12,4	20,3	2,4	79,3	39,8	285,7
2020	38,1	9,3	12,7	14,9	16,0	0,8	0,3	16,5	0,0	14,8	126,1	58,6	308,1
Long-term	39,6	37,0	29,0	12,4	10,2	6,4	1,3	4,1	33,3	36,3	52,5	38,4	300,5

The amount of long-term precipitation in the territory is 300.5 mm; in 2018–2019, this indicator was less than the long-term average. But in the last year of the study, precipitation increased to 308.1 mm. Research shows that these important features need to be taken into account when planting and growing soybeans. Therefore, we tried to determine the optimal time for planting soybeans by planting them at different times.

Results and Discussion

In order to obtain high green biomass and soybean grain yield, it is necessary to properly observe the timing of sowing, agrotechnical measures and cultivation technology. Also, with a weak development of root nodules, the application of nitrogen fertilizers as a topdressing helps to increase productivity.

The studies were conducted in Absheron Peninsula under irrigation conditions, and this significantly affects the nutrition regime and yield of soybeans. Experiments show that the application of mineral fertilizers at an optimal rate and optimal hydrothermal conditions affects the increase in soybean grain yield. Fertilization also helps to restore soil fertility in conditions of intensive crop production, completes the balance of nutrients for plants and regulates the humus content in the soil. On the other hand, along with mineral fertilizers, we used organic fertilizers and manure to a sufficient extent. As we have already mentioned, soybeans are sensitive to factors and growing conditions, so their choice in this direction is very important.

Taking into account the fact that the yield of soybeans cultivated for grain harvesting depends on agrotechnical measures, a difference in yield was revealed at different sowing timing, schemes and conditions of topdressing of the studied soybean variety “Bison”. It can also be noted that in all replays of the variants, the harvest was collected and weighed, and the average figure was subtracted and the yield in hectares was determined.

Based on the conducted research, it was found that soybean yields in 2019 were higher in all variants than in 2018 and 2020, which indicates the importance of cultivation factors along with meteorological and climatic conditions.

The yield results obtained from the variants are entered in the table as indicated (Table 3). It can be seen here that in the second decade of April, when sowing in variants without fertilizers, in the 60 x 5 sowing scheme the grain yield was 16.79 c/ha, in the 60 x 10 sowing scheme the yield was 17.0 c/ha, and in the 60 x 15 sowing scheme, despite the high content of structural elements, due to a decrease in the number of plants per hectare, the number of the yield was 15.5 c/ha, which is 0.9–3.5 c/ha less, depending on the sowing schemes of other sowing periods.

With the application of $N_{60}P_{40}$+15 tonnes of manure, the yield increase from 21.4 c/ha to 4.75 c/ha; from 23.3 c/ha – 6.3 c/ha; from 20.1 c/ha – 4.6 c/ha. With the $N_{90}P_{60}K_{60}$ option and a 60 x 5 cm sowing scheme, the yield is 20.4 c/ha, an increase of 3.7 c/ha; with 60 x 10 cm, the corresponding figures are 21.5 c/ha and 4.5 c/ha; 60 x 15 cm – 19.2 c/ha and 3.7 c/ha.

In the 3rd decade of April, when sowing in the variant without fertilizers in the 60 x 5 cm sowing scheme, the average grain yield was 18.7 c/ha, in the 60 x 10 cm sowing scheme – 19.7 c/ha and in the 60 x 15 cm sowing scheme, despite the high content of structural elements, due to a decrease in the amount of plants per hectare, the yield decreased and amounted to 19.0 c/ha.

Table 3
The impact of sowing timing, scheme, and nutritional conditions on soybean grain yield, c/ha (average for 2018–2020)

Sowing timing	Sowing scheme, cm	Nutrition conditions	Grain yield	Increase
2nd decade of April	60 x 5	without fertilizers	16,7	–
		$N_{60}P_{40}$+15 tons manure	21,4	4,7
		$N_{90}P_{60}K_{40}$	20,4	3,7
	60 x 10	without fertilizers	17,0	–
		$N_{60}P_{40}$+15 tons manure	23,3	6,3
		$N_{90}P_{60}K_{40}$	21,5	4,5
	60 x 15	without fertilizers	15,5	–
		$N_{60}P_{40}$+15 tons manure	20,1	4,6
		$N_{90}P_{60}K_{40}$	19,2	3,7
	60 x 5	without fertilizers	18,7	–

3rd decade of April		$N_{60}P_{40}$+15 tons manure	26,2	7,5
		$N_{90}P_{60}K_{40}$	25,3	6,6
		without fertilizers	19,7	–
	60 x 10	$N_{60}P_{40}$+15 tons manure	32,0	12,3
		$N_{90}P_{60}K_{40}$	31,0	11,3
		without fertilizers	19,0	–
	60 x 15	$N_{60}P_{40}$+15 tons manure	27,4	8,4
		$N_{90}P_{60}K_{40}$	26,4	7,4
1st decade of May	60 x 5	without fertilizers	17,6	–
		$N_{60}P_{40}$+15 tons manure	23,1	5,5
		$N_{90}P_{60}K_{40}$	22,3	4,7
	60 x 10	without fertilizers	19,4	–
		$N_{60}P_{40}$+15 tons manure	29,9	10,5
		$N_{90}P_{60}K_{40}$	28,5	9,1
	60 x 15	without fertilizers	18,5	–
		$N_{60}P_{40}$+15 tons manure	27,0	8,5
		$N_{90}P_{60}K_{40}$	25,6	7,1

In the variant with the addition of $N_{60}P_{40}$+15 tons of manure, respectively, the grain yield was 26.2 c/ha, with an increase of 7.5 c/ha; from 32.0 c/ha an increase was 12.3 c/ha; from 27.4 c/ha an increase was 8.4 c/ha. In the $N_{60}P_{40}$+15 manure application variant, with a 60x5 cm sowing scheme, the yield was 25.3 c/ha, an increase was 6.65 c/ha; with a 60 x 10 cm sowing scheme, 31.0 c/ha, respectively, an increase was 11.3 c/ha; 60 x 15 cm – 26.4 c/ha, an increase was 7.4 c/ha.

In the first decade of May, during sowing operations, in the variant without fertilizers, in the 60 x 5 cm sowing scheme, the yield was 19.4 c/ha, and in the 60x15 cm sowing scheme, despite the high content of structural elements, due to a decrease in the number of plants per hectare, the yield was 18.5 c/ha. When applying manure $N_{60}P_{40}$+15 tons, respectively, the grain yield was 23.1 c/ha, an increase was 5.5 c/ha; 29.9 c/ha an increase was 10.5 c/ha; 27.9 c/ha an increase was 8.5 c/ha. In the $N_{90}P_{60}K_{40}$ variant, with a 60x5 cm sowing scheme, 22.3 c/ha, an increase was 4.7 c/ha, in a 60x10 cm sowing scheme, 28.5 c/ha, an increase was 9.1 c/ha; with a 60x15 cm sowing scheme, it is 25.6 c/ha, with an increase of 7.1 c/ha.

A statistical analysis was performed to determine the accuracy of the obtained results. As a result of the analysis of variance, it was determined that the timing of sowing, sowing schemes and nutritional conditions significantly affect plant yields. The combined and separate effects of each of these factors are shown in table 4.

Table 4
Results of a three-factor analysis of variance of the combined effect of sowing timing, sowing schemes, and nutritional conditions on soybean grain yields (2018–2010, on average)

Factors and their combined effect	Df	SS	MS	F	Pr (>F)	PES
A	2	1824,253	912,126	682,468	0,000	0,821
B	2	645,214	322,607	241,380	0,000	0,619
C	2	3671,413	1835,707	1373,505	0,000	0,902

AB	4	191,771	47,943	35,872	0,000	0,326
AC	4	244,642	61,160	45,761	0,000	0,381
CB	4	168,062	42,016	31,437	0,000	0,297
ABC	8	44,376	5,547	4,150	0,000	0,101
Error rate	297	396,944	1,337			
Sum	324	173727,750				
Corrected amount R ≈ 0,940	323	7186,674				

Note. A – Sowing timing, B – Sowing scheme, C – Nutritional conditions; ABC – the effect of the combined impact of factors with a significance level of 0.05% is valid, Df – Degree of freedom, SS – sum of squares, MS – the average square, Pϕ – the actual value of the Fisher criterion F (significant impact: Pϕ ≥ F critical), P – value (Pr (>F), PES-a measure of the impact of factors (rp part) = eta part of a square

The P–value of all three factors is less than 0.05, and the effect of the sowing period (factor A) on plant yield is 82.1%, the effect of the sowing scheme is 61.9%, and the effect of nutritional conditions (AC) is 90.2%. It is the highest indicator.

The influence of two factors: the sowing timing and the sowing scheme (AC) – 32.6%, the combined effect of the sowing timing and the conditions of nutrition (AC) – 38.1%, the sowing scheme and the fertilizer rate (BC) – 29.7%. In addition, the combined effect of sowing timing, sowing schemes and nutritional conditions is 10.1%, and there is a significant relationship between all three factors. In general, P-square reflects this variation and correction well. P-square affects the accuracy of the model.

The final results of the variance analysis according to the Duncan criterion of the effect of sowing timing, schemes and nutritional conditions on the yield of soybeans grown for grain crops are shown in Table 5.

Table 5
Variance analysis of the impact of soybean grain cultivation factors on its fertility according to the Duncan criterion (2018–2020, on average)

Factors	The average value
Sowing in the second decade of April	19,4565
Sowing in the third decade of April	25,1111
Sowing in the first decade of may	23,4481
60 x 5	21,3056
60 x 10	24,6148
60 x 15	22,0954
Without fertilizers	17,9509
$N_{60}P_{40}$+15 tons of manure	25,5630
$N_{90}P_{60}K_{40}$	24,5019

Note. The average value used =36 Calculations not performed; α = 0,01

As a result of the conducted scientific research, it was established that when sowing soybeans in the third decade in the conditions of the Absheron Peninsula, the yield was 32.0 c/ha with a sowing scheme of 60 × 10 cm against the background of the application of $N_{60}P_{40}$+15 tons of manure, and the increase was 12.3 c/ha compared to the control variant without fertilizers, early sowing in the second decade of April and late sowing in the first decade of May.

According to the Duncan criterion, it was determined that the highest yield was obtained in the third decade of April with a 60 x 10 cm sowing scheme and with the $N_{60}P_{40}$+15 tons of manure variant. This result is also influenced by current climate change, as the first decade of April are characterized by relatively low temperatures and high humidity, which leads to more intensive plant growth and development. Subsequently, the air becomes too hot and humidity decreases, slowing this process. As a result, it is clear that current climate change is not without its impact on grain yields (Kubar et al., 2021).

Conclusion

When growing soybeans for grain crops under climate change, with sowing in the third decade of April and a 60 x 10 cm sowing scheme, stages of mass germination and development are observed, as well as significant differences in fertilizer application rates at different stages. It was found that on gray-brown soils, with the application of $N_{60}P_{40}$+15 tons of manure, mass germination and maturation began 2–3 days earlier than in the case without fertilizer, and ripened 3–4 days later, creating optimal conditions for grain filling. For grain production, the dynamics of soybean height at different stages was higher with the application of $N_{60}P_{40}$+15 tons of manure in the optimal sowing scheme, and the grain yield was 32.0 c/ha, which is 123 c/ha higher than in the case without fertilizer. This method was also found to be cost-effective.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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