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Efficiency of Fertilizers Under Agricultural Crops in Different Soil–Climatic Conditions of Azerbaijan

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Abstract. *The Republic of Azerbaijan has a very rich natural environment. The geography and relief of the republic, and the formation of manifestations of eleven climatic belts in this territory, have played an important role in the formation of soil–climatic conditions and, overall, of the landscape. For this reason, the soil types formed within the republic are favorable for the development of various branches of agriculture. Under the soil–climatic conditions of the republic, it is possible to develop fruit growing, viticulture, vegetable growing and other agricultural cultivation and obtain high yields from these fields. In the article, the main regularities of fertilizer efficiency under agricultural crops in various soil–climatic zones of Azerbaijan have been investigated. Thus, in the Kura–Araz and Lankaran plains, under different soil–climatic conditions, the characteristics of crop cultivation and the results of scientific research on the efficiency of fertilizer application under cotton and tomato on irrigated meadow-gray and meadow-marsh soils are presented. The scientific analyses carried out show that the effectiveness of fertilizers varies significantly depending on soil texture, humus reserves, soil reaction, and climatic factors. It has been determined that in the irrigated meadow-gray soils of the Mughan–Salyan zone and in the meadow-marsh soils of the Lankaran–Astara zone, the combined application of organic and mineral fertilizers under cotton and tomato has a better effect on increasing soil fertility and crop productivity compared to variants where they were applied separately.*

Keywords: *cotton, tomato, Mughan–Salyan, Lankaran–Astara, meadow-gray, meadow-marsh, fertilizer, crop, productivity, nitrogen, phosphorus, potassium*

Introduction

In the modern period, rapid population growth, increasing demand for agricultural products, and limited land resources have made raising productivity in agricultural production a priority task. In this regard, the scientifically grounded application of fertilizers is of particular importance in increasing the yield of agricultural crops. Fertilizer efficiency is directly and closely related to soil–climatic conditions, agrochemical properties of the soil, biological requirements of the cultivated crop, and the applied agrotechnical measures.

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Aghayev N. A., Ismayilov S. N., Aghayev A. N. (1999, p. 20), in the work “Agrochemical characteristics of some soils in Azerbaijan,” indicate that in order to use soils efficiently it is necessary to increase their potential fertility. Increasing soil fertility can be achieved through the application of organic and mineral fertilizers (Aghayev, 1999, pp. 20−23).

Guliyev A. A. (2015, p. 140) notes that an arid, i.e., dry and semi-desert climate prevails in the lowland zone of our republic, and nitrogen and phosphorus deficiency is observed more distinctly in the soils formed there. However, in the Lankaran–Astara zone there is a humid subtropical climate. In this region, abundant precipitation and the intensity of leaching processes increase fertilizer losses, especially nitrogen fertilizers. In mountainous and foothill areas, the temperature regime, soil reaction, and erosion processes seriously affect the uptake of fertilizers by plants (Guliyev, 2015, pp. 140−148).

Studying fertilizer efficiency under agricultural crops is relevant not only for increasing yield, but also for protecting soil fertility, maintaining ecological balance, and ensuring sustainable agriculture. Excessive or improperly selected fertilizer application can cause soil degradation, pollution of water bodies, and a decrease in the quality of agricultural products. Many studies have led scientists to conclude that applying fertilizers above the norm, or without selecting them according to soil–climatic conditions and also the biological characteristics of the crop, causes the acceleration of a number of negative ecological and agrochemical processes in agroecosystems. Such applications primarily deepen soil degradation by resulting in the disruption of the physical, chemical, and biological properties of soils (Alosmanov, 2022, pp. 225−229).

Excessive application of mineral fertilizers, especially nitrogen-containing fertilizers (Ismayilov, 2018, p. 236), leads to the accumulation of nitrates in the soil solution. As a result, nitrate leaching intensifies and, entering groundwater, causes its pollution. Studies conducted in arid and humid subtropical zones of our republic show that under conditions of intensive irrigation or abundant precipitation, nitrate leaching occurs more rapidly. This is considered one of the factors creating serious ecological risks for both water bodies and drinking water sources (Babayev, 2006). This, studying fertilizer efficiency under cotton and vegetable (tomato) crops on meadow-gray and meadow-marsh soils under different soil–climatic conditions within the Republic of Azerbaijan is an important issue and stands out for its relevance.

Research object and Methodology

Field work was carried out in 2025 in individually owned farms on cotton-growing soils in the territory of Qarabaglar village, Salyan administrative district, and on vegetable (tomato) soils in the territory of Shirinsu village, Lankaran administrative district. In order to study the agrochemical characteristics of the research site, soil samples were taken by the envelope method from depths of 0–20, 20–40, 40–60, and 60–80 cm, and the soil reaction—pH (in a water suspension)—was determined with a potentiometric device; total humus (I. B. Tyurin), total nitrogen (Kjeldahl), total phosphorus (K. E. Ginzburg), and total potassium (P. K. Smit) were determined accordingly. Absorbed ammonium (N–NH4) was determined by D. P. Konev, nitrate nitrogen (N–NO3) by Grandval–Lyaj, available phosphorus (soluble in 1% ammonium carbonate) by Machigin, and exchangeable potassium by the Protasov method in C. Huseynov’s modification. Agrochemical analyses in the soil for both crops were carried out using the following methods:Total nitrogen—I. V. Tyurin; absorbed ammonium (N–NH4)—D. P. Konev; nitrate nitrogen (N–NO3)—Grandval–Lyaj; total phosphorus—A. M. Mesheryakov; available phosphorus—M. P. Machigin; total potassium—P. K. Smit; exchangeable potassium—P. V. Protasov method.

Nitrogen, phosphorus and potassium in plants were determined using the methods of K. E. Ginzburg and Q. M. Sheglova. Mathematical calculation of yield indicators was performed using the method of A. M. Mesheryakov (1972). Field experiments for cotton were carried out in accordance with the accepted agrotechnical rules in the Mughan–Salyan region, in the territory of Qarabaglar village of Salyan district, on irrigated meadow-gray soils, in an individually owned farm. The experiments were conducted in 5 variants, 4 replications, with each plot area being 100 m². Sowing was carried out in the 3rd ten-day period of April (April 23). The first emergence was obtained in early May.

During the experiments, ammonium nitrate was used as a nitrogen fertilizer, simple superphosphate as phosphorus, potassium sulfate as potassium, and cattle manure as an organic fertilizer. As nitrogen fertilizer ammonium nitrate (33.4%), as phosphorus—ammophos (51%), as potassium—potassium sulfate (52%), and as organic fertilizer—cattle manure were applied. Accounting of raw cotton yield was carried out for all replications and variants. In order to determine fiber yield and technological quality of the fiber, before harvesting 20 cotton bolls were collected from each variant and replication. The BO-440 "white gold" cotton variety was used in field experiments. During field experiments, 5 complex cultivation operations and 3 irrigations were carried out.

During yield recording, harvesting was carried out separately for each variant. The accuracy of the obtained yield was calculated by the Mesheryakov method. To study the dynamics of nutrients as a result of applying organo-mineral fertilizers, soil samples were taken from depths of 0–25 and 25–50 cm at the budding, flowering and maturation phases of the crop, and laboratory analyses were carried out. In experiments conducted with tomato, ammonium nitrate (active nitrogen 34%) was used as the nitrogen fertilizer, simple superphosphate (active phosphorus 18%) as phosphorus, potassium chloride (active potassium 52%) as potassium; and as organic fertilizer, semi-rotted cattle manure containing 0.5% nitrogen, 0.3% phosphorus and 0.6% potassium with 65% moisture was used. In the variant with 10 tons of manure + N75P45K90 (N75P45K90 equivalent to 15 tons of manure), mineral fertilizers were applied in that proportion; in the variant with 20 tons of manure + N50P30K60 (N50P30K60 equivalent to 10 tons of manure), mineral fertilizers were applied in that amount. The semi-rotted cattle manure applied to the experimental plot was mixed with the soil at sowing time according to variants. Of the annual norm of mineral fertilizers by variants, 50% was applied at transplanting and 50% when 10–15 leaves formed and during the flowering period. Fertilizers were applied by hand, evenly distributed in the experimental plots, then incorporated into the soil and irrigated. All agrotechnical works were carried out in accordance with the agrotechnical rules intended for vegetable cultivation in the republic (except for fertilizer application). To study nutrient dynamics in soil according to the development phases of tomato, soil samples were taken and analyzed during flowering, maturation, first harvest, and last harvest periods. The "Zarrabi" tomato variety was used in the experiment.

Analysis and Discussion

Territorial features of the regions: The Mughan–Salyan zone is located in the south-eastern part of Azerbaijan and covers the main part of the Kura–Araz plain. The climate in the zone is dry and semi-desert (arid). The average annual air temperature of the region is +12.5–14.6 °C. According to the temperature regime, being subtropical, the summer is dry and hot, and the winter is mild and with little snow. The low precipitation and high evaporation level make irrigation a main condition of agriculture (Jafarov, 2006).

The soil cover of the Kura–Araz plain mainly consists of gray, gray-meadow, meadow-gray, solonchak, and saline soils. These soils are weakly supplied with humus (1–2%). Carbonate content and salinity are widespread in the soils of the region, and as a result, fertilization and reclamation measures play an important role in agro-production. The natural vegetation cover mainly consists of semi-desert and desert plants. Wormwood, saltwort, ephemeral and ephemeroid plants dominate. In irrigated areas, cotton, cereals, forage crops and vegetable growing are widely developed. The

Lankaran–Astara region of our republic, being located on the southern border of our country, covers an area stretching from the Caspian Sea coast to the foothills of the Talysh mountains. It borders Masalli district to the north, the Islamic Republic of Iran to the south, the Caspian Sea to the east, and the Talysh mountains to the west. This geographical position has caused the formation of a specifically natural and climatic environment in the region (Madatzadeh & Shikhlinski, 1968, pp. 16–30). The region is located in Azerbaijan's humid subtropical climate zone. The average annual air temperature is 14–16 °C, and annual precipitation is 1200–1600 mm. Although precipitation falls more in autumn and winter months, humidity remains high throughout the year in the region. Such climatic features generally manifest themselves in the soil-forming processes of the zone. Year-round high humidity creates conditions for intensive development of leaching and gleying processes in soils (Mammadov, 2010, pp. 214–216). Yellow-podzolic, yellow-gley alluvial-meadow, mountain-forest, meadow-marsh and other soils are widespread in the region. The soils are characterized by high moisture, a tendency toward acidic reaction, and humus accumulation mainly in the upper horizons.

Due to its natural soil–climatic conditions, the region differs from other provinces of the republic. The subtropical climate and high precipitation make this region suitable for tea growing, citrus and subtropical crops, and also vegetable cultivation (Alosmanov, 2022). The vegetation cover mainly consists of moisture-loving subtropical forest and shrub plants. Chestnut, iron tree, pistachio, and relict species belonging to the Hyrcanian flora are widely distributed. In agriculture, tea, citrus fruits, rice and vegetable growing are considered the main fields. The soil–climatic conditions and fertility properties of the regions where we carried out the research have been studied by a number of scientists such as Zakharov, Tyuremnov, Volobuyev, M. E. Salayev, M. I. Jafarov, Y. J. Hasanov, Q.Sh.Mammadov, M. P. Babayev, Q. Z. Azizov. According to granulometric composition, the meadow-gray soils of the Mughan plain studied by us are heavy loamy and loamy, while the meadow-marsh soils of the Lankaran zone are light and medium loamy. They contain noticeably soluble salts and are moderately supplied with nutrients. (Abdullayev & Gulahmadov, 1956, p. 105).

The Mughan–Salyan and Lankaran–Astara regions are important zones for agricultural cultivation in our country. Studying these soils is among the factors affecting the country's economy and the formation of ecological sustainability policy. Both in the Mughan–Salyan and in the Lankaran–Astara region, investigating, studying and analyzing the widespread soils is a relevant issue for the development of agriculture. Against the background of climate change, obtaining high yields from agricultural crops and at the same time preserving soil fertility is of very great importance. Research shows that applying fertilizers according to normative rates adapted to soil–climatic conditions creates conditions both for increasing productivity and for long-term preservation of soil fertility. F. H. Mishustin and I. V. Moslova, in their studies, note that long-term application of mineral fertilizers under crops accelerates biological and physico-chemical processes in soil. They show that long-term application of mineral fertilizers affects the transition of nutrients from one form to another in soil and also affects the movement of nutrients in the soil. M. K. Daraselja (1953) and M. M. Kononova (1951) state that applying mineral fertilizers affects the biological activity of the soil, and as a result, the decomposition and mineralization of organic matter in soil proceeds rapidly and completely.

During the conducted experiment, the effect of different rates and ratios of organo-mineral fertilizers on the yield of cotton and tomato was studied by us (Tables 1 and 2). As can be seen from the table, in the variant where background + 20 t/ha manure was applied, the yield was higher compared to other variants. Thus, if in the control unfertilized variant the yield was 1785 kg/ha, in the N90K60-background variant it was 2342 kg/ha, in the background + N120 variant it was 3200 kg/ha, and in the background + N30 + 15 t/ha manure variant it was 3488 kg/ha.

When analyzing the table, it is clearly seen that in the variants where mineral and organic fertilizers were applied together, yield was higher. This is explained by the fact that organic fertilizers influence biological activity in the soil. As a result, the process of easier uptake of mineral fertilizers by plants occurs. In heavy loamy soils like meadow-gray soils, organic fertilizers affect soil structure and improve its compaction ability, which results in better development of the plant root system and causes greater uptake of nutrients. In addition, the combined application of organo-mineral fertilizers affects soil microflora, which leads to activation of bacteria functioning in the soil and, as a result, to continuous mineralization of organic matter in the soil. In turn, this increases the soil's moisture retention ability and raises its air capacity, which positively affects plant development.

Table 1.
Effect of different rates and ratios of fertilizers on the yield of cotton

№	Experimental variants	Average number of plants per hectare (pcs)	2025		
			Yield (centner/ha)	Increase	
				c/ha	%
1	Control (unfertilized)	75 000	1785		–
2	$N_{90}K_{60}$-fon	75 000	2342	557	31,2
3	Fon +N_{120}	75 000	3200	1415	79,3
4	Fon+N_{30}+ 15t/ha manure	75 000	3488	1703	95,4
5	Fon+20 t/ha manure	75 000	3963	2178	122,0

Scientific research shows that correct organization of agrotechnical measures has an important impact on tomato yield. Studies have shown that an optimal fertilization system and a correct irrigation regime lead to a 20–35% increase in yield (Mammadov, 2023). Productivity mainly depends on environmental factors. These include the fertilizer and water regime, sunlight, soil type, and so on. In well-cultivated soil, with appropriate fertilization, production increases. Yield begins mainly with seedling planting. Healthy seedlings have healthy roots, which is important for the future development of plants. Researchers note that the most important for yield is correct soil cultivation, subsequence of irrigation, and timely elimination of diseases (Zamanov et al., 2009).

As a result, increasing tomato yield and optimizing production costs makes an important contribution to ensuring economic sustainability in agriculture and strengthening food security. During the study, the yield under tomato when organo-mineral fertilizers were applied together and separately was also studied. During the conducted experiment, it was determined that combined application of organic and mineral fertilizers under tomato was also effective. Analysis of the experimental results shows that the applied fertilizer variants significantly affected tomato yield. In the control (unfertilized) variant, yield was 231 c/ha, which characterizes the natural fertility level of the soil.

Table 2.
Effect of different rates and ratios of mineral and organic fertilizers on tomato yield on gray-brown soils

№	Experimental variants	2025		
		Yield (centner/ha)	Increase	
			c/ha	%
1	Control (unfertilized)	231	–	–
2	$N_{90}P_{90}K_{90}$	296.3	65,3	28,3
3	Organic fertilizer (manure) 10 t + N75P45K90	373.7	142,7	62,0
4	Organic fertilizer 20 t + N50P30K60	420.7	189,7	82,1

In the mineral fertilizer variant N90P90K90, yield was 296.3 c/ha. Compared to the control variant, this means an increase of 65.3 c/ha or 28.3%. This result indicates that mineral nutrient elements enhanced vegetative development and the formation of generative organs. In the variant with 10 t manure + N75P45K90, yield was 373.7 c/ha, and compared to the control, an increase of 142.7 c/ha (62.0%) was obtained. Improvement of the physical-chemical properties of soil and increased microbial activity by organic fertilizers can be considered the main reason for this result.

The highest yield in the experiment was observed in the combined variant of 20 t organic fertilizer + N50P30K60. In this variant, yield was 420.7 c/ha, yield increase was 189.7 c/ha or 82.1%. This result proves that the complex application of organic and mineral fertilizers shows a synergistic effect and ensures tomato yield at a higher level. During the experiments, the correlative relationship between the selected fertilization scheme and yield was analyzed. Correlation is evaluated only between fertilization system and yield. The analysis of the correlative relationship shows that as fertilization intensity increases, yield rises. This indicates a positive correlation. It is linear in nature and indicates a strong correlative relationship. Scientifically, this relationship is strong, direct, and statistically meaningful in experimentally accepted agronomic terms. The yield increase by variants is consecutive and sharp. The correlation strengthens as one moves from mineral fertilizer to organic fertilizer. Thus, there is a strong positive correlative relationship between yield and fertilization intensity, and the application of organic fertilizers further strengthens this correlation. In soil, organic fertilizers play the main role in increasing soil fertility. The obtained results, having a linear and stable character of yield increase, confirm that the fertilization system was chosen correctly.

Conclusion

In the irrigated meadow-gray soils of the Mughan–Salyan zone and the meadow-marsh soils of the Lankaran–Astara zone, combined application of organic and mineral fertilizers under cotton and tomato, compared to variants where they were applied separately, was found to have a better effect on increasing soil fertility. The highest yield under cotton during the application of organic and mineral fertilizers was obtained in the background + 20 t/ha manure variant, and in the tomato experiments in the variant 20 t organic fertilizer + N50P30K60.

Declaration of Competing Interest

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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