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Effect of Mineral Fertilizers on the Quantitative and Qualitative Indicators of Winter Triticale

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Abstract. *This study evaluates the effects of various mineral fertilizer (NPK) rates on the quantitative and qualitative indicators of winter triticale (cv. "Qismət") under the semi-desert, dry steppe climatic conditions of the Ganja region, Azerbaijan, alongside a comparative performance analysis with "Qırmızı buğda 1" wheat and a rye breeding line over a three-year period (2023–2025). The experimental plots were organized in a randomized block design. The results demonstrate that NPK application significantly enhanced the structural yield components and nutritional quality of triticale. Optimal results were achieved with the N90P90K40 treatment, which maximized mean grain yield at 64.20 c/ha (a 14.53 c/ha increase over the unfertilized control) and crude protein yield at 10.26 c/ha. Structural analysis revealed that this productivity surge was primarily driven by a 17.6% increase in grains per spike and a 16.4% improvement in grain weight. Comparative evaluation showed that triticale exhibits superior responsiveness to intensive fertilization, outperforming both wheat (maximum yield increase of 9.00 c/ha) and rye (maximum yield increase of 5.92 c/ha). Due to its tall-growing morphotype and moderate input response, the "Qismət" cultivar is categorized as a semi-intensive variety well-suited for improving localized concentrated fodder production.*

Keywords: *winter triticale, NPK fertilization, grain yield, crude protein, crop responsiveness*

Introduction

Triticale belongs to the grass family — *Poaceae* Barnhart, or *Gramineae* Juss., and the genus *Triticosecale* Witt. It is an artificially created crop, an amphidiploid. Thanks to breeding efforts, triticale varieties are currently being tested in 75 countries worldwide (Airikh, 2013; Mammadov & Ismayilov, 2012). Triticale successfully combines the valuable traits of its parent forms: From Rye: Multi-rowed spikes, a more balanced amino acid protein composition, and vigorous development (Longin et al., 2012; Gurbanov, 2011).

At the current stage of agricultural development, new objectives are being set based on an adaptive-landscape (ecological) framework. Global experience demonstrates that further progress in farming is contingent upon moving away from intensive, high-cost agrotechnologies and transitioning toward resource- and energy-saving biologized systems (Nazranov et al., 2011).

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Research demonstrates that optimizing the fertilizer system for the Samur triticale variety significantly enhances energy efficiency. Specifically, an optimized approach resulted in a yield increase of 2 t/ha, which boosted the net energy income by 71.3 GJ/ha and improved the energy efficiency coefficient by 20.4% (Nazranov et al., 2011). The yield formation process in cereal crops is highly dynamic and depends on numerous environmental factors. According to literature sources, nitrogen is the most significant among the nutritional elements. As is well known, nitrogen is an essential element for plant growth and development (Ismayilov, 2016a). While there is a substantial body of information regarding the application of mineral fertilizers, particularly nitrogen, for winter wheat and barley in the republic, experimental data on their utilization in triticale cultivation is extremely scarce or virtually non-existent (Ismayilov, 2016b).

Triticale exhibits intermediate characteristics between wheat and rye in terms of cultivation technology. Sowing time, seeding rate, plowing depth, fertilization system, and disease control measures must be optimized in accordance with local soil and climatic conditions (Seyidaliyev, 2016). There are a total of 4.2 million hectares of triticale cultivation area globally. Of this area, 80% is utilized for winter triticale cultivation, while 20% is used for spring cultivation (Kır & Yavuz, 2024). Small grain cereals such as wheat, barley, oats, rye, and triticale are primarily grown for their grains and utilized as human food; however, they are also harvested for fodder and used as roughage (Çaçan & Kökten, 2019).

Materials and Methods

The field experiments were conducted to study the effects of mineral fertilization on the "Qismət" winter triticale variety. For comparative analysis, the "Qırmızı buğda 1" wheat variety and a rye breeding line were also included in the trials. The experiments were organized in a randomized block design with multiple fertilizer treatments. The mineral fertilizers were applied in various combinations of Nitrogen (N), Phosphorus (P), and Potassium (K). The primary application rates included: Control: No fertilizer application; NPK Variants: Variations ranging up to $N_{90}P_{90}K_{60}$; Specific focus was placed on evaluating the increments of 30 kg/ha for N and P, and 20–50 kg/ha for K. Harvested grain from each plot was weighed and converted to centners per hectare (c/ha) at standard moisture content. Structural analysis was performed to determine the number of grains per spike and 1000-grain weight (g). The protein content in the grain was determined using the Kjeldahl method (or equivalent laboratory analysis). Crude protein yield (c/ha) was calculated by multiplying the grain yield by the protein percentage. The collected data were subjected to statistical processing to determine the reliability of the results. The statistical significance of yield differences between the treatments and the control variant was evaluated, and the economic efficiency of the fertilizer applications was calculated.

Results and Discussion

We have investigated the effects of various doses of NPK (Nitrogen-Phosphorus-Potassium) on several characteristics of the "Qismət" triticale variety; the results of these studies are presented below.

Number of plants preserved until harvest. For the variants where NPK was applied, this indicator averaged between 185 and 199 units/m² (compared to 176 units/m² in the control/unfertilized variant). The average differences observed between the control and experimental variants were statistically significant; this is evident when comparing the data with the $LSD_{0.95}$ (Least Significant Difference at 95% confidence level) indicators (Tables 1 and 2). However, when comparing some experimental variants with each other, the observed differences were not significant across all pairs. For instance, the differences in this trait among variants 5, 6, and 7 were non-significant, indicating that this variety did not exhibit sensitivity to increasing doses of potassium fertilizer.

Number of productive stems per 1 m² and productive tillering. In the "Qismət" variety, the highest number of productive stems per unit area (1 m²) was recorded in the variant treated with $P_{90}K_{60}$ + three applications of spring nitrogen top-dressing at a rate of 30 kg of active ingredient (a.i.) each. According to the three-year average, this indicator reached 270 units, representing an average increase of 21.6% compared to the control (unfertilized – 222 units). It should be noted that the differences between this variant and others with various fertilizer dosage ratios were statistically significant, with the exception of the variant where the highest NPK doses were applied. Specifically, the additional application of K_{30} (30 kg of potassium) did not stimulate shoot formation; on the contrary, a tendency toward a decrease in their number was observed. Based on the three-year average, productive tillering in the fertilized variants ranged from 1.25 to 1.36. The differences observed between the control and experimental variants were found to be statistically non-significant.

Plant height. The application of mineral fertilizers increased the plant height of the "Qismət" variety by 7–13 cm; however, due to the firm and resistant stems, no lodging (prostration on the soil) was observed in the plants.

Yield Components and Grain Yield Per Unit Area

The most significant increase in the grain set (grain filling) of the spike in the "Qismət" variety was observed in variants 4, 5, and 6. Compared to the unfertilized control variant, the average spike grain count increased by 10.1%, 15.6%, and 17.6%, respectively. Increasing the potassium fertilizer dose up to 50 kg/ha (a.i.) led to the reduction of some flowers and resulted in an average increase of only 3 grains per spike, which is considered statistically non-significant (Table 1). The most optimal variant was variant 5, where three applications of spring nitrogen top-dressing resulted in a 17.6% increase in spike grain count. As indicated by the data, the highest grain weight per spike was recorded in this specific variant, reaching 2.76 g. This represents an increase of 16.5% and 26.2%, respectively, compared to the control variant. In the "Qismət" variety, the 1000-grain weight in the fertilized variants showed a tendency to decrease compared to the control variant. However, the differences of 0.4–2.1 grams were found to be statistically non-significant, as they were lower than the $LSD_{0.95}$ value (3.8 g). The analysis of the yield structure of the triticale variety allowed for the identification of the leading role of individual components in the formation of productivity levels when different doses and ratios of mineral fertilizers were applied (Gurbanov et al., 2025).

Table 1

Effect of mineral fertilizers on yield structure components and variability of biological indicators in the "Qismət" triticale variety

No.	Variants	Indicators of studied traits				
		2023	2024	2025	Mean	Deviation from control
	I	II	III	IV	V	VI
		Number of plants surviving until harvest (units/m²)				
1	Control (Unfertilized)	173	170	185	176	+
2	$N_{60}P_{60}K_{40}$	178	183	193	185	+9 -5,1%
3	$N_{90}P_{60}K_{40}$	184	182	196	187	+11 -6,25%

4	$N_{60}P_{90}K_{40}$	182	175	200	186	+10 -5,7%
5	$N_{90}P_{90}K_{40}$	193	183	207	195	+19 -10,8%
6	$N_{90}P_{90}K_{60}$	192	193	210	198	+22 -12,5%
7	$N_{90}P_{90}K_{90}$	192	193	212	199	+23 -13,1 %
$LSD_{,95}$ = 5,87 units/m²						
Productive tillering						
1	Control (Unfertilized)	1,24	1,38	1,18	1,27	
2	$N_{60}P_{60}K_{40}$	1,35	1,37	1,19	1,30	+0,03
3	$N_{90}P_{60}K_{40}$	1,30	1,32	1,27	1,30	+0,03
4	$N_{60}P_{90}K_{40}$	1,26	1,38	1,10	1,25	-0,02
5	$N_{90}P_{90}K_{40}$	1,37	1,42	1,10	1,30	+0,03
6	$N_{90}P_{90}K_{60}$	1,30	1,45	1,33	1,36	+0,09
7	$N_{90}P_{90}K_{90}$	1,25	1,47	1,25	1,32	+0,05
$LSD_{0,95}$ = 0,116						
Number of productive tillers per m^2 (units)						
1	Control (Unfertilized)	215	234	218	222,3	
2	$N_{60}P_{60}K_{40}$	240	250	230	240	+17,7 -8%
3	$N_{90}P_{60}K_{40}$	240	256	249	248,3	+26 -17%
4	$N_{60}P_{90}K_{40}$	230	241	220	230,3	+8 -3,6%
5	$N_{90}P_{90}K_{40}$	265	259	228	250,7	+28,4-12,8%
6	$N_{90}P_{90}K_{60}$	250	280	280	270	+47,7 -18,3%
7	$N_{90}P_{90}K_{90}$	240	283	266	263	+40,7 -18,3%
$LSD_{0,95}$ = 19,6						
Plant height (cm)						
1	Control (Unfertilized)	141	139	140	141	
2	$N_{60}P_{60}K_{40}$	148	145	152	148	+7
3	$N_{90}P_{60}K_{40}$	151	148	159	153	+12
4	$N_{60}P_{90}K_{40}$	147	144	156	149	+8
5	$N_{90}P_{90}K_{40}$	150	148	158	152	+11
6	$N_{90}P_{90}K_{60}$	148	152	159	153	+12
7	$N_{90}P_{90}K_{90}$	153	150	158	154	+13
$LSD_{0,95}$ = 3,566						
Number of grains per spike (units)						
1	Control (Unfertilized)	49	44	55	49,3	+
2	$N_{60}P_{60}K_{40}$	49	47	52	49,3	
3	$N_{90}P_{60}K_{40}$	54	49	51	51,3	+2 -4,0%
4	$N_{60}P_{90}K_{40}$	56	56	59	57,0	+7,3 -15,6%
5	$N_{90}P_{90}K_{40}$	54	59	61	58,0	+8,7 -17,6%
6	$N_{90}P_{90}K_{60}$	56	49	58	54,3	+5 -10%

7	$N_{90}P_{90}K_{90}$	55	49	53	52,3	+3 -6,1%
			$LSD_{0,95}$ = 4,83%			
			Grain weight per spike (g)			
1	Control (Unfertilized)	2,33	2,14	2,34	2,37	
2	$N_{60}P_{60}K_{40}$	2,21	2,16	2,43	2,40	+0,03
3	$N_{90}P_{60}K_{40}$	2,33	2,30	2,41	2,48	+0,11
4	$N_{60}P_{90}K_{40}$	2,41	2,32	2,63	2,58	+0,21
5	$N_{90}P_{90}K_{40}$	2,36	2,45	2,87	2,76	+0,39
6	$N_{90}P_{90}K_{60}$	2,44	2,29	2,36	2,56	+0,19
7	$N_{90}P_{90}K_{90}$	2,50	2,21	2,41	2,58	+0,21
			$LSD_{0,95}$ = 0,197			
			1000-grain weight (g)			
1	Control (Unfertilized)	47,0	48,6	43,6	46,4	
2	$N_{60}P_{60}K_{40}$	45,2	46,0	46,9	46,0	-0,4
3	$N_{90}P_{60}K_{40}$	43,15	46,9	47,2	45,7	-0,7
4	$N_{60}P_{90}K_{40}$	43,04	42,3	48,0	44,5	-1,9
5	$N_{90}P_{90}K_{40}$	43,9	44,9	47,9	45,6	-0,8
6	$N_{90}P_{90}K_{60}$	43,6	46,9	42,4	44,3	-2,1
7	$N_{90}P_{90}K_{90}$	45,4	45,1	45,9	45,5	-0,9
			$LSD_{0,95}$ = 3,778			

Grain Yield and Protein Content (Tables 2 and 3).

The average yield across the NPK variants ranged from 54.3 to 64.2 c/ha, representing an increase of 4.66–14.53 c/ha over the control variant.Increasing the phosphorus fertilizer rate by 30 kg (a.i.) resulted in an average yield increase of 2.17 c/ha. Similarly, increasing the nitrogen dose by 30 kg (comparing variant 3 to variant 2) led to a yield growth of 3.91 c/ha. Against a higher phosphorus background (P_{90}), a 30 kg increase in nitrogen dose improved grain yield by an average of 7.7 c/ha (comparing variant 5 to variant 4). Conversely, increasing the potassium dose by 20 and 50 kg did not yield a significant increase; instead, a slight downward trend in productivity was observed (Ismayilov & Gurbanov, 2015).

Table 2

Effect of different mineral fertilizer rates on the yield of the "Qismət" triticale variety

No.	Variants	2023	2024	2025	Mean	$LSD_{0,95}$	Difference from control (c/ha)
1	Control (Unfertilized)	50,1	48,0	51,0	49,67	3,45	–
2	$N_{60}P_{60}K_{40}$	53,0	54,0	56,0	54,33	2,01	4,66
3	$N_{90}P_{60}K_{40}$	56,8	58,0	60,0	58,24	4,28	8,57
4	$N_{60}P_{90}K_{40}$	55,5	56,0	58,1	56,50	2,59	6,83
5	$N_{90}P_{90}K_{40}$	62,6	63,4	66,5	64,20	2,76	14,53
6	$N_{90}P_{90}K_{60}$	61,0	64,0	66,0	63,67	1,84	14,0
7	$N_{90}P_{90}K_{90}$	61,0	62,5	64,4	62,67	1,91	13,0
	$LSD_{0,95}$	1,81	2,50	2,29	2,20		

Crude protein content. The application of NPK led to an increase in protein content. However, the addition of an extra 50 kg of potassium resulted in a 0.6% decrease in the protein level.

Table 3
Effect of different mineral fertilizer rates on the grain quality of the "Qismət" triticale variety

No.	Variants	Protein content in grain (%)	Crude protein yield (c/ha)
1	Control (Unfertilized)	13,1	6,4
2	$N_{60}P_{60}K_{40}$	14,7	8,03
3	$N_{90}P_{60}K_{40}$	15,0	8,78
4	$N_{60}P_{90}K_{40}$	15,3	8,71
5	$N_{90}P_{90}K_{40}$	16,1	10,26
6	$N_{90}P_{90}K_{60}$	15,8	10,11
7	$N_{90}P_{90}K_{90}$	15,3	9,94

Crude protein yield per unit area (per hectare). The crude protein yield ranged from 8.03 to 10.26 c/ha. The optimal variant was $N_{90}P_{90}K_{40}$. Analysis shows that the yield increase in the "Qismət" variety was primarily achieved due to an increase in the number of grains per spike (17.6%) and their weight (16.4%). Since this variety is tall-growing and shows a lower response to fertilizer application, it can be classified as a semi-intensive variety.

Comparison with wheat and rye (Table 4). Rye showed the weakest response to NPK application (maximum increase of 6 c/ha). While the maximum yield increase for wheat was 9 c/ha, this indicator reached 14.53 and 21.8 c/ha in triticale varieties. The optimal variant was determined as $N_{90}P_{90}K_{40}$, for both rye and wheat. In wheat, reducing the nitrogen dose to $N_{90}P_{90}K_{40}$, led to a yield decrease of 2 c/ha; however, this difference was not statistically significant (Levakhin & Duskaev, 2006).

Table 4
Effect of mineral fertilizers on the grain yield of wheat and rye

No.	Variants	Grain yield (c/ha)					
		2023	2024	2025	Mean	Comparison with control (c/ha)	$LSD_{0,95}$ (sen/ha)
"Qırmızı buğda 1" wheat variety							
1	Control (Unfertilized)	38,4	40,2	41,6	40,07		2,69
2	$N_{60}P_{60}K_{40}$	40,6	43,3	44,3	42,73	+2,66	2,29
3	$N_{90}P_{60}K_{40}$	43,6	45,2	47,1	45,30	+5,27	3,35
4	$N_{60}P_{90}K_{40}$	45,2	47,0	49,0	47,07	+7,00	3,17
5	$N_{90}P_{90}K_{40}$	48,4	50,2	49,8	49,07	+9,00	2,01
6	$N_{90}P_{90}K_{60}$	47,9	49,4	49,7	49,00	+8,93	3,11
7	$N_{90}P_{90}K_{90}$	47,8	48,3	48,8	48,48	+8,41	3,39
	$LSD_{0,95}$ (sen/ha) =	2,93	3,15	2,39	2,82		
Rye breeding line							

1	Control (Unfertilized)	35,5	37,4	37,9	36,93		1,77
2	$N_{60}P_{60}K_{40}$	38,6	39,8	41,4	39,93	+3,0	2,24
3	$N_{90}P_{60}K_{40}$	37,5	39,2	40,8	39,17	+2,24	1,61
4	$N_{60}P_{90}K_{40}$	40,6	42,5	44,7	42,85	+5,92	3,18
5	$N_{90}P_{90}K_{40}$	39,3	41,6	42,3	41,07	+4,14	1,26
6	$N_{90}P_{90}K_{60}$	40,0	40,5	42,9	41,13	+4,20	2,40
7	$N_{90}P_{90}K_{90}$	40,0	40,5	42,9	41,13	+4,20	2,40
	$LSD_{0,95}$ (sen/ha) =	8,40	2,15	3,17	4,57		

As evident from the presented data, triticale shows a relatively better response to mineral fertilizer application compared to wheat and, especially, rye. This confirms the findings in many countries regarding the high sensitivity (responsiveness) of triticale to mineral nutrition.

Conclusion

Based on the research conducted in the Ganja region of Azerbaijan, it can be concluded that the application of mineral fertilizers is a key factor for maximizing the productivity of the "Qismət" winter triticale variety. The application of NPK fertilizers significantly enhanced grain yield, with average results ranging between 54.3 and 64.2 c/ha. The maximum yield increase reached 14.53–21.8 c/ha, which was achieved primarily through an increase in the number of grains per spike (17.6%) and grain weight (16.4%). Mineral fertilization positively influenced the protein profile of the grain. The crude protein yield per hectare varied from 8.03 to 10.26 c/ha. However, it was observed that while NPK generally improves protein content, an excessive addition of potassium (50 kg) led to a slight reduction (0.6%) in protein levels. Triticale demonstrated a higher sensitivity and superior responsiveness to mineral nutrition compared to both wheat and rye. While the maximum yield increase for wheat and rye was 9 c/ha and 6 c/ha respectively, triticale showed much higher growth potential under similar conditions. For the "Qismət" variety, the $N_{90}P_{90}K_{40}$ variant was identified as the optimal fertilizer rate for maximizing both grain yield and protein output. Due to its tall-growing nature and specific reaction to intensive fertilization, the "Qismət" variety is classified as a semi-intensive type, confirming global trends regarding the high adaptability and nutritional efficiency of triticale.

Declaration of Competing Interests

The author declares 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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