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Effect of Seeding Rate And Fertilizer Application Rates on The Growth, Development, and Yield of Barley Varieties Under The Soil and Climatic Conditions of Central Region of Uzbekistan

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Abstract: Barley (*Hordeum vulgare* L.) is one of the major cereal crops cultivated for food, feed and malting purposes. Its productivity is strongly influenced by genotype, sowing time, seeding rate, soil fertility, nutrient availability and climatic conditions. Among agronomic practices, optimization of sowing date and fertilizer application is particularly important because these factors determine the duration of vegetative development, tillering, canopy formation, biomass accumulation, yield-component formation and grain filling. Numerous studies have therefore investigated the interaction between barley varieties and crop-management practices under different environmental conditions. This article presents brief overview of the results obtained regarding the effect of seeding rate and fertilizer application rates on the growth, development, and yield of barley varieties under the soil and climatic conditions of central region of Uzbekistan.

Keywords: barley, variety, cereal crop, food, feed, seeding rate, fertilizer, growth, development, condition, grain, productivity, yield.

Introduction

Sowing date is one of the most important determinants of barley productivity because it regulates the environmental conditions experienced during germination, tillering, stem elongation, heading and grain filling. Early or optimum sowing generally allows barley plants to establish a sufficient stand and develop an effective photosynthetic canopy before the onset of unfavorable temperatures or moisture stress. Conversely, delayed sowing can shorten the vegetative period and reduce yield components. Weston et al. [1] investigated the interaction of planting date and nitrogen fertilization in spring barley under dryland conditions in North Dakota. Their results demonstrated that delayed planting significantly reduced grain yield and fine-grind malt extract. The authors also found considerable interactions between genotype and nitrogen availability, indicating that barley cultivars differ in their ability to maintain productivity under different nutrient regimes.

A similar relationship was reported by Gozdowski et al. [2], who studied naked spring barley under Polish conditions. Delaying sowing by approximately three weeks reduced grain yield by an average of 37%, mainly because of decreases in the number of spikes per square meter, grains per spike and thousand-grain weight. The results confirm that delayed sowing affects not only final yield but also the structural components responsible for yield formation.

Patel et al. [3] evaluated sowing dates together with nitrogen and phosphorus fertilizer rates under irrigated conditions. Barley sown in the middle or second half of November produced significantly higher grain and straw yields than crops sown in December. The researchers concluded that timely sowing combined with adequate N and P nutrition improved nutrient uptake, productivity and economic returns.

Effect of seeding rate on barley growth and yield. In addition to sowing date, the quantity of seed used per unit area plays a critical role in determining plant population and crop canopy structure. Low seeding rates may result in insufficient plant density and reduced spike number per unit area, whereas excessive seeding can intensify competition among plants for light, water and nutrients. Okafor [4] found that barley planted before the end of November produced higher yields than December-sown crops under irrigated conditions in the Lake Chad Basin. Increasing nitrogen application improved plant height, tiller number, spike number, spike length and grains per spike. However, higher seed rates did not necessarily improve grain yield, demonstrating that optimum plant density is essential for efficient resource utilization.

Hajighasemi et al. [5] evaluated three seeding rates and four nitrogen levels in two barley cultivars. Grain yield showed a quadratic response to seeding rate, with approximately 600 seeds m⁻² providing the optimum under their experimental conditions. Increasing the seeding rate above the optimum reduced grain yield, illustrating the negative effects of excessive intra-specific competition.

Influence of nitrogen fertilization on growth and yield. Nitrogen is one of the most important nutrients determining barley growth and yield. It participates in chlorophyll and protein synthesis and strongly influences leaf development, tillering, biomass accumulation and reproductive development. Consequently, nitrogen deficiency usually restricts canopy development and yield formation, whereas excessive nitrogen can increase lodging, grain protein concentration and environmental losses.

The physiological and agronomic significance of nitrogen in barley has been comprehensively reviewed by Xu et al. [6]. Nitrogen availability affects early vegetative growth, leaf development, stem elongation, tiller production, grain number and grain size. However, excessive nitrogen application may decrease nitrogen-use efficiency and increase production costs and environmental risks.

Anbessa and Juskiw [7] emphasized that nitrogen-use efficiency (NUE) is an important component of sustainable barley production. Their review demonstrated that increasing nitrogen fertilizer rates does not necessarily result in proportional increases in grain yield. Both nitrogen uptake efficiency and nitrogen utilization efficiency may decline when fertilizer application exceeds crop requirements.

Nitrogen application timing and split fertilization. Not only the amount but also the timing of nitrogen application influences barley growth and yield. Split nitrogen application can synchronize nutrient availability with periods of high crop demand and may improve nitrogen recovery.

Sardana and Zhang [8] compared different nitrogen application timings in two barley cultivars. Nitrogen application at tillering or split application between tillering and booting produced considerably higher grain yields than nitrogen application at booting alone. The results indicate that supplying nitrogen during active tillering is particularly important for the formation of productive shoots and yield components. [9]

Khudaykulova [10] studied winter barley varieties under irrigated conditions and reported that both sowing date and fertilizer rate significantly influenced plant height and photosynthetic potential. Optimum sowing around 15 October produced higher photosynthetic potential, while increasing nitrogen fertilizer from 60 to 180 kg ha⁻¹ increased this parameter. However, delayed or excessively early sowing reduced photosynthetic potential.

Aim and Objectives of the Study

The aim of this study was to investigate the effects of different seeding rates and mineral fertilizer application rates on the growth, development, and yield performance of locally adapted barley

varieties under the typical sierozem soil and climatic conditions of the Tashkent region, Uzbekistan, with the ultimate goal of obtaining high and good-quality grain yields.

To achieve this aim, the following research objectives were established:

1. To evaluate the effects of different seeding rates and mineral fertilizer application rates on laboratory and field seed germination, overwintering survival, and tillering in barley varieties.
2. To determine the effects of different seeding rates and mineral fertilizer application rates on the growth, developmental stages, and biometric characteristics of barley varieties.
3. To identify the optimal seeding and mineral fertilizer application rates for achieving high grain yields and improved grain quality in winter barley varieties.
4. To assess the economic efficiency of different seeding rates and mineral fertilizer application regimes in winter barley production.[11]

Research site and soil-climatic conditions

The field experiments were conducted in 2022–2023 at the Research and Educational Experimental Farm of the Plant Genetic Resources Research Institute, located in Qibray District, Tashkent Region, Uzbekistan. The experimental site lies in the upper reaches of the Chirchiq River basin, at an elevation of 481 m above sea level. Its geographical coordinates were reported as 41°11' N and 38°31' E; these coordinates should be verified against the actual location of the experimental site.

The experimental farm is located approximately 1,500 m from the university campus. The Salar stream borders the site to the east, the Bozsui Canal to the west, the Tashkent Pediatric Medical Institute hospital to the south, and a residential area to the north.

The soil at the experimental site is classified as typical sierozem soil that has been under long-term irrigation. The humus content ranges from 0.8% to 1.0%, while the reported concentrations of nitrogen and phosphorus are 0.058–0.089% and 0.141–0.184%, respectively. The reported potassium content ranges from 0.148% to 0.154%; this range should be verified against the original soil analysis data. These values indicate relatively low humus content and potentially limited nutrient availability, although the actual nutrient status depends on the analytical methods used and the forms of nutrients measured. The soil is non-saline. The experimental site is also characterized by specific water-permeability properties and soil-working conditions, which may influence soil moisture dynamics and crop management practices.[12]

Atmospheric precipitation in the Tashkent region varies considerably with altitude and topography. In mountainous areas, precipitation occurs mainly as snow, whereas rainfall predominates in foothill and lowland areas. Most annual precipitation occurs during the winter and spring months, while relatively small amounts are recorded in autumn. Summer is generally characterized by hot and dry conditions, with little or no precipitation.

Autumn is typically characterized by a gradual decline in air temperature, with relatively warm conditions persisting into the season. The first frosts generally occur in late October or early November, although their timing varies among years. These conditions mark the seasonal transition toward the end of active crop growth. Precipitation generally increases during the autumn–winter period.

During the field experiments, precipitation was taken into account when determining irrigation requirements. Consequently, the number and rates of irrigation applications varied between growing seasons depending on the prevailing weather conditions and crop water requirements.

Overall, the climatic conditions of the Tashkent region, characterized by abundant solar radiation, warm growing seasons, and the availability of irrigation water, provide favorable opportunities for cultivating a wide range of agricultural crops. However, successful crop production, including winter barley cultivation, depends on appropriate irrigation management and the adaptation of agronomic practices to seasonal weather variability.

Research Objects. The research objects comprised irrigated typical sierozem soils of the Tashkent region, Uzbekistan; two barley varieties, 'Bolg'ali' and 'Ixtiyor'; two seeding rates; and three mineral fertilizer application rates.

Research Subject. The study focused on evaluating the effects of mineral fertilizer application rates on laboratory and field seed germination, plant growth, the duration of developmental stages, plant height, the dynamics of fresh and dry biomass accumulation, the quantity of root and stubble residues,

biometric characteristics, grain and straw yields, and economic performance of the two barley varieties grown under irrigated typical sierozem soil conditions in the Tashkent region.[13]

Materials and Methods

The study involved laboratory and field experiments, phenological observations, biometric measurements, soil and plant sampling, and laboratory analyses. The experimental procedures and measurements were conducted in accordance with established methodological guidelines, including Methods of Conducting Field Experiments, Methodology for State Variety Testing of Agricultural Crops, and Methodological Recommendations for Grain Quality Assessment. The experimental data were subjected to statistical analysis following B. A. Dospekhov's Methodology of Field Experiment. Data processing and statistical calculations were performed using Microsoft Excel.

Sowing Method and Depth. In the present field experiments, furrows spaced 70 cm apart were initially prepared using a KXU-4 cultivator. Because the experiments were conducted on small experimental plots, barley seeds were sown manually at a depth of 3–4 cm, according to the designated seeding rates for each experimental treatment.

Results

Effects of Seeding Rates and Mineral Fertilizer Application Rates on the Growing Season Duration of Winter Barley. In the study of winter barley varieties, the effects of mineral fertilizer application rates on the duration of the growing season and the timing of developmental stages were assessed for each experimental treatment. The results presented below refer to winter barley seeds sown on 10 October 2024.

The results showed that, in Treatment 1, the winter barley variety 'Ixtiyor' was sown at a rate of 3.5 million seeds ha^{-1} and fertilized with $\text{N}_{100}\text{P}_{75}\text{K}_{50}$ kg ha^{-1} . Seedling emergence was recorded on 17 October, the full-tillering stage on 20 November, the full stem-elongation stage on 20 March, the full heading stage on 9 April, the full flowering stage on 16 April, and the full maturity stage on 20 May. The period from sowing to full maturity was 215 days.

In Treatments 2 and 3, mineral fertilizers were applied at rates of $\text{N}_{150}\text{P}_{110}\text{K}_{75}$ and $\text{N}_{200}\text{P}_{145}\text{K}_{100}$ kg ha^{-1} , respectively. The timing of developmental stages differed slightly between these treatments. Seedling emergence occurred on 17 October, while full tillering was recorded on 22 November. Full stem elongation occurred between 22 and 24 March, full heading between 10 and 12 April, full flowering between 18 and 20 April, and full maturity between 22 and 26 May. The duration from sowing to full maturity ranged from 217 to 221 days.[14]

Overall, the results indicate that higher mineral fertilizer application rates were associated with a longer period from sowing to full maturity in the winter barley variety 'Ixtiyor'. Compared with Treatment 1, the growing season was extended by 2-6 days in Treatments 2 and 3. These differences suggest that mineral nutrition may influence the timing of developmental stages and crop maturity under the soil and climatic conditions of the Tashkent region.

Effects of Mineral Fertilizer Application Rates on Leaf Area Development in Winter Barley. Previous studies have demonstrated that leaf area development in cereal crops is influenced by agronomic practices, particularly mineral fertilizer application rates and nutrient management. Adequate mineral nutrition can promote vegetative growth and increase leaf area, thereby improving the crop's potential for light interception and photosynthetic activity.

The present study also revealed differences in leaf area development among winter barley treatments in response to mineral fertilizer application rates.

In Treatment 1, the winter barley variety 'Ixtiyor' was sown at a rate of 3.5 million seeds ha^{-1} and fertilized with $\text{N}_{100}\text{P}_{75}\text{K}_{50}$ kg ha^{-1} . The leaf area per plant was 14.21 cm^2 at the seedling stage, 52.41 cm^2 at tillering, 114.34 cm^2 at stem elongation, and 164.56 cm^2 at heading. During grain maturation, leaf area decreased to 147.82 cm^2 at the milk stage and 141.75 cm^2 at the dough stage.

In Treatments 2 and 3, where annual mineral fertilizer rates of $\text{N}_{150}\text{P}_{110}\text{K}_{75}$ and $\text{N}_{200}\text{P}_{145}\text{K}_{100}$ kg ha^{-1} were applied, respectively, leaf area per plant ranged from 16.13 to 16.95 cm^2 at the seedling stage, 55.82 to 58.57 cm^2 at tillering, 118.17 to 121.94 cm^2 at stem elongation, and 169.43 to 173.61 cm^2 at heading.

During grain maturation, leaf area ranged from 153.46 to 158.17 cm² at the milk stage and from 146.28 to 151.52 cm² at the dough stage.

Compared with Treatment 1, Treatments 2 and 3 exhibited higher leaf area per plant at all recorded developmental stages. The increases ranged from 1.92 to 2.74 cm² at the seedling stage, 3.41 to 6.16 cm² at tillering, 3.83 to 7.60 cm² at stem elongation, and 4.87 to 9.05 cm² at heading. At the milk stage, leaf area increased by 5.64–10.35 cm², while at the dough stage, the increase ranged from 4.53 to 9.77 cm² per plant.

In Treatment 4, the 'Ixtiyor' variety received mineral fertilizers at N₁₀₀P₇₅K₅₀ kg ha⁻¹. Leaf area was reported as 16.54 thousand m² ha⁻¹ at the seedling stage, 55.82 thousand m² ha⁻¹ at tillering, 122.65 thousand m² ha⁻¹ at stem elongation, and 176.85 thousand m² ha⁻¹ at heading. During grain maturation, leaf area was 170.74 thousand m² ha⁻¹ at the milk stage and 165.07 thousand m² ha⁻¹ at the dough stage. Overall, the results indicate that mineral fertilizer treatments were associated with differences in leaf area development in winter barley. The higher leaf area recorded in Treatments 2 and 3 suggests that increased mineral nutrient supply may promote leaf expansion and canopy development. However, the magnitude and statistical significance of these treatment effects should be established using the results of the relevant statistical analyses.

Effects of Seeding Rates and Mineral Fertilizer Application Rates on Yield Components of Winter Barley Varieties. One of the major determinants of grain yield in cereal crops is the set of yield components associated with the spike. To evaluate the effects of agronomic practices on the yield components of winter barley, plant samples were collected from all experimental treatments. In each replicate, barley plants were harvested using a sickle from three sampling points within a 1 m² area. The following parameters were measured: spike length, number of grains per spike, grain weight per spike, 1,000-grain weight, and test weight (grain bulk density).

Analysis of the results for the winter barley variety 'Ixtiyor' showed that, in Treatment 1, where mineral fertilizers were applied at N₁₀₀P₇₅K₅₀ kg ha⁻¹, the mean spike length was 8.5 cm, the number of grains per spike was 33.6, grain weight per spike was 1.04 g, 1,000-grain weight was 32.1 g, and test weight was 625.3 g L⁻¹.

In Treatment 6, where mineral fertilizers were applied at N₂₀₀P₁₄₅K₁₀₀ kg ha⁻¹, the 'Ixtiyor' variety exhibited a mean spike length of 9.0 cm, 32.0 grains per spike, a grain weight per spike of 1.03 g, a 1,000-grain weight of 32.2 g, and a test weight of 642.3 g L⁻¹. [15]

Compared with Treatment 1, Treatment 6 resulted in a 0.5 cm increase in mean spike length and a 17.0 g L⁻¹ increase in test weight. The 1,000-grain weight increased slightly by 0.1 g, whereas grain weight per spike decreased by 0.01 g and the number of grains per spike decreased by 1.6. These results indicate that the higher fertilizer rate was associated with improvements in spike length and grain bulk density, but did not increase all yield components uniformly.

Table 1. For the winter barley variety 'Bolg'ali', Treatment 7, which received mineral fertilizers at N₁₀₀P₇₅K₅₀ kg ha⁻¹, produced a mean spike length of 7.9 cm, 30.8 grains per spike, a grain weight per spike of 0.96 g, a 1,000-grain weight of 31.1 g, and a test weight of 611.2 g L⁻¹.

Taken together, these findings demonstrate that the measured yield components varied with barley variety and mineral fertilizer treatment. The responses of individual traits were not uniform, highlighting the importance of evaluating spike characteristics, grain weight, and test weight together when assessing the effects of fertilizer management on winter barley productivity.

Table 1. Spike Length, Number of Grains per Spike, Grain Weight per Spike, and 1,000-Grain Weight of Winter Barley (2024-2025)

No	Winter Barley Variety	Seeding Rate (million seeds/ha)	Annual Mineral Fertilizer Application Rate (kg/ha)	Spike Length (cm)	Number of Grains per Spike (grains/spike)	Grain Weight per Spike (g)	1,000-Grain Weight (g)	Test Weight (g/L)
1	Ixtiyor	3,5	N ₁₀₀ P ₇₅ K ₅₀	8,5	33,6	1,04	32,1	625,3
2		3,5	N ₁₅₀ P ₁₁₀ K ₇₅	8,7	34,5	1,07	32,8	635,1
3		3,5	N ₂₀₀ P ₁₄₅ K ₁₀₀	9,3	35,1	1,09	33,3	657,7
4		4,0	N ₁₀₀ P ₇₅ K ₅₀	8,1	31,1	0,98	31,5	617,4
5		4,0	N ₁₅₀ P ₁₁₀ K ₇₅	8,5	31,7	1,01	31,9	629,7
6		4,0	N ₂₀₀ P ₁₄₅ K ₁₀₀	9,0	32,0	1,03	32,2	642,3
7	Bolg'ali	3,5	N ₁₀₀ P ₇₅ K ₅₀	7,9	30,8	0,96	31,1	611,2
8		3,5	N ₁₅₀ P ₁₁₀ K ₇₅	8,3	31,4	0,99	31,6	631,5
9		3,5	N ₂₀₀ P ₁₄₅ K ₁₀₀	8,8	31,9	1,03	31,9	642,8
10		4,0	N ₁₀₀ P ₇₅ K ₅₀	7,7	30,4	0,93	30,6	602,8
11		4,0	N ₁₅₀ P ₁₁₀ K ₇₅	8,0	30,6	0,95	31,2	623,5
12		4,0	N ₂₀₀ P ₁₄₅ K ₁₀₀	8,4	30,8	0,97	31,6	636,4

Analysis of the data obtained from Treatment 12, in which mineral fertilizers were applied at rates of N₂₀₀P₁₄₅K₁₀₀ kg/ha, showed that the winter barley variety 'Bolg'ali' had an average spike length of 8.4 cm, 30.8 grains per spike, a grain weight per spike of 0.97 g, a 1,000-grain weight of 31.6 g, and a test weight of 636.4 g/L. Compared with Treatment 7, where mineral fertilizers were applied at rates of N₁₀₀P₇₅K₅₀ kg/ha, Treatment 12 resulted in increases of 0.5 cm in spike length, 0.01 g in grain weight per spike, 0.5 g in 1,000-grain weight, and 25.2 g/L in test weight. However, the number of grains per spike remained unchanged at 30.8. These results indicate that increasing the mineral fertilizer application rate improved several yield components of the 'Bolg'ali' winter barley variety, although it did not affect the number of grains per spike.

Discussion

Effects of Seeding Rates and Mineral Fertilizer Application Rates on Grain and Straw Yields of Winter Barley Varieties. According to the scientific literature, grain and straw yields are among the key agronomic traits determining the economic value of barley varieties. The field experiments conducted in this study demonstrated that the agronomic practices applied across the experimental treatments considerably influenced grain and straw yields of the winter barley varieties.

Grain and straw yields of the studied winter barley varieties were determined after the plants had reached the full maturity stage. For this purpose, plant samples were manually harvested from a measured area of 1 m² in each of the three replications of every treatment. Under laboratory conditions, the total aboveground biomass harvested from each 1 m² sampling area was determined. The spikes were then separated, and their weight and grain weight were measured using a balance. The stems were weighed separately to determine straw yield per square metre. The resulting data were used to

evaluate grain and straw productivity of the 'Bolg'ali' and 'Ixtiyor' winter barley varieties over the two growing seasons.

Results of the 2024-2026 Growing Seasons. Analysis of the results obtained during the first growing season (2024-2025) showed that, in Treatment 1, where the 'Ixtiyor' winter barley variety was grown with a mineral fertilizer application rate of N100P75K50 kg/ha, grain yield reached 40.0 centners per hectare (c/ha), while straw yield was 44.4 c/ha. The grain-to-straw yield ratio was approximately 0.90. In Treatment 6, where mineral fertilizers were applied at N200P145K100 kg/ha, the 'Ixtiyor' variety produced a grain yield of 54.1 c/ha and a straw yield of 66.0 c/ha. The grain-to-straw yield ratio was approximately 0.82. Compared with Treatment 1, grain yield increased by 14.1 c/ha, while straw yield increased by 21.6 c/ha.

For the 'Bolg'ali' variety, Treatment 7, which received mineral fertilizers at N100P75K50 kg/ha, produced a grain yield of 36.1 c/ha and a straw yield of 39.0 c/ha. The grain-to-straw yield ratio was approximately 0.93.

In Treatment 12, where the fertilizer application rate was increased to N200P145K100 kg/ha, grain yield of the 'Bolg'ali' variety reached 47.2 c/ha, while straw yield amounted to 56.1 c/ha. The grain-to-straw yield ratio was approximately 0.84. Relative to Treatment 7, grain yield increased by 11.1 c/ha and straw yield by 17.1 c/ha.

Analysis of the second growing season (2025–2026) showed that Treatment 1, in which the 'Ixtiyor' variety received mineral fertilizers at N100P75K50 kg/ha, produced a grain yield of 42.1 c/ha and a straw yield of 47.6 c/ha. The grain-to-straw yield ratio was approximately 0.88.

In Treatment 6, with mineral fertilizers applied at N200P145K100 kg/ha, grain yield of the 'Ixtiyor' variety reached 59.6 c/ha, while straw yield was 73.2 c/ha. The grain-to-straw yield ratio was approximately 0.81. Compared with Treatment 1, grain yield increased by 17.5 c/ha and straw yield by 25.6 c/ha.

For the 'Bolg'ali' variety, Treatment 7, receiving N100P75K50 kg/ha, produced a grain yield of 37.9 c/ha and a straw yield of 41.3 c/ha. The grain-to-straw yield ratio was approximately 0.92.

In Treatment 12, where mineral fertilizers were applied at N200P145K100 kg/ha, grain yield of the 'Bolg'ali' variety increased to 52.3 c/ha, while straw yield reached 63.2 c/ha. The grain-to-straw yield ratio was approximately 0.83. Compared with Treatment 7, grain yield increased by 14.4 c/ha and straw yield by 21.9 c/ha.

Conclusion

Across both growing seasons, increasing the mineral fertilizer application rate from N100P75K50 to N200P145K100 kg/ha was associated with higher grain and straw yields in both winter barley varieties. The 'Ixtiyor' variety achieved higher yields than 'Bolg'ali' under the corresponding fertilizer treatments in both years.

The yield increases observed in the second growing season were also greater than those recorded in the first season for both varieties.

These findings suggest that mineral fertilizer application rates played an important role in determining winter barley productivity under the experimental conditions. However, statistical analysis is required to establish whether the observed differences were statistically significant.

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