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Impact of varied NPK fertilizer application rates and seed quantities on barley yield and soil nutrient availability in chestnut soil of Azerbaijan

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Abstract

In the Gobustan district of Azerbaijan, the cultivation of barley is influenced by a complex interplay of soil properties, climate change effects, and agricultural practices. This study explores the impact of varying NPK fertilizer application rates and seed quantities, under natural climatic conditions, on barley yield and soil nutrient availability within Chestnut soils. The district's unique Chestnut soils, combined with evolving precipitation patterns due to climate change and the role of agricultural irrigation, create intricate challenges for successful barley farming. The experiment, conducted from 2016 to 2019, utilized a randomized complete block design with four replications to investigate the "Celilabad-19" barley variety. The results reveal a significant positive correlation between nitrogen application and grain yield. Notably, treatment 140-N60P45K45 (140 kg seed rate, 60 kg N/ha, 45 kg P/ha and 45 kg K/ha) demonstrated the highest average grain yield of 5.14 t/ha. The years 2017-2018 exhibited higher yields, possibly due to favorable climate conditions. Soil analyses indicated that higher NPK application rates led to elevated soil nutrient levels. However, nutrient content declined as plants progressed through growth stages, emphasizing the dynamic nutrient exchange between plants and soil. This study underscores the importance of adaptive agricultural strategies that consider climate variability and changing environmental conditions. The findings offer insights into sustainable cultivation practices essential for food security and crop production in the evolving climate of the Gobustan district.

Keywords: Barley cultivation, NPK fertilizer, seed rates, climate change, soil nutrient dynamics.

Introduction

Barley is the fourth most-produced cereal worldwide behind wheat, rice and maize (Oliveira et al., 2019). Also, Barley, a vital cereal crop in arid and semi-arid regions, assumes particular significance in Azerbaijan. As demonstrated by Cammarano et al. (2019) in the Mediterranean context, the cultivation of barley stands as a linchpin for food security. It is cultivated from the equator to the Arctic Circle and at different elevations (Friedt et al., 2010; Dawson et al., 2015). In Azerbaijan, this cereal is subject to an intricate interplay of factors, including unique soil properties, evolving climate patterns, and agricultural practices. In the Gobustan district of Azerbaijan, a distinctive intersection of factors profoundly influences the cultivation of barley. The region's Chestnut soils, providing an essential substrate for agricultural activities, play a pivotal role in sustaining plant growth and nutrient retention. However, the complex interplay between these soil properties, evolving precipitation patterns resulting from climate change, and the significant role of agricultural irrigation intensifies the impact of these elements on barley farming in the area. However, little attention has been focused on the effects of varied NPK fertilizer application rates and seed quantities on barley yield and soil nutrient availability in chestnut soil of Gobustan district, Azerbaijan.

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Azerbaijan's diverse topography encompasses a variety of soil compositions, with Chestnut soils standing out prominently within the Gobustan district. These soils, characterized by moderate drainage and fertility levels, offer a versatile foundation for diverse agricultural practices (Aliyev, 2021). Notably, in the context of barley cultivation, the attributes of Chestnut soils wield a direct influence over crop yield and quality.

The ever-evolving patterns of temperature and precipitation associated with climate change present a spectrum of challenges and opportunities for agricultural activities (Malhi et al., 2021; Abbass et al., 2022). Variations in temperature and shifting rainfall trends have far-reaching effects on planting schedules, water availability, and pest dynamics, all of which are crucial determinants of successful barley cultivation (Ullah et al., 2021; Skendžić et al., 2021). The Gobustan district, facing modifications in its traditional climate dynamics, must swiftly adapt its agricultural approaches to align with these changing conditions.

Of equal significance is the role of agricultural irrigation, emerging as a linchpin in upholding barley farming within the Gobustan district. As climate change renders precipitation patterns less predictable, the role of irrigation becomes even more pronounced in ensuring a consistent water supply for crops. Implementing efficient irrigation methodologies can ameliorate the repercussions of water scarcity and bolster crop resilience amid the shifting climatic backdrop.

In essence, the intricate interrelationship between Azerbaijan's distinctive topography, the inherent attributes of Chestnut soils, the ongoing ramifications of climate change, and the strategic deployment of agricultural irrigation collectively emphasize the paramount importance of these factors in barley cultivation within the Gobustan district. A comprehensive grasp and adept management of these intertwined elements stand as imperatives for upholding successful and sustainable barley farming practices in this region. Consequently, this study seeks to explore the influence of varying NPK fertilizer application rates and seed quantities, under distinct irrigation-absent conditions, on barley yield and the available forms of nitrogen, phosphorous, and potassium within Chestnut soils over a three-year period.

Material and Methods

Experimental Site

The field experiments were conducted from 2016 to 2019 in the Mereze area of the Gobustan Experimental Station, which is part of the Azerbaijan Research Institute of Crop Husbandry (40^{0}31’07.6372”N, 48^{0}53’50.8362”E). The experiments were carried out under rainfed conditions in the open dry chestnut soils of the Gobustan district, located in the Mountainous Shirvan region of Azerbaijan (Figure 1).

Figure 1. Experimental field

The Gobustan district, situated in the Mountainous Shirvan region of Azerbaijan, exhibits distinct long-term climate characteristics. The region experiences a semi-arid warm temperate desert climate in the southern part and a semi-arid warm temperate steppe climate in the northern part. The average annual temperatures range from 6 to 14°C, with the coldest months experiencing temperatures of 2 to 4°C, while the warmest period sees temperatures ranging from 15 to 25°C. The temperature remains relatively stable despite variations. The annual precipitation ranges from 360.3 mm to 542.9 mm, with an average of 412 mm. Notably, the distribution of rainfall during the crop vegetation period varies across years, impacting agricultural practices and water management strategies. These climate features play a crucial role in shaping agricultural sustainability and the livelihoods of the local population.

A chestnut soil sample was collected from the experimental field at the outset of the experiment. Some chemical properties of the soil were determined using methods outlined by Rowell (1996) and Jones (2001).

Experimental Design

The experimental design employed the "Celilabad-19" barley variety, known for its resilience to drought and rust diseases, and extensively cultivated in the region. The field trial was conducted between 2016 and 2019 using a randomized complete block design with four replications, resulting in a total of 48 plots. Each plot measured 50 m^2 (25 m x 2 m), with a spacing of 0.30 m between adjacent plots. During the three-year field trial, barley seeds were sown 5 cm below the soil surface using agricultural mechanization tools in the second week of October each year. Plant harvesting was performed in June, aligning with the climatic conditions of the region. The preceding crop in the rotation was a leguminous plant, which was mixed with the soil.

Different seed rates and NPK fertilizer doses were selected as experimental factors. The varying seed rates used in the trial were 2.67 million/ha (120 kg/ha), 3.11 million/ha (140 kg/ha), and 3.55 million/ha (160 kg/ha). The different NPK fertilizer treatments consisted of application doses of 30, 45, and 60 kg/ha (Table 1). Ammonium Nitrate (34% N) was used as the nitrogen fertilizer, Superphosphate (20.5% P_2O_5) as the phosphorus fertilizer, and Potassium Sulfate (46% K_2O) as the potassium fertilizer. For phosphorus and potassium fertilizers, the entire dose, along with 30% of the nitrogen fertilizer, was applied at seeding. The remaining 70% of the nitrogen fertilizer was applied during the tillering stage of barley plants in March.

Table 1. Experimental design

Treatments	Seed Rate (kg/ha)	Nitrogen fertilizer rate (kg/ha)	Phosphorus fertilizer rate (kg/ha)	Potassium fertilizer rate (kg/ha)
120-$N_0P_0K_0$	120	0	0	0
120-$N_{30}P_{30}K_{30}$	120	30	30	30
120-$N_{45}P_{45}K_{45}$	120	45	45	45
120-$N_{60}P_{45}K_{45}$	120	60	45	45
140-$N_0P_0K_0$	140	0	0	0
140-$N_{30}P_{30}K_{30}$	140	30	30	30
140-$N_{45}P_{45}K_{45}$	140	45	45	45
140-$N_{60}P_{45}K_{45}$	140	60	45	45
160-$N_0P_0K_0$	160	0	0	0
160-$N_{30}P_{30}K_{30}$	160	30	30	30
160-$N_{45}P_{45}K_{45}$	160	45	45	45
160-$N_{60}P_{45}K_{45}$	160	60	45	45

Throughout the trial period, no artificial irrigation was applied, and no plant protection chemicals were used. The trial design aimed to investigate the effects of different seed rates and NPK fertilizer doses on the growth, development, and yield of the "Celilabad-19" barley variety under the natural climatic and soil conditions of the Gobustan district. The experiment's focus on these factors aims to provide insights into sustainable cultivation practices for barley in the region.

Plant and Soil Sampling and Analyses

During the three-year field trial conducted from 2016 to 2019, mature barley plants were harvested to determine grain yields. Additionally, soil samples were collected at a depth of 25 cm during different developmental stages of the barley plant, including tillering, heading, and full maturity. These samples underwent various analyses to assess the dynamics of plant-available nitrogen, phosphorus, and potassium in response to different NPK fertilizer applications and varying levels of barley planting.

Following the methods outlined by Rowell (1996) and Jones (2001), mineral nitrogen (NH_4 and NO_3), available phosphorus, and exchangeable potassium contents were determined through 1 N KCl extraction and 1% $(NH_4)_2CO_3$ extraction from the soil samples. These analyses facilitated the assessment of the impacts of different NPK fertilizer dosages and varying levels of barley planting on the soil's capacity to supply plant-available nitrogen, phosphorus, and potassium. These insights contribute to a comprehensive understanding of how different soil nutrient dynamics interact with barley growth and development during various growth stages, thereby enriching the interpretation of the experiment's outcomes.

Data Analysis

Statistical analysis of the research results was conducted using the SPSS26 program.

Results and Discussion

The results obtained from soil samples taken at depths of 0-25 cm, 25-50 cm, and 50-70 cm, with the aim of determining the soil properties of the trial area with Chestnut soil type, are presented in Table 2. According to the acquired outcomes, it is observed that as the subsoil depth increases, the soil's calcium carbonate ($CaCO_3$)

content increases, consequently leading to an elevation in soil pH. In contrast, within the uppermost 0-20 cm soil layer, higher levels of organic matter, total nitrogen (N), mineral nitrogen forms (NH_4-N and NO_3-N), available P_2O_5, and exchangeable K_2O contents were detected. As the subsoil depth increases, these components were found to decrease.

Table 2. Characteristics of Chestnut soil type in the experimental area

Soil Dept, cm	pH	$CaCO_3$, %	Organic Matter, %	Total N, %	NH_4-N, mg/kg	NO_3-N, mg/kg	Available P_2O_5, mg/kg	Exchangeable K_2O, mg/kg
0-25	8,25	4,34	2,23	0,165	18,2	14,0	30,45	292
25-50	8,45	5,90	1,37	0,099	12,8	8,5	12,60	167
50-70	8,60	7,70	0,73	0,056	8,2	5,2	5,75	112

Changes in Grain Yield

The experimental design encompassed a comprehensive investigation into the effects of varying seed rates and different levels of NPK fertilizers on barley grain yield within the Chestnut soil type of the Gobustan district. The data collected over three consecutive years, spanning from 2016 to 2019, along with their averages, shed light on the dynamic relationship between the applied treatments and the resultant grain yields. Across the examined years, it becomes evident that the treatment combinations had a significant impact on barley yield. Among the treatments, those involving N application exhibited an observable trend of enhancing grain yield. For instance, treatment 140-N60P45K45 consistently demonstrated the highest average grain yield of 5.14 t/ha across the three years, indicating the substantial positive effect of nitrogen fertilization on yield improvement (Figure 2). Similarly, in a field experiment conducted by Mengie et al. (2021) under Ethiopian conditions, aiming to investigate the impact of varying seed rates (5, 7.5, 10, 12.5, and 15 kg/ha) on the growth, yield, and yield components of Tef, it was observed that different seed rates significantly influenced the yield and yield components of the Tef plant. The maximum yield of 2.301 kg/ha was achieved with a seed rate of 5 kg/ha, demonstrating the importance of appropriate seed rate selection. This finding aligns with the outcomes of the current study, where varying seed quantities and sowing methods were found to interactively affect barley yield and its related parameters. Therefore, the significance of optimizing seed rates for enhanced crop productivity is further highlighted by both studies. Kiria's (2022) study in Kenya reinforces our findings, emphasizing the vital role of seeding rates. Optimal outcomes were observed at 10 kg/ha seeding rate for highest grain yield and biomass production in teff cultivation, aligning with our results. After a 3-year field experiment, it was determined that increasing doses of NPK application significantly increased barley yield in the soils. Similarly, other studies have also demonstrated that increasing fertilizer application doses enhance crop yields (Shah et al., 2009; Nogalska et al., 2009; Wilczewski et al., 2013; Agegnehu et al., 2016).

Analyzing the results, it becomes evident that higher crop yields were achieved during the 2017-2018 period in comparison to both the preceding 2016-2017 and succeeding 2018-2019 periods. This observation is noteworthy, particularly considering that the 2017-2018 period experienced the lowest levels of precipitation. To provide specific figures, there was 704.4 mm of rainfall during the 2016-2017 period, 435.4 mm during the 2017-2018 period, and 692 mm during the 2018-2019 period (Figure 3). Interestingly, this situation contradicts the common assumption in the literature that increased rainfall positively influences barley yield. The higher yield during the 2017-2018 period may plausibly be attributed to the cultivation of leguminous plants in the preceding year, which were incorporated into the soil before the trial. This practice likely contributed to soil improvement, potentially explaining the yield increase observed during that specific period. The studies (Freidenreich et al., 2022; Gou et al., 2023) have shown that incorporating leguminous plants into the soil as cover crops increases crop production. Prior to setting up the experiment, leguminous plants, which were used as cover crops in the field, were mixed with the soil just before the experiment, followed by barley planting. The higher barley yield in the second year (2017-2018) of the experiment, compared to the first (2016-2017) and third years (2018-2019), is primarily attributed to the incorporation of leguminous plants into the soil. It is believed that immediately after incorporation, the effect of the legume residue becomes more pronounced in the following year due to its slow mineralization, while in the third year, it has completely decomposed and lost its impact on the soil. Furthermore, when comparing the three annual periods, it is clear that variations exist in grain yield performance. Notably, the years 2017-2018 recorded consistently higher yields compared to the preceding and succeeding years. This discrepancy could potentially be attributed to climate fluctuations specific to the Gobustan region during those years. The relatively milder conditions and possibly favorable precipitation patterns during the 2017-2018 period might have significantly contributed to the enhanced barley yields observed during that time frame. Conversely, the dip in yields during the 2018-2019 period suggests the potential influence of less conducive climate conditions or other environmental factors. These disparities underscore the intricate relationship between agricultural outcomes and the broader climatic context, emphasizing the need for adaptable strategies to accommodate such variations and maintain sustainable yields.

In conclusion, the results of this study highlight the dynamic interplay between seed rates, NPK fertilizer application, and climate dynamics on barley grain yield within the Chestnut soil type of the Gobustan district. The observed variations in yield across the three years further emphasize the importance of considering climate variability and its potential implications for agricultural outcomes. Going forward, the insights derived from this study can contribute significantly to the development of targeted and adaptable agricultural strategies, which are essential for ensuring sustainable crop production in the face of the region's changing climate scenario. This conclusion aligns with the findings of Clark (1974), who, in his study on barley, suggested that the variation in barley yields over successive years may be attributed to climate fluctuations. Similarly, Cammarano (2019) conducted research on the influence of climate change on barley yield in the Mediterranean and projected a negative impact due to drier and hotter conditions. The study explored various climate scenarios, indicating potential yield reductions of up to 27% under dry conditions, while wetter projections saw an 8% increase. The study also emphasized the role of interactions between soil type, rainfall, and temperature in influencing water-stress dynamics and yield variations, reinforcing the necessity of location-specific adaptation strategies in response to changing climate conditions.

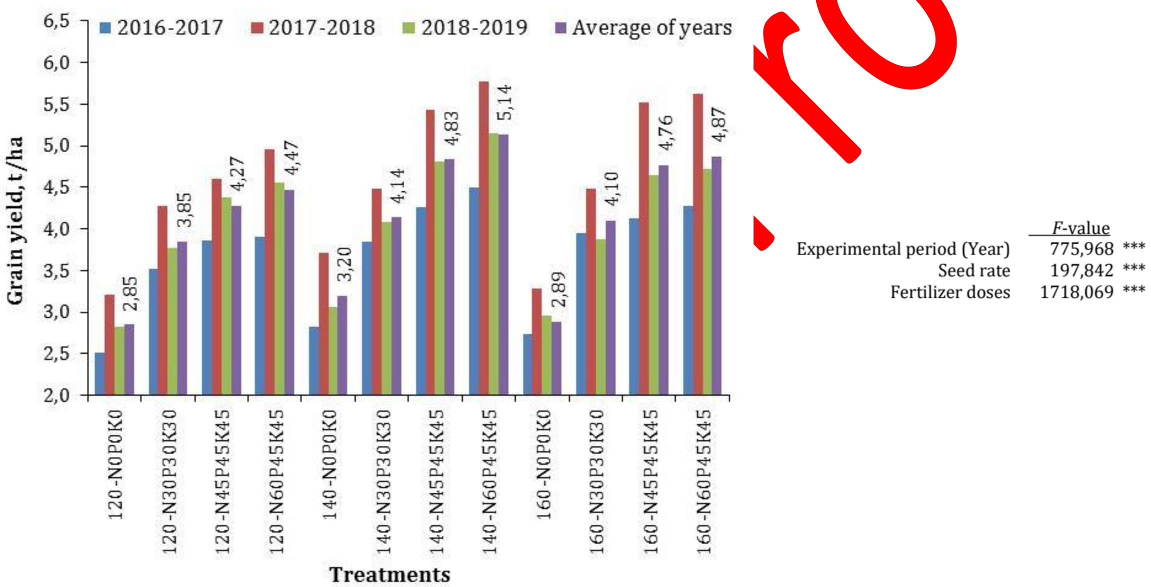


Figure 2. Changes in grain yield across treatments during the experimental periods

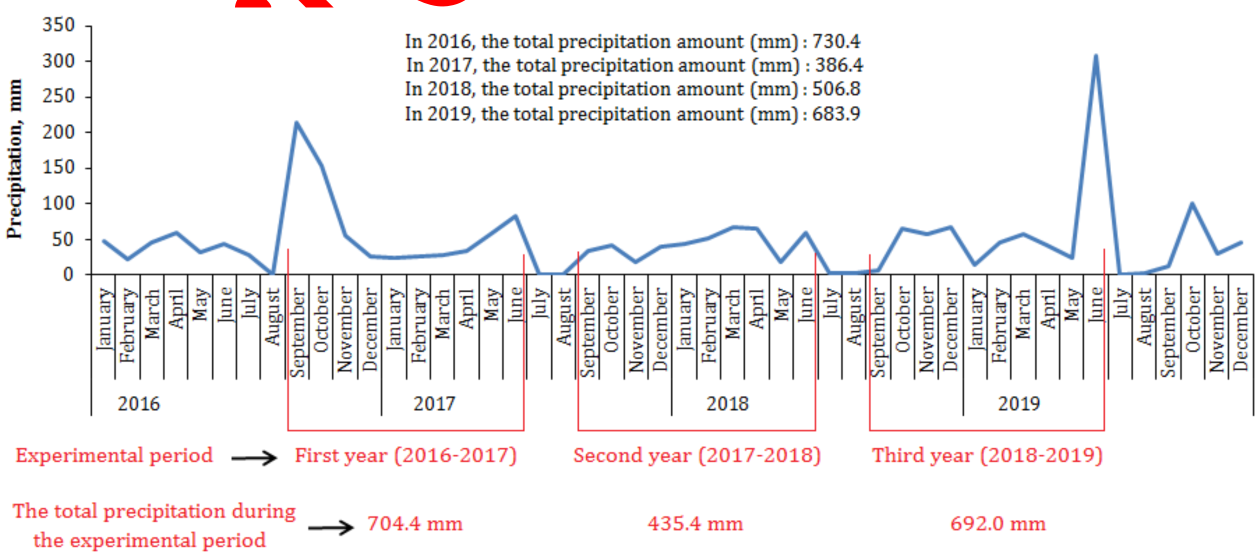
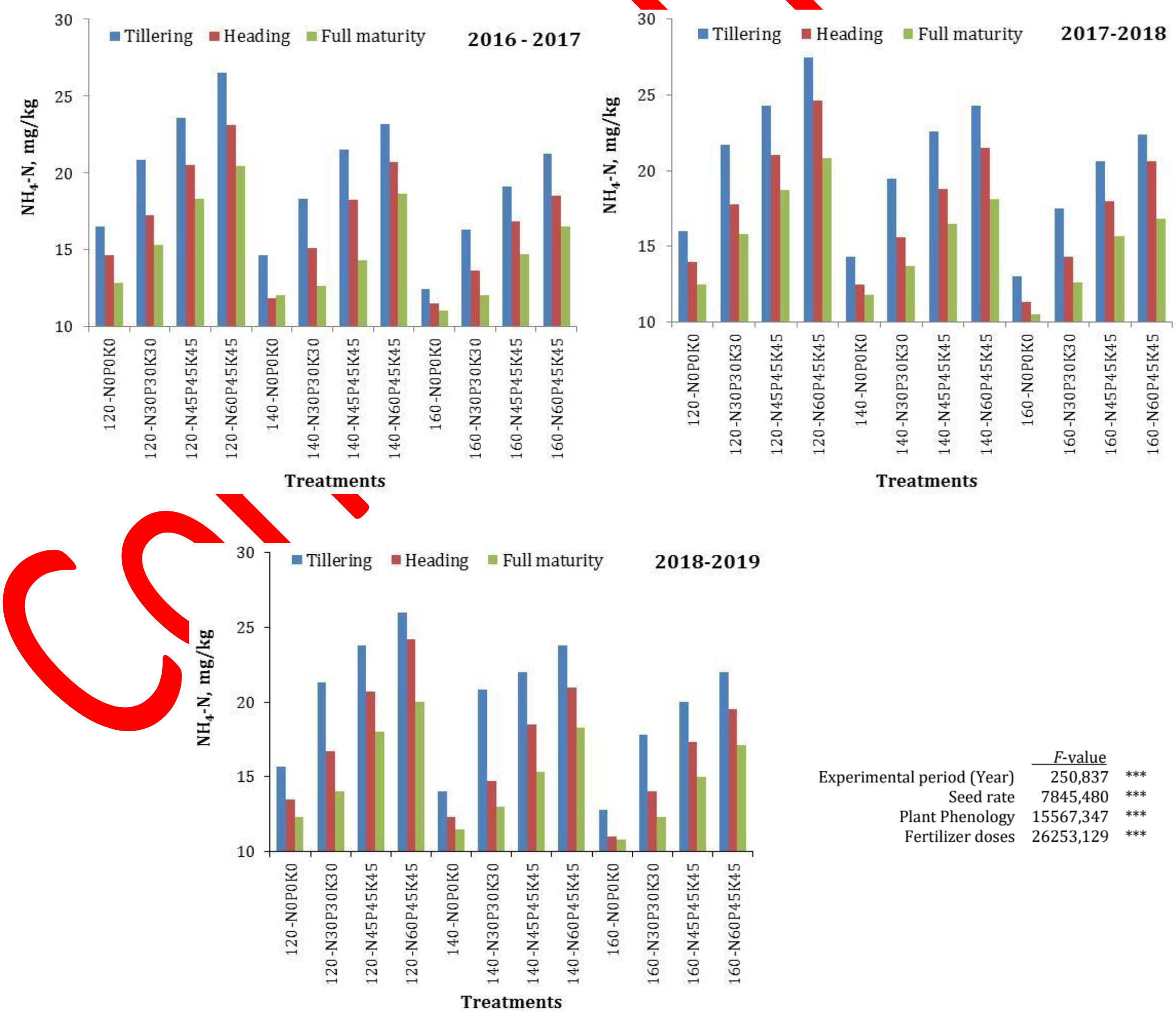


Figure 3. The precipitation amounts in the location where the trial site is located during the experimental periods

Changes in Soil Ammonium Content

Figure 3 illustrates the dynamics of soil NH_4^+ content across different growth stages and treatments over the three-year experimental period (2016-2019). The data provides insights into how varying NPK fertilizer applications and different barley seed quantities influence NH_4^+ levels. The investigation into the variations in soil NH_4^+ content across different treatments and growth stages offers crucial insights into the complex interactions between fertilizer applications, barley growth, and nutrient dynamics. As the barley plant progresses from the tillering to the full maturity stage, it is observed that the soil NH_4^+ content tends to decrease. This decline can be attributed to the plant's uptake of NH_4^+-N from the soil as it transitions through its phenological development.

NPK fertilization had a significant impact on the NH_4^+ content of the soil (Figure 4). With the increase in the dose of NPK fertilizer, the content of NH_4^+-N increased. Similarly, Rutkowski and Łysiak (2023) found that increasing doses of nitrogen fertilizer application (0 kg, 60 kg, and 120 kg N/ha) in soils where cherries are cultivated resulted in an increase in the ammonium content of the soil. Throughout the experimental years (2016-2019), the results consistently indicate that as the plant advances through its growth stages, the soil's NH_4^+ content decreases. This decline in NH_4^+ levels is consistent with the notion that the growing barley plants actively absorb NH_4^+-N from the soil to fulfill their nutritional requirements. Consequently, the reduced availability of NH_4^+ in the soil is a direct consequence of the plant's NH_4^+ uptake. The significant impact of plant uptake on NH_4^+ levels highlights the dynamic nature of nutrient exchange between the soil and the plants. The observed differences in NH_4^+ content among the various treatments and years emphasize the interplay between fertilizer application, nutrient availability, and plant demand. Treatments with higher NPK fertilizer application rates generally exhibited elevated NH_4^+ levels, reaffirming the positive relationship between fertilization and NH_4^+ content. However, as the plant progresses from the tillering to the full maturity stage, the nutrient requirements change, leading to increased ammonium uptake and subsequent reduction in NH_4^+ content.



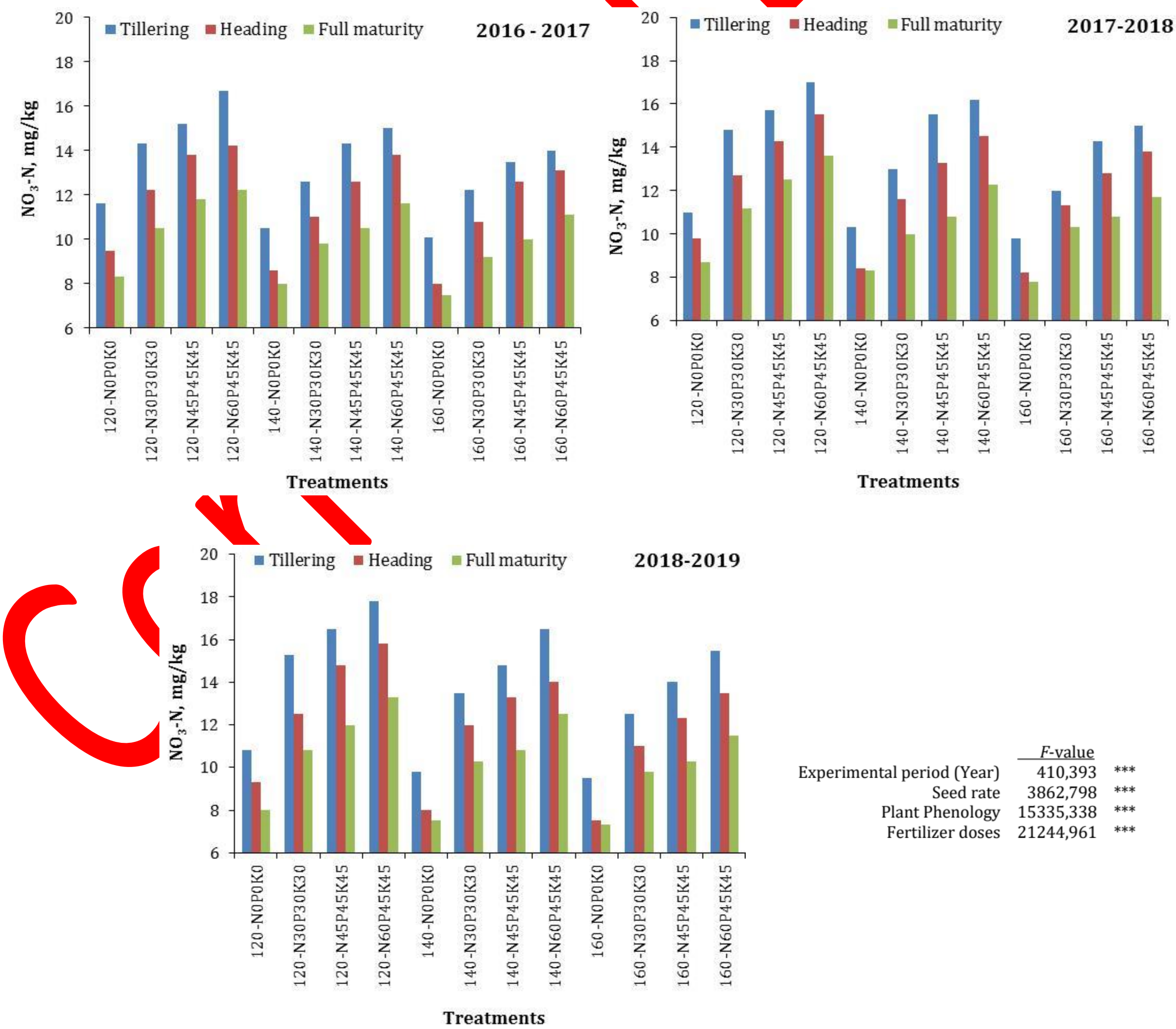
	F-value	
Experimental period (Year)	250,837	***
Seed rate	7845,480	***
Plant Phenology	15567,347	***
Fertilizer doses	26253,129	***

Figure 4. Changes in soil ammonium (NH_4-N) content across growth stages and treatments

Changes in Soil Nitrate Content

Figure 5 reveals the alterations in soil NO_3^- levels in response to varying NPK fertilizer applications and different seed quantities. Throughout the experimental years (2016-2019), consistent patterns emerged with regard to soil nitrate content in relation to different growth stages and treatments. While no significant variations were observed among the years, notable differences existed among the treatments in terms of their impact on soil NO_3^- levels. As the barley plant advanced from the tillering to the full maturity stage, a distinct trend in soil nitrate content became evident (Carillo and Rouphael, 2022). The observed trend of decreasing soil nitrate content as the plant progressed through its growth stages can be attributed to the plant's active uptake of NO_3^--N from the soil. This phenomenon is consistent with the concept that growing barley plants utilize nitrate nitrogen as a crucial nutrient to support their development and growth (Tischner, 2000; Nacry et al., 2013).

The findings suggest that the varying treatments, including different seed rates and NPK fertilizer doses, played a significant role in influencing soil NO_3^- content. Treatments with higher NPK fertilizer application rates generally led to elevated soil NO_3^- levels. This outcome is in line with the positive correlation between fertilizer application and soil nitrogen content. However, the observed decline in soil NO_3^- content from tillering to full maturity underscores the dynamic relationship between plant uptake and nutrient availability in the soil. Similarly, studies conducted by Chen et al. (2004), Petropoulos et al. (2008) and Liu et al. (2014) have found that the application of N-based chemical fertilizers at increasing levels to the soil increases the nitrogen conten of both the soil and the plant. Depending on the growth stage of the plant, they have determined that NO_3^- is transported from the soil to the plant through plant roots, leading to a decrease in soil concentration. It is noteworthy that the absence of significant year-to-year variations in soil NO_3^- content points to the stability of the results over the experimental period. This stability implies that the observed trends are consistent and can be reliably attributed to the experimental treatments.



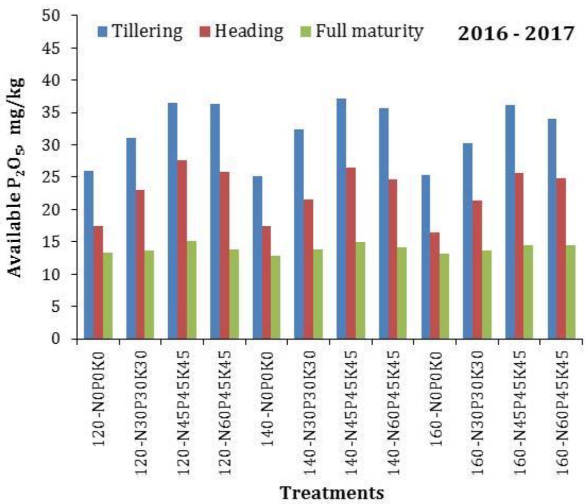
	F-value	
Experimental period (Year)	410,393	***
Seed rate	3862,798	***
Plant Phenology	15335,338	***
Fertilizer doses	21244,961	***

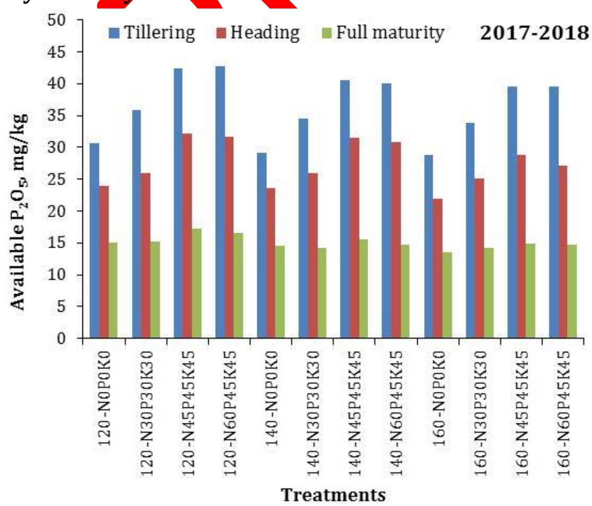
Figure 5. Changes in soil nitrate (NO_3-N) content across growth stages and treatments

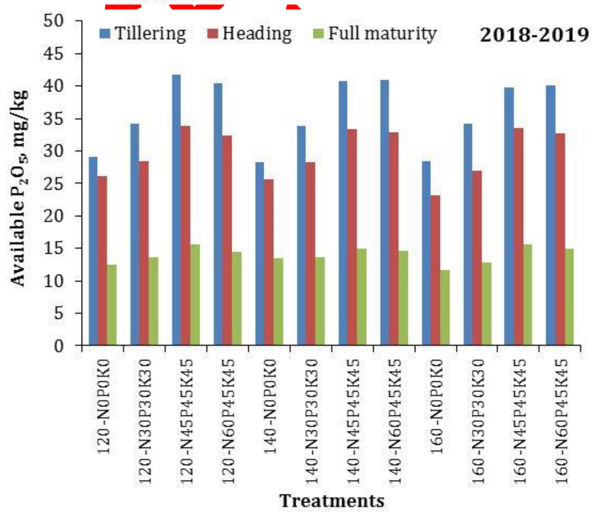
Changes in Soil Available Phosphorus Content

The alterations in soil available P_2O_5 content were examined across different treatments and growth stages over the three-year experimental period (2016-2019). The data from the soil samples collected during the tillering, heading, and full maturity stages were analyzed to understand the impact of varying NPK fertilizer applications and different seed quantities on soil phosphorus levels (Figure 6).

The trends observed in the changes of soil available P_2O_5 content were consistent with the experimental design factors. The results indicated distinct patterns in phosphorus availability influenced by both the applied treatments and the developmental stages of the barley plants. As the plant progressed from tillering to full maturity, a general trend of decreasing soil available P_2O_5 content was evident. Similarly, studies conducted by Medinski et al. (1998), Wu et al. (2020) and Wang et al. (2022) have determined that increasing application rates of NPK chemical fertilizers to the soil result in both increased crop yields and improved phosphorus content in the soil. The observed decrease in soil available phosphorus content aligns with the understanding that growing plants actively uptake phosphorus from the soil to support their growth and development. This dynamic exchange between plants and soil nutrients contributes to the observed trend of declining soil P_2O_5 levels as the plant advances through its phenological stages. Among the different treatments, those with higher NPK fertilizer application rates tended to exhibit elevated soil available P_2O_5 content. This relationship between fertilization and soil nutrient content emphasizes the influence of applied nutrients on soil properties. However, the decline in soil P_2O_5 availability over the growth stages underscores the importance of considering plant nutrient requirements and uptake dynamics in designing effective fertilization strategies. It's worth noting that while the variations in soil available P_2O_5 content were evident among different treatments and growth stages, there were no significant year-to-year differences.







	F-value	
Experimental period (Year)	1613,691	***
Seed rate	158,595	***
Plant Phenology	38578,394	***
Fertilizer doses	2972,110	***

Figure 6. Changes in soil available phosphorus (P_2O_5) content across growth stages and treatments

Changes in Soil Exchangeable Potassium Content

The variation in soil exchangeable potassium content was investigated across different treatments and growth stages over the three-year experimental period (2016-2019). Soil samples collected during the tillering, heading, and full maturity stages were analyzed to understand the impact of diverse NPK fertilizer applications and different seed quantities on soil potassium levels. Figure 7 present the changes in soil exchangeable potassium content for each treatment and growth stage across the three experimental years. These tables reveal the dynamic nature of soil potassium availability and its response to varying experimental factors. While no significant year-to-year differences were observed, notable variations emerged among the treatments in terms of their influence on soil potassium levels.

Throughout the experimental period, the results consistently indicate trends in soil exchangeable potassium content that align with the applied treatments and barley growth stages. Higher NPK fertilizer application rates generally led to elevated soil potassium levels. This outcome reflects the positive correlation between fertilization and soil nutrient content. However, as the barley plant progressed from the tillering to the full maturity stage, a noticeable reduction in soil exchangeable potassium content was observed. The observed decrease in soil exchangeable potassium content as the barley plant advanced through its phenological development can be attributed to the plant's active uptake of potassium from the soil. This trend suggests that as the plant matures, its demand for potassium increases, leading to enhanced potassium uptake and subsequent depletion of soil potassium content.

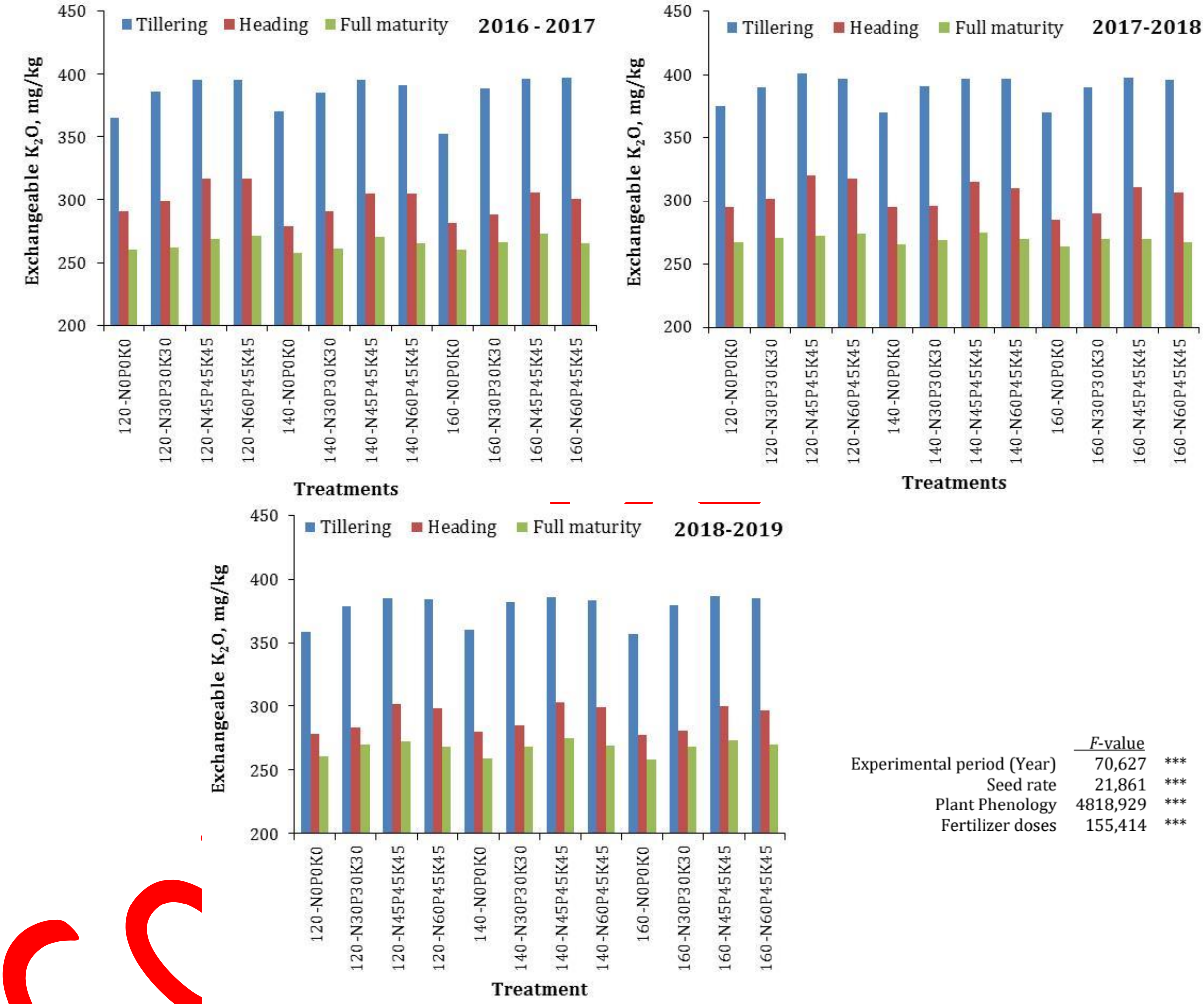


Figure 7. Changes in soil exchangeable potassium (K_2O) content across growth stages and treatments

It was determined that changes in soil exchangeable potassium content, it is noteworthy that the dynamics of soil potassium availability mirror the growth and developmental stages of the barley plant. This alignment suggests a close relationship between the plant's potassium requirements and its phenological progression. As the plant transitions from the tillering stage, characterized by early vegetative growth, to the full maturity stage, marked by reproductive and grain-filling processes, its demand for potassium increases. This intensified potassium uptake is attributed to the plant's metabolic activities, which peak during the reproductive phase. Similarly, studies conducted by Song et al. (2020) and Setu (2022) have determined that increasing levels of NPK chemical fertilizers applied to the soil, depending on the increasing application rates, both increase crop yield and enhance the available potassium content. In the field trial, the effect of increasing NPK doses on the available potassium content of the soil, while showing a similar effect to mineral nitrogen and available phosphorus content, is not as pronounced between application doses, unlike N and P. This situation is undoubtedly related to the behavior of nutrients in the soil. In a study conducted by Wihardjaka et al. (2022), it was found that potassium added to the soil is continuously taken up by plants from germination to harvest, and the remaining amount in the soil continuously decreases, with the difference being reduced at high K doses. The decrease in soil exchangeable potassium content can be attributed to the plant's ability to absorb potassium from the soil to fulfill its physiological needs. This observation aligns with the widely recognized phenomenon that plants actively extract nutrients from the soil to support their growth and reproduction. In the case of potassium, the plant's demand is particularly pronounced during the latter stages of development, when it allocates resources for grain production. Furthermore, the variations among different treatments in terms of their impact on soil exchangeable potassium content indicate that fertilization strategies play a significant role in influencing soil nutrient dynamics. Treatments with higher NPK fertilizer application rates led to elevated soil potassium levels, reinforcing the positive relationship between fertilization and soil nutrient availability. However, the plant's dynamic potassium requirements during different growth stages resulted in the decline of soil potassium content as the plant progressed towards full maturity.

Conclusion

In this study, we conducted field experiments over a three-year period to assess the effects of different seed rates and NPK fertilizer doses on the growth, development, and yield of the "Celilabad-19" barley variety in the Chestnut soil type of the Gobustan district. The results obtained from this investigation shed light on the dynamic interplay between agricultural practices, soil properties, and climate dynamics, contributing valuable insights to sustainable barley cultivation strategies in the region. The findings from the experimental site characterization emphasized the significance of the Gobustan district's unique climate characteristics, which encompass a semi-arid warm temperate desert climate in the southern part and a semi-arid warm temperate steppe climate in the northern part. These distinct climatic conditions, characterized by variations in temperature and precipitation, significantly influence agricultural practices and water management strategies. The variations in climate conditions across the experimental years highlighted the need for adaptable strategies to ensure consistent and sustainable yields.

The experimental design encompassed a comprehensive investigation into the effects of varying seed rates and NPK fertilizer applications on barley grain yield. The results demonstrated that nitrogen (N) application had a significant positive impact on grain yield, with treatment 140-N60P45K45 consistently yielding the highest grain yield. However, the study also revealed year-to-year variations in grain yield performance, indicating the influence of climate fluctuations on agricultural outcomes. Analyzing soil nutrient dynamics, we observed trends in soil ammonium, nitrate, available phosphorus, and exchangeable potassium content across different treatments and growth stages. The results highlighted the intricate relationships between fertilizer applications, plant uptake, and soil nutrient availability. Treatments with higher NPK fertilizer application rates generally led to elevated soil nutrient levels. Nonetheless, the decline in soil nutrient content as the barley plant progressed from tillering to full maturity underscored the dynamic nature of nutrient exchange between plants and soil.

In conclusion, this study provides valuable insights into the complex interactions between seed rates, NPK fertilizer applications, soil properties, and climate dynamics on barley growth, development, and yield. The observed variations in yield and soil nutrient content across the experimental years underscore the need for adaptive agricultural strategies that account for climate variability and changing environmental conditions. The knowledge gained from this study can guide the development of targeted and sustainable cultivation practices, crucial for ensuring food security and crop production in the Gobustan district's changing climate scenario. Additionally, the insights gleaned from this research can serve as a foundation for further studies on optimizing nutrient management and enhancing agricultural resilience in similar agroecological contexts.

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