EUROASIA
Matematik, Mühendislik, Doğa ve Tıp Bilimleri Dergisi
Journal of Mathematics, Engineering, Natural & Medical Science

Research Article e-ISSN: 2667-6702 https://doi.org/10.5281/zenodo.20515147

# Effects of Basal Fertilizer Forms, Nitrogen Sources and Nitrogen Doses on Wet Gluten Content and Hectoliter Weight of Bread Wheat under Rain-fed and Irrigated Conditions

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**Article Info**

Received: 03.02.2026
Accepted: 15.03.2026

**Keywords**
Nitrogen fertilization
Fertilizer forms
Wet gluten
Hectoliter weight
Wheat

**Abstract:** Nitrogen fertilization plays a critical role in determining both yield and technological quality of bread wheat. This study aimed to evaluate the effects of different basal fertilizer forms, nitrogen sources, and nitrogen doses on wet gluten content and hectoliter weight of bread wheat. The experiment was conducted during the 2021–2022 growing season in Diyarbakır, Türkiye under rain-fed and irrigated conditions using a randomized complete block design with four replications. Three different basal fertilizer forms (13-25-5, 18-46-0 and 20-20-0) were applied at sowing, while nitrate and urea were used as top-dressing nitrogen sources at two nitrogen levels (120 and 170 kg $ha^{-1}$). The results showed that fertilizer applications significantly affected wet gluten content and hectoliter weight under both environmental conditions. The highest wet gluten values were obtained from the @13-25-5 + Urea2 treatment under rain-fed conditions and from the @13-25-5 + Nitrate2 treatment under irrigated conditions. Conversely, the lowest wet gluten values were observed in the @20-20-0 + Nitrate1 treatment. Hectoliter weight was also significantly influenced by fertilizer treatments, with the highest values obtained from the @18-46-0 + Urea1 application under rain-fed conditions and from the @20-20-0 + Urea1 treatment under irrigated conditions. The results indicate that both nitrogen form and nitrogen dose play an important role in improving wheat grain quality parameters. Appropriate combinations of basal fertilizer and nitrogen source may enhance technological quality traits of bread wheat under different conditions.

## 1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops worldwide and plays a critical role in global food security (Filip et al., 2023) According to FAO statistics, global wheat production exceeded 800 million tons in 2022, making it one of the most widely cultivated staple crops (FAO, 2022). Wheat provides a major portion of daily caloric intake for more than one-third of the world's population and is an essential source of carbohydrates and plant protein (Shewry and Hey, 2015). Grain quality traits such as wet gluten content and hectoliter weight are among the most important technological parameters determining the suitability of wheat for bread production. Wet gluten content is directly associated with dough elasticity, bread volume, and baking performance (Ortolan & Steel, 2017; Kızılgeçi & Cebeli, 2024). Similarly, hectoliter weight is widely used as a quality indicator reflecting grain density, milling yield, and grain filling efficiency (Svečnjak et al., 2007; Okuyama et al., 2020). Therefore, improving grain quality parameters has become an important objective in wheat production systems. Nitrogen fertilization plays a crucial role in improving both yield and grain quality of wheat. Nitrogen is a key component of amino acids and proteins and significantly affects grain protein accumulation and gluten strength (Zecevic et al., 2010). Numerous studies have demonstrated that increasing nitrogen availability enhances protein content and gluten characteristics of wheat grains (Horvat et al., 2021; Yildirim et al., 2022). However, the response of wheat quality traits to nitrogen fertilization may vary depending on nitrogen source, fertilizer form, environmental conditions, and crop management practices. Different nitrogen forms such as nitrate ($NO_3^-$-N), ammonium ($NH_4^+$-N), and urea are commonly used in agricultural production systems. Among these forms, urea is the most widely used nitrogen fertilizer globally due to its high nitrogen content and relatively low cost (Wang et al., 2025). However, nitrogen form influences plant uptake efficiency, nitrogen metabolism, and grain quality parameters (Glass, 2003; Liao et al., 2023). Previous research has reported that different nitrogen sources may lead to variations in grain protein composition and gluten quality (Horvat et al., 2021). In addition to nitrogen form, basal fertilizer composition also plays an important role in wheat nutrition. Balanced fertilization involving nitrogen, phosphorus, and potassium can improve plant growth, grain filling, and grain quality attributes (Grant et al., 2001). Phosphorus is essential for root development and energy metabolism, while potassium plays an important role in enzyme activation and grain filling processes (Marschner, 2012). Therefore, the interaction between basal fertilizer composition and nitrogen fertilization may significantly affect wheat quality characteristics. Environmental conditions such as water availability also influence wheat quality parameters. Rain-fed and irrigated production systems often exhibit different nitrogen dynamics and grain protein accumulation patterns (Garrido-Lesmes et al., 2018). Under limited water conditions, nitrogen utilization efficiency may decrease, which may affect grain quality traits. Despite numerous studies evaluating nitrogen fertilization in wheat, limited research has investigated the combined effects of basal fertilizer forms, nitrogen sources, and nitrogen doses on technological grain quality traits under different moisture conditions. Therefore, this study aimed to evaluate the effects of different basal fertilizer forms, nitrogen sources, and nitrogen doses on wet gluten content and hectoliter weight of bread wheat under rain-fed and irrigated conditions.

## 2. Material and Methods

### 2.1. Experimental site

The field experiment was conducted during the 2021–2022 growing season at the Agricultural Research Area of Teknobiltar Company located in Diyarbakır, Southeastern Anatolia Region of Türkiye (37°55′ 36.27″ N latitude and 40°15′ 17.90″ E longitude at an altitude of approximately 580 m above sea level). Meteorological conditions during the 2021–2022 growing season are presented in Table 1. According to the data, the total rainfall recorded during the wheat growing season (November–June) was 237 mm, which was considerably lower than the long-term average precipitation of 492.6 mm reported for the region between 1929 and 2023 (MS, 2023). Monthly rainfall distribution was irregular, with the highest precipitation observed in March (56.8 mm), whereas relatively low rainfall occurred in April (9.8 mm) and June (10.8 mm). The mean temperature during the experimental period was 11.95 °C, which was slightly higher than the long-term regional average. Temperatures were relatively low during the winter months (December–February), while a noticeable increase was observed during the spring and early summer periods, reaching 27.6 °C in June. Trials were conducted under both rainfed and irrigated regimes; Irrigation was applied twice, at the stem elongation and heading stages, using a sprinkler system. Each irrigation lasted approximately 12 hours. Rain-fed plots received no irrigation. The soil reaction was slightly alkaline with a pH of 7.87, while the electrical conductivity (EC) was 0.1 dS $m^{-1}$, indicating non-saline soil conditions. Soil nutrient analysis showed that available nitrogen and phosphorus contents were relatively low, with values of 2.7 kg $ha^{-1}$ and 10.3 kg $ha^{-1}$, respectively. In contrast, the potassium content of the soil was high (969.5 kg $ha^{-1}$).

**Table 1**. Monthly mean temperature (°C) and total rainfall (mm) during the wheat growing season (November–June) in the experimental area.

| Months | November | December | January | February | March | April | May | June | Mean/Total |
|---|---|---|---|---|---|---|---|---|---|
| Temperature (°C) | 11.9 | 4.5 | 2.3 | 7.4 | 5.9 | 17.4 | 18.6 | 27.6 | 11.95 |
| Rainfall (mm) | 20.8 | 33.2 | 25.8 | 35.8 | 56.8 | 9.8 | 44.0 | 10.8 | 237 |

## 2.2. Experimental design

The experiment was arranged in a randomized complete block design (RCBD) with a factorial arrangement and four replications. Bread wheat (*Triticum aestivum* L.) cultivar Empire Plus was used as plant material. The wheat was sown on 11 December 2021 at a planting density of 500 seeds $m^{-2}$. The total number of experimental plots was 96 (3 basal fertilizer forms × 2 nitrogen sources × 2 nitrogen doses × 2 water regimes × 4 replications). Each plot measured 1.2 m × 4 m (4.8 $m^2$) and consisted of six rows spaced 20 cm apart. The distance between plots and blocks was 1 m and 2 m, respectively (Figure 1).

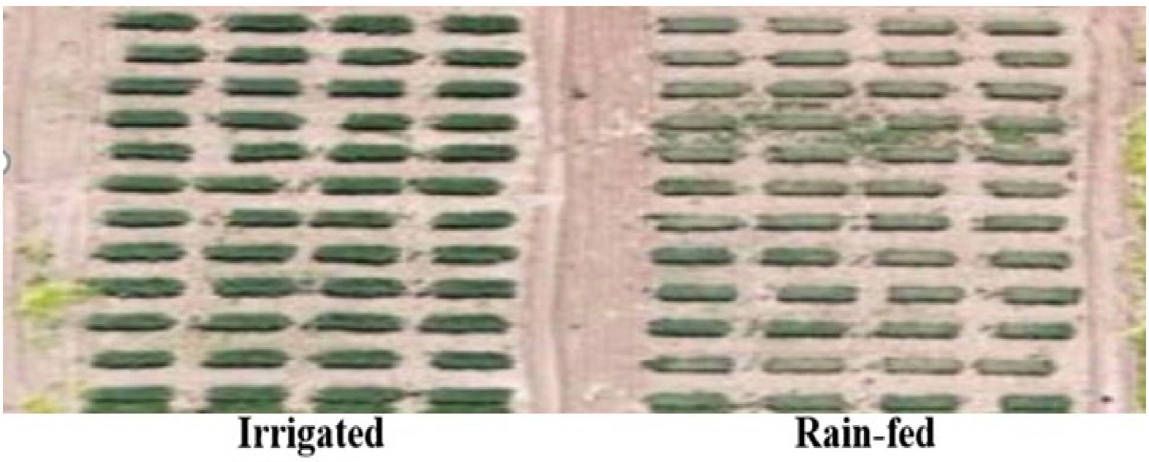


**Figure 1.** Aerial view of the experimental field showing rain-fed and irrigated wheat plots.

## 2.3. Fertilizer treatments

Three different basal fertilizers were used in the experiment: 13–25–5, 18–46–0, and 20–20–0. Basal fertilizers were applied to the soil at sowing time. In addition to basal fertilization, nitrogen was applied as top dressing using two different nitrogen sources: nitrate-based fertilizer and urea. Nitrate source: Calcium ammonium nitrate (26% N) and Urea: 46%

N. Two nitrogen application levels were evaluated for each nitrogen source. The nitrogen 1 treatment corresponded to a total nitrogen application of 120 kg N $ha^{-1}$, while the nitrogen 2 treatment corresponded to 170 kg N $ha^{-1}$. The total nitrogen amounts were calculated by considering the nitrogen supplied by both basal and top-dressing fertilizers. Phosphorus was applied at a constant rate of 70 kg P $ha^{-1}$ in all treatments. Potassium was applied at 14 kg K $ha^{-1}$ only in the treatments where 13–25–5 basal fertilizer was used, while no potassium was applied in the treatments receiving 18–46–0 and 20–20–0 basal fertilizers. Top-dressing nitrogen fertilizers were applied during the crop growth period according to the treatment combinations. The experimental treatments consisted of three basal fertilizers × two nitrogen sources (nitrate and urea) × two nitrogen levels, resulting in a total of 12 fertilizer treatments. The nutrient amounts applied in each treatment are presented in Table 2.

**Table 2**. Nutrient composition (N, P, and K) of the fertilizer forms, nitrogen sources, and nitrogen dose treatments applied in the experiment.

| Fertilizer Forms | N (kg $ha^{-1}$) | P (kg $ha^{-1}$) | K (kg $ha^{-1}$) |
|---|---|---|---|
| @13.25.5+Nitrate1 | 120 | 70 | 14 |
| @13.25.5+Nitrate2 | 170 | 70 | 14 |
| @13.25.5+Urea1 | 120 | 70 | 14 |
| @13.25.5+Urea2 | 170 | 70 | 14 |
| @18.46.0+Nitrate1 | 120 | 70 | 0 |
| @18.46.0+Nitrate2 | 170 | 70 | 0 |
| @18.46.0+Urea1 | 120 | 70 | 0 |
| @18.46.0+Urea2 | 170 | 70 | 0 |
| @20.20.0+Nitrate1 | 120 | 70 | 0 |
| @20.20.0+Nitrate2 | 170 | 70 | 0 |
| @20.20.0+Urea1 | 120 | 70 | 0 |
| @20.20.0+Urea2 | 170 | 70 | 0 |

### 2.4. Crop management

Herbicides were applied to control both broadleaf and grassy weeds during the growing season. Standard agronomic practices were followed throughout the experimental period.

### 2.5. Measured Parameters

Wet gluten content (%): Grain quality measurements were conducted directly on intact grain samples without milling. Representative samples collected from each plot were analyzed using a GrainSense device, and wet gluten content was expressed as percentage (%).

Hectoliter weight (kg $hL^{-1}$): Grain samples obtained from each replication were subsampled three times. Each subsample was uniformly filled into a 1/4 liter standard hectoliter container, leveled without compression, and weighed. Hectoliter weight was calculated based on the measured mass and container volume.

### 2.6. Statistical analysis

The experimental data were analyzed using analysis of variance (ANOVA) according to a randomized complete block design (RCBD) with a factorial arrangement and four replications. Differences among treatment means were evaluated using the Duncan test at the 5% significance level**.** All statistical analyses were performed using JMP Clinical 18 statistical software (SAS Institute Inc., Cary, NC, USA)**.**

## 3. Result and Discussion

### 3.1. Wet gluten content

Fertilizer applications had a statistically significant ($p < 0.01$) effect on wet gluten content under both rain-fed and irrigated conditions (Table 3). The analysis of variance indicated that fertilizer treatments significantly influenced gluten formation in bread wheat, suggesting that nitrogen management plays a critical role in determining grain gluten quality. Under rain-fed conditions, wet gluten values ranged between 30.06% and 39.00%. The highest wet gluten content (39.00%) was obtained from the @13.25.5 + Urea2 treatment, while the lowest value (30.06%) was observed in the @ 20.20.0 + Nitrate1 treatment. Under irrigated conditions, wet gluten values ranged from 30.69% to 34.19%. The highest wet gluten content (34.19%) was recorded in the @13.25.5 + Nitrate2 treatment, whereas the lowest value (30.69%) was obtained from the @20.20.0 + Nitrate1 application (Table 3). Mean comparisons showed statistically significant differences among fertilizer treatments. Higher nitrogen doses generally resulted in increased wet gluten values. This trend can be explained by the role of nitrogen in protein synthesis and gluten formation in wheat grains. Nitrogen availability during grain filling enhances the accumulation of storage proteins such as gliadins and glutenins, which directly contribute to gluten strength (Zecevic et al., 2010). Similar findings were reported by Abad et al. (2004), who observed that increased nitrogen fertilization significantly improved gluten content and baking quality in wheat. Conversely, the lowest gluten values observed in the @20.20.0 + Nitrate1 treatment may be associated with insufficient nitrogen availability during the critical grain filling period. Limited nitrogen supply can reduce protein synthesis and ultimately decrease gluten formation in wheat kernels (Grant et al., 2001).

**Table 3**. Effects of fertilizer forms, N forms and N doses on contents of gluten (%) of bread wheat in rain-fed and irrigation conditions

| Wet Gluten (%) | | | |
|---|---|---|---|
| Application of Fertilizer | | Rain-fed | Irrigation |
| @13.25.5+Nitrate1 | | 37.25bcd | 31.91cde |
| @13.25.5+Nitrate2 | | 36.44cde | 34.19a |
| @13.25.5+Urea1 | | 36.94b-e | 33.50ab |
| @13.25.5+Urea2 | | 39.00a | 34.06a |
| @18.46.0+Nitrate1 | | 36.25c-f | 30.88de |
| @18.46.0+Nitrate2 | | 37.69abc | 33.44ab |
| @18.46.0+Urea1 | | 35.69def | 33.13abc |
| @18.46.0+Urea2 | | 38.13ab | 33.56ab |
| @20.20.0+Nitrate1 | | 30.06g | 30.69e |
| @20.20.0+Nitrate2 | | 35.38ef | 33.25abc |
| @20.20.0+Urea1 | | 34.81f | 32.25bcd |
| @20.20.0+Urea2 | | 38.19ab | 32.63bc |
| Source | df | MS (rain-fed) | MS (irrigation) |
| Fertilizer application | 11 | 23.92** | 5.31** |
| CV (%) | | 3.1 | 3 |
| LSD(%5) | | 1.60 | 1.40 |

** %1 significant; MS: Mean square

The radar chart presented in Figure 2 illustrates the variation in wet gluten content of bread wheat under rain-fed and irrigated conditions across different fertilizer treatments. The graphical representation clearly shows that nitrogen management significantly influenced gluten formation in wheat grains. Under rain-fed conditions, the polygon corresponding to the fertilizer treatments expands notably in the applications involving higher nitrogen doses. In particular, the @13-25-5 + Urea2 treatment exhibited the highest wet gluten content, indicating that the combination of balanced basal fertilization and higher nitrogen availability promotes protein accumulation in wheat grains. Conversely, the @20-20-0 + Nitrate1 treatment showed the lowest gluten values, reflecting the limited nitrogen availability in this treatment. Under irrigated conditions, the variation among fertilizer treatments was relatively narrower compared with rain-fed conditions. Nevertheless, treatments involving higher nitrogen levels still produced relatively higher gluten contents. The @13-25-5 + Nitrate2 and @13-25-5 + Urea2 applications showed superior performance, suggesting that adequate nitrogen supply combined with favorable moisture conditions improves gluten formation.

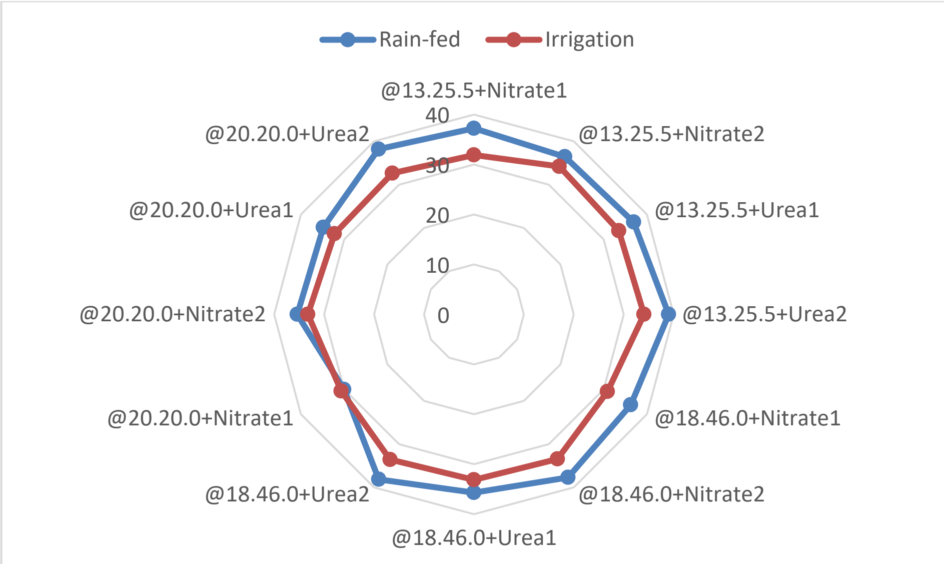


**Figure 2**. Radar chart illustrating the variation in wet gluten content (%) of bread wheat under rain-fed and irrigated conditions as affected by different basal fertilizer forms, nitrogen sources, and nitrogen doses.

### 3.2. Hectoliter weight

Hectoliter weight was also significantly affected by fertilizer treatments under both rain-fed and irrigated conditions. The analysis of variance revealed highly significant ($p < 0.01$) differences among treatments under rain-fed conditions and significant differences ($p < 0.05$) under irrigated conditions (Table 4). Under rain-fed conditions, hectoliter weight varied between 62.80 kg and 71.85 kg. The highest hectoliter value (71.85 kg) was obtained from the @18.46.0 + Urea1 treatment, while the lowest value (62.80 kg) was observed in the @20.20.0 + Nitrate1 treatment. Under irrigated conditions, hectoliter weight ranged from 66.80 kg to 71.40 kg. The highest value (71.40 kg) was recorded in the @20.20.0 + Urea1 treatment, while the lowest value (66.80 kg) was obtained from the @18.46.0 + Urea2 treatment (Table 4). Hectoliter weight is widely considered an indicator of grain density and grain filling efficiency. Balanced nutrient supply improves photosynthetic activity and assimilate translocation to developing grains, thereby increasing grain density and hectoliter weight (Liu et al., 2007). In the present study, treatments involving balanced nitrogen supply and appropriate fertilizer combinations produced higher hectoliter values. Environmental conditions also influenced the response of hectoliter weight to fertilizer treatments. Irrigation may enhance nutrient uptake and grain filling processes, which can lead to improved grain density and grain quality parameters (Garrido-Lesmes et al., 2018).

**Table 4**. Effects of fertilizer forms, N forms and N doses on hectoliter weight (%) of bread wheat in rain-fed and irrigation conditions

| | | Hectoliter (kg) | |
|---|---|---|---|
| Application of Fertilizer | | Rain-fed | Irrigation |
| @13.25.5+Nitrate1 | | 63.95de | 70.05abc |
| @13.25.5+Nitrate2 | | 69.80ab | 67.95bcd |
| @13.25.5+Urea1 | | 68.20bc | 67.60cd |
| @13.25.5+Urea2 | | 68.90bc | 68.25bcd |
| @18.46.0+Nitrate1 | | 67.80bc | 70.10abc |
| @18.46.0+Nitrate2 | | 64.95de | 67.05d |
| @18.46.0+Urea1 | | 71.85a | 68.70a-d |
| @18.46.0+Urea2 | | 68.05bc | 66.80d |
| @20.20.0+Nitrate1 | | 62.80e | 70.20abc |
| @20.20.0+Nitrate2 | | 68.80bc | 70.65ab |
| @20.20.0+Urea1 | | 68.60bc | 71.40a |
| @20.20.0+Urea2 | | 66.73cd | 68.40bcd |
| Source | df | MS (rain-fed) | MS(irrigation) |
| Application of fertilizer | 11 | 28.69** | 9,05* |
| CV (%) | | 2.9 | 2.9 |
| LSD(%5) | | 2.84 | 2.86 |

*,** %5, %1 significant, respectively; MS: Mean square

The radar chart presented in Figure 3 illustrates the variation in hectoliter weight of bread wheat under rain-fed and irrigated conditions across different fertilizer treatments. The graphical distribution indicates that fertilizer composition, nitrogen source, and nitrogen dose had a considerable influence on grain density and grain filling characteristics. Under rain-fed conditions, substantial variation among fertilizer treatments was observed. The @18-46-0 + Urea1 treatment exhibited the highest hectoliter weight, indicating that an adequate nitrogen supply combined with appropriate phosphorus availability can enhance grain filling efficiency under limited moisture conditions. In contrast, the lowest hectoliter weight was recorded in the @20-20-0 + Nitrate1 treatment, suggesting that lower nitrogen availability may reduce grain density and grain filling performance. Under irrigated conditions, hectoliter weight values were generally higher and more stable across treatments compared with rain-fed conditions. The @20-20-0 + Urea1 treatment produced the highest hectoliter value, indicating that sufficient soil moisture together with balanced nitrogen fertilization may promote better assimilate translocation and grain development.

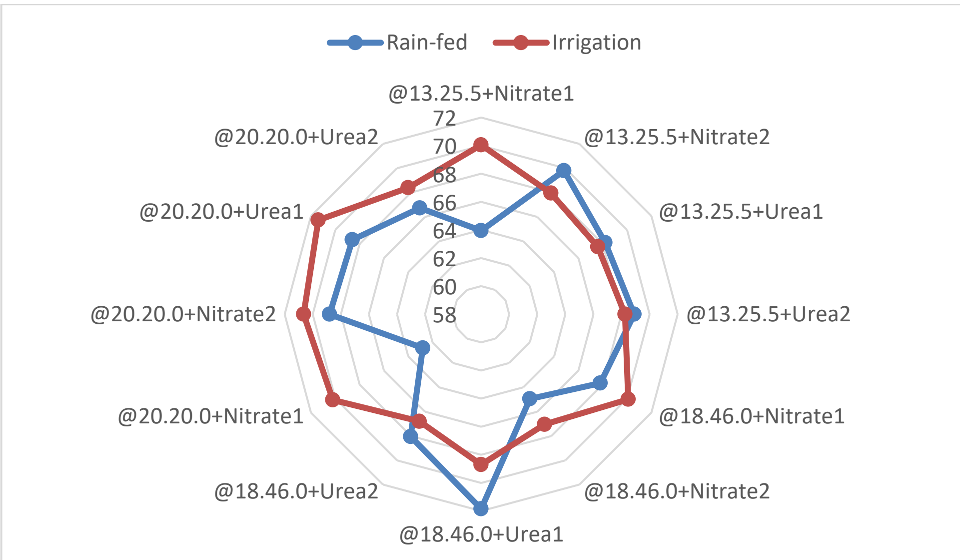


**Figure 3.** Radar chart illustrating the variation in hectoliter weight (kg) of bread wheat under rain-fed and irrigated conditions as affected by different basal fertilizer forms, nitrogen sources, and nitrogen doses.

## 4. Conclusion

The results of this study demonstrated that fertilizer form, nitrogen source, and nitrogen dose significantly influence the technological quality parameters of bread wheat. In particular, wet gluten content was strongly affected by nitrogen management practices. Higher nitrogen doses generally increased gluten content, indicating the positive role of nitrogen availability in protein accumulation in wheat grains. Among the treatments, the @13-25-5 basal fertilizer combined with higher nitrogen levels (Urea2 or Nitrate2) produced the highest wet gluten values under both rain-fed and irrigated conditions. Similarly, hectoliter weight showed significant variation among fertilizer treatments. The highest hectoliter values were generally obtained from applications involving balanced nitrogen supply and appropriate fertilizer combinations. The results suggest that optimizing nitrogen fertilization strategies can improve grain quality traits without compromising agronomic performance. Overall, the findings highlight the importance of selecting appropriate fertilizer forms and nitrogen doses for improving wheat quality parameters. These results provide valuable insights for sustainable nitrogen management strategies in bread wheat production under both rain-fed and irrigated environments.

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