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Original Article

Nutrient Use Efficiency in Wheat (*Triticum aestivum* L.) Variety, DBW-187, Affected by Different Doses of Nitrogen, Phosphorus and Potassium

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Abstract: Although nitrogen (N), phosphorus (P), and potassium (K) are important nutrients for the creation of high crop yields that support the growing global population, overuse of these nutrients and their underuse cause ecological damage. Therefore, optimization of NPK use efficiency should be the focus for better sustainable agricultural practices. At Uttaranchal University in Dehradun, Uttarakhand, India, a field experiment named "A comparative study of nutrient use efficiency in wheat (*Triticum aestivum* L.) variety DBW-187 affected by different doses of NPK" was carried out during the Rabi season (October to March) of 2023–2024. Seven treatments and three replications were used in the randomized complete block design (experiment: T1 was control (no fertilizer), T2 was 25% recommended dose of fertilizers (RDF), T3 was 50% RDF, T4 was 75% RDF, T5 was 100% RDF, T6 was 125% RDF, and T7 was 150% RDF. On December 6, 2023, the DBW-187 cultivar was planted with inorganic fertilizers, specifically urea, Diammonium Phosphate, and Muriate of Potash. Seventy-five kg ha^{-1} of nitrogen, 40 kg ha^{-1} dosages of potassium, and 60 kg ha^{-1} phosphorus were applied at the base, with the remaining nitrogen being top-dressed at 40 days after sowing (DAS) before the second watering. Results showed that application of 100% RDF (150:60:40 kg ha^{-1} N:P:K) significantly improved crop performance, recording the highest grain yield (75.8 q ha^{-1}), biological yield (189.3 q ha^{-1}), leaf area index (1.97 at 90 DAS), and benefit–cost ratio (2.54) compared with the control. Grain protein content increased with higher fertilizer doses, ranging from 8.24% (control) to 10.75% (150% RDF); however, yields did not increase proportionately beyond 100% RDF. Excess fertilizer application (125–150% RDF) resulted in taller plants and higher protein content but lower nutrient use efficiency and economic returns. Overall, 100% RDF was identified as the optimum fertilizer dose for maximizing yield, nutrient use efficiency, and profitability of wheat variety DBW-187 under irrigated conditions.

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most important staple cereal crops globally, contributing more than 20% of the total dietary calories and protein consumed worldwide. In India, wheat plays a central role in ensuring food security, occupying over 30 million hectares with steadily increasing production demands driven by population growth and changing consumption patterns. Sustaining wheat productivity under these conditions requires efficient nutrient management, particularly the balanced application of nitrogen (N), phosphorus (P), and potassium (K), which are essential for crop growth, yield formation, and grain quality [1-3].

Despite widespread fertilizer use, nutrient use efficiency (NUE) in wheat remains relatively low, with a substantial proportion of applied nutrients lost through leaching, volatilization, runoff, and denitrification. Such inefficiencies not only increase production costs but also pose serious environmental concerns, including soil degradation and greenhouse gas emissions. Previous studies have demonstrated that NUE is influenced by multiple factors, including fertilizer rate, timing, soil properties, climatic conditions, and varietal characteristics. However, many fertilizer recommendations remain generalized, with limited emphasis on variety-specific responses to graded nutrient doses under local agro-ecological conditions [4-6].

The wheat variety DBW-187 is widely cultivated under irrigated conditions due to its yield potential and adaptability; however, systematic information on its NUE and yield response to different nitrogen-phosphorus-potassium application levels is limited. Existing studies on NUE in wheat have largely focused on nitrogen management or broad varietal comparisons, leaving a knowledge gap regarding the integrated effects of graded NPK doses on growth, yield, nutrient uptake, and economic returns in specific high-yielding cultivars. Addressing this gap is critical for optimizing fertilizer use, improving NUE, and promoting sustainable wheat production [7-10].

Increasing agricultural productivity is a national objective with an intent to reduce the plant production deficit. In order to achieve good and abundant yields, it is essential to cultivate the soil in a manner that favors optimal crop growth. In order to obtain a high-yield crop, chemical fertilizers are used. Food security of modern agriculture depends on fertilizers. As fertilizer application is one of the most common management practices in crops, its overuse poses important environmental problems by exacerbating pollution levels [11-13].

Therefore, the main objective of the present study was to evaluate the effect of different doses of NPK fertilizers on NUE, growth, yield attributes, yield, grain quality, and economic returns of wheat variety DBW-187 under irrigated field conditions. By linking fertilizer response with NUE and economic performance, this study aims to provide practical, variety-specific recommendations for efficient nutrient management in wheat cultivation.

2. Materials and Methods

The 2023 rabi season saw the presentation of a field trial called "A comparative study of NUE in wheat variety, DBW-187 affected by different doses of NPK." The Crop Research Centre, Uttaranchal University, Dehradun, situated around 6.8 km past IMA, Dehradun (30°20′56.8968″ N, 77°58′16.4064″ E) at an elevation of 670 m above sea level in the Doon Valley, was the site of this study during the rabi season of 2023–2024. With a slightly acidic pH of 6.52, a low electrical conductivity (EC) of 0.167 dS m^{-1}, and organic carbon of 1.19%, the experimental soil was a sandy clay loam that had 53.40% sand, 25.40% silt, and 21.30% clay [4]. Through the use of the alkaline permanganate, Olsen, and ammonium acetate methods, the available nitrogen (62.72 kg ha^{-1}), phosphorus (26.88 kg ha^{-1}), and potassium (224.2 kg ha^{-1}) were found to be low, moderate, and high, respectively.

Soil samples were collected from the experimental field at 0–15 cm depth before sowing to determine the initial physicochemical properties of the soil. After harvest, soil samples were again collected separately from each treatment plot to assess changes in soil fertility status due to different NPK levels. The samples were air-dried, ground, and analyzed for available nitrogen, phosphorus, and potassium using standard procedures. Soil pH and EC were determined in a 1:2.5 soil-water suspension, and organic carbon was estimated using the Walkley and Black method.

2.1. Climatic Conditions

The experimental site at Dehradun, Uttarakhand, experiences a subtropical humid climate. During the rabi season (October–March), the mean minimum and maximum temperatures ranged from approximately 6–10 °C and 18–25 °C, respectively. Rainfall during the cropping period was limited and irregular, and therefore, supplemental irrigations were provided as per crop requirements. These climatic conditions were generally favorable for wheat growth and nutrient uptake.

With three replications and seven fertilizer treatments—T_1 (control), T_2 (25% recommended dose of fertilizers (RDF)), T_3 (50% RDF), T_4 (75% RDF), T_5 (100% RDF), T_6 (125% RDF), and T_7 (150% RDF)—the experiment was conducted using a randomized complete block design, where RDF = 150:60:40 kg ha^{-1} N: P: K. On December 6, 2023, 100 kg ha^{-1} of the wheat variety Karan Vandana (DBW-187), which is appropriate for timely irrigated circumstances, was manually seeded with a 20 cm row spacing and a 5–7 cm depth using seed. The entire experimental area was 126 m^2, with each plot measuring 3 × 2 m (6 m^2). At 41 days after sowing (DAS) (January 16, 2024), the remaining nitrogen was top-dressed, while half of the nitrogen, all of the phosphorus, and potassium were treated basally.

Preliminary tillage started field activities on November 30. Then came layout and soil sampling (December 2–5). Grain filling (119 DAS), blooming (95 DAS), late jointing (72 DAS), tillering (46 DAS), and crown root initiation (Crown Root Initiation; ~20 DAS) all received five irrigations. The crown root initiation (CRI) stage is a critical physiological phase in wheat, during which crown roots develop and establish the foundation for effective nutrient uptake, tiller formation, and plant anchorage. Timely irrigation at the crown root initiation stage is essential to ensure optimum root development and subsequent crop growth. The wedding was completed at 39 DAS. Harvesting took place on May 3 (150 DAS), while threshing took place on May 7 (154 DAS). Observations of growth comprised leaf area index (LAI) (60, 90, 120 DAS), dry matter accumulation (60, 90, and 120 DAS), and plant height (30–120 DAS). Dry matter accumulation was determined by randomly selecting five representative plants from each plot at 60, 90, and 120 DAS. The sampled plants were thoroughly washed to remove soil particles and oven-dried at 65 ± 2 °C until a constant weight was attained. The dry weight was recorded using an electronic balance, and the mean dry matter accumulation per plant was calculated. LAI was measured at 60, 90, and 120 DAS by estimating the total leaf area per plant. Leaf area was calculated using leaf length and maximum width multiplied by a correction factor of 0.75. LAI was computed as the ratio of total leaf area to the ground area occupied by the plant. The following yield parameters were noted: test weight, spike count m^{-2}, spike length, spikelets $spike^{-1}$, grains $spike^{-1}$, and yields of biological output, grain, and straw. At harvest, grain protein content was determined using Lowry's method [14]. Soil characteristics (NPK, organic carbon, pH, and EC) were also evaluated before and after harvest. The benefit-cost ratio, gross and net returns, and cultivation costs were all included in the economic study.

2.2. Economic Analysis

The economic evaluation of the treatments was carried out by calculating the cost of cultivation, gross returns, net returns, and benefit–cost (B:C) ratio. The cost of cultivation included expenses for land preparation, seed, fertilizers, irrigation, labor, and other cultural operations. Gross return was calculated based on the market price of grain and straw multiplied by their respective yields. Net return was computed as the difference between gross return and the total cost of cultivation [15]. The benefit–cost ratio was calculated using the formula:

B:C ratio = Gross return / Cost of cultivation

Economic values in Indian Rupees were converted into United States Dollars (USD) using an average exchange rate of 1 INR = 0.0111 USD to facilitate international comparison

2.3. Statistical Analysis

All recorded data on growth parameters, yield attributes, yield, nutrient uptake, and economic returns were statistically analyzed using analysis of variance appropriate for a randomized complete block design. Treatment means were compared at the 5% level of significance, and critical difference values were calculated wherever the F-test was significant. Standard error of mean and coefficient of variation were also computed to assess experimental precision. The SPSS version 29 and OPSTAT software were used for all analyses.

3. Results

In the study several growth and yield metrics were observed and analyzed in detail under various fertilizer regimes. To determine how the crop will react to different nitrogen treatment levels, measurements of plant height, dry matter accumulation, LAI, yield characteristics, and economic and nutrient absorption factors were assessed. All treatment comparisons were evaluated at a significance level of $p \leq 0.05$ unless otherwise stated.

At 30, 60, 90, and 120 DAS, the height of the wheat plants was measured. Plant height was significantly influenced by fertilizer levels across growth stages (Table 1), showing a general increasing trend with higher NPK application.

Plant height was generally positively impacted by higher fertilizer levels, with the 150% RDF treatment consistently yielding the tallest plants. Fertilizer levels had a major impact on the dry matter accumulation per plant, which gradually rose with crop age. Dry matter accumulation increased progressively with crop age and fertilizer dose, with higher levels of NPK enhancing biomass production (Table 1).

As a result, dry matter accumulation increased as fertilizer dosages increased, with 150% RDF showing the highest results. As a result of leaf senescence, the LAI decreased by 120 DAS after rising till 90 DAS. LAI was significantly affected by fertilizer application, increasing up to 100% RDF and declining thereafter, indicating an optimum nutrient level for canopy development (Table 1). Up to 100% RDF, LAI generally improved with fertilizer dosage; after that, no discernible improvement was seen.

Yield attributes, including spike density, spike length, and grains per spike, were significantly influenced by graded fertilizer levels, with optimum performance observed at 100% RDF (Table 1).

Grain yield was significantly affected by fertilizer application, with optimum performance achieved at 100% RDF (Table 1). Straw yield followed a pattern similar to grain yield, increasing with fertilizer level up to the recommended dose and stabilizing thereafter (Table 1). Biological yield and harvest index exhibited relatively smaller variation among treatments, reflecting balanced biomass partitioning under optimum nutrient supply (Table 1).

Grain protein content increased with increasing fertilizer levels, reflecting enhanced nitrogen availability at higher NPK doses (Table 1). Economic analysis indicated that the highest net returns and benefit–cost ratio were achieved at the recommended fertilizer level (100% RDF), whereas further increases in fertilizer input did not result in proportional economic benefits (Table 2). The higher economic returns obtained under the 100% RDF (T5) treatment were primarily due to its superior grain and straw yields combined with optimized fertilizer input costs. Although higher fertilizer doses (125% and 150% RDF) slightly increased some growth and quality parameters, the additional input costs were not offset by proportional yield gains, resulting in comparatively lower net returns and B:C ratios.

Greater fertilizer dosages resulted in greater accessible N, P, and K, according to post-harvest soil analysis. Grain and straw also absorbed more nutrients when fertilizer levels rose. These findings demonstrate that fertilizer treatment greatly increased nutrient absorption, with 100% RDF (T_5) showing the best outcomes for total crop growth, yield, and nutrient usage efficiency without the need for larger dosages.

The initial soil available nitrogen, phosphorus, and potassium were 62.72, 26.88, and 224.2 kg ha^{-1}, respectively. Post-harvest analysis revealed treatment-wise variation in residual soil fertility. In the control plot, available nitrogen decreased to 59.26 kg ha^{-1}, indicating nutrient mining. In contrast, higher fertilizer treatments, particularly 100% RDF (68.21 kg ha^{-1}) and 150% RDF (72.82 kg ha^{-1}), showed improvement in residual nitrogen compared to the initial status (Table 2). A similar trend was observed for available phosphorus and potassium. Soil pH, EC, and organic carbon remained within safe ranges after harvest, indicating no adverse effect of fertilizer treatments on soil health.

Table 1: Effect of different levels of fertilizer application on growth, yield attributes, yield, and quality parameters of the crop.

Treatments		Plant's height (cm)	Leaf Area Index	Number of spike count of m^{-2}	Length of Spike (cm)	Number of grains per spike	Test weight (1000-grain weight)	Protein content of grain (%)	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	Biological yield (q ha^{-1})	Harvest Index (%)
T1	Control	100 ± 3.52	0.90 ± 0.088	37[g] ± 0.30	10[d] ± 0.41	36.33[b]	43.56 ± 0.30	8.24g ± 0.002	71.9 ± 0.89	107.85e ± 0.03	179.75 ±2.07	39.55 ±0.10
T2	25% RDF	107 ± 3.77	0.85 ± 0.083	39[f] ± 0.32	11.67[bc] ± 0.48	36.00[b]	43.06 ± 0.30	8.42f ± 0.002	73.3 ± 0.91	109.85cd ± 0.03	183.15 ±2.11	40.02 ±0.10
T3	50% RDF	106 ± 3.74	1.03 ± 0.10	41[e] ± 0.34	11.33[c] ± 0.47	36.33[b]	43.66 ± 0.30	8.87e ± 0.002	72.8 ± 0.90	109.41d ± 0.03	182.21 ±2.10	39.95 ±0.10
T4	75% RDF	110 ± 3.88	1.17 ± 0.11	44[d] ± 0.36	11.67[bc] ± 0.48	36.00[b]	43.3 ± 0.30	9.21d ± 0.003	73.9 ± 0.92	110.35c ± 0.03	184.25 ±2.12	40.10 ±0.10
T5	100% RDF	116 ± 4.09	1.35 ± 0.13	51[a] ± 0.42	12.33[ab] ± 0.51	38.00[a]	44.26 ± 0.31	10.07c ± 0.003	75.8 ± 0.94	113.53a ± 0.04	189.33 ±2.18	40.03 ±0.10
T6	125% RDF	116 ± 4.09	1.01 ± 0.10	46[c] ± 0.38	11[cd] ± 0.45	36.67b	43.76 ± 0.30	10.28b ± 0.003	75.1 ± 0.93	112.65b ± 0.04	187.75 ±2.16	40.00 ±0.10
T7	150% RDF	118 ± 4.16	1.04 ± 0.10	48[b] ± 0.39	12.67[a] ± 0.52	37.00b	43.93 ± 0.31	10.75a ± 0.003	75.6 ± 0.94	113.43a ± 0.04	189.03 ±2.18	39.99 ±0.10
SE (m) ±		3.890	0.103	0.356	1.381	NS	0.302	0.003	0.055	0.034	1.396	0.069
CD at 5%		NS	NS	1.110	1.461	0.716	NS	0.008	NS	0.105	NS	NS
CV (%)		6.094	16.850	1.412	7.127	3.389	1.200	0.047	2.135	0.052	1.996	0.455

Critical difference (CD) values are significant at $p \leq 0.05$. Means followed by different superscript letters within a column differ significantly at $p \leq 0.05$ according to LSD test. SE: standard error of the mean. CV: coefficient of variation.

Table 2: Available nutrients, nutrient uptake, residual fertility, and economics of the wheat crop.

Treatments		Available nutrient (kg ha^{-1})			Nutrient uptake (kg ha^{-1})									Net Return (INR. ha-1)	Net Return (USD. ha^{-1})	Benefit-cost ratio
		N	P	K	Nitrogen uptake (kg ha^{-1})			Phosphorus uptake (kg ha^{-1})			Potassium uptake (kg ha^{-1})					
					Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total			
T1	Control	59.26 2.63	24.57 ± 1.12	218.27 ± 3.11	45.10 ± 0.58	67.64 ± 0.78	112.74 ± 1.34	19.33 ± 0.23	28.99 ± 0.33	48.32 ± 0.56	161.20 ± 1.87	241.80 ± 2.77	403.00 ± 4.64	1,45,205 ± 2363	1,611.28 ± 155	2.36[e] ± 0.03
T2	25 % of RDF	60.74 2.70	25.63 ± 1.17	220.79 ± 3.15	45.97 ± 0.59	68.90 ± 0.79	114.87 ± 1.36	19.70 ± 0.23	29.53 ± 0.34	49.23 ± 0.57	164.34 ± 1.90	246.28 ± 2.83	410.62 ± 4.73	1,49,185 ± 2428	1,656.99 ± 159	2.42[cd] ± 0.03
T3	50 % of RDF	63.22 2.81	26.07 ± 1.19	223.67 ± 3.19	45.66 ± 0.0.59	68.62 ± 0.79	114.28 ± 1.35	19.57 ± 0.23	29.41 ± 0.34	48.98 ± 0.56	163.22 ± 1.89	245.30 ± 2.82	408.51 ± 4.70	1,47,887 ± 2407	1,642.54 ± 158	2.40[d] ± 0.03
T4	75 % of RDF	65.86 2.93	26.88 ± 1.23	226.03 ± 3.23	45.35 ± 0.58	69.21 ± 0.80	114.56 ± 1.35	19.86 ± 0.23	29.66 ± 0.34	49.53 ± 0.57	165.68 ± 1.92	247.40 ± 2.85	413.09 ± 4.76	1,50,730 ± 2453	1,672.10 ± 160	2.45[c] ± 0.03
T5	100 % of RDF	68.21 3.03	27.59 ± 1.26	229.59 ± 3.28	47.54 ± 0.61	71.21 ± 0.82	118.75 ± 1.40	20.38 ± 0.24	30.52 ± 0.35	50.89 ± 0.59	169.94 ± 1.97	254.53 ± 2.93	424.48 ± 4.89	1,56,341 ± 2544	1,737.09 ± 167	2.54[a] ± 0.04
T6	125 % of RDF	70.58 3.14	28.87 ± 1.32	231.25 ± 3.30	47.10 ± 0.60	70.65 ± 0.81	117.75 ± 1.39	20.19 ± 0.24	30.28 ± 0.35	50.47 ± 0.58	168.37 ± 1.95	252.56 ± 2.91	420.94 ± 4.85	1,54,405 ± 2513	1,716.29 ± 165	2.51[b] ± 0.04
T7	150 % of RDF	72.82 3.24	30.96 ± 1.41	233.34 ± 3.33	47.42 ± 0.61	71.14 ± 0.82	118.56 ± 1.40	20.32 ± 0.24	30.49 ± 0.35	50.81 ± 0.59	169.50 ± 1.96	254.31 ± 2.93	423.81 ± 4.88	1,55,856 ± 2536	1,733.03 ± 166	2.53[ab] ± 0.04
SE (m) ±		1.908	0.814	2.107	0.387	0.523	0.901	0.152	0.224	0.375	1.263	1.870	3.131	1,613.70	1681.33	0.0231
CV (%)		7.672	7.912	2.466	2.212	1.989	2.056	2.016	1.989	1.993	2.013	1.988	1.996	2.82	16.64	2.49
SD		5.049	2.154	5.576	1.024	1.385	2.383	0.401	0.594	0.991	3.342	4.947	8.283	4,269.44	44.02	0.0611
Initial status		62.72	26.88	224.2	46.3057	69.62	115.93	19.91	29.84	49.75	166.04	248.88	415.06	1,51,372.71	2.62	2.4586

Means followed by different superscript letters within a column differ significantly at $p \leq 0.05$ according to LSD test. Differences among treatments were tested at $p \leq 0.05$. All values in USD have been converted from Indian Rupees (INR) using the exchange rate of 1 INR = 0.0111 USD (approximate) for international comparison.

4. Discussion

The outcomes of the experiment clearly indicate that application of nutrients at various levels of NPK played a significant role in the growth of wheat variety DBW-187 yield attributes, productivity, nutrient uptake, and the economic returns. There was a steady pattern of growth parameters like plant height, dry matter accumulation and LAI to increase steadily with the added doses of fertilizers to the recommended dose (100% RDF), after which the gains began to level off or slightly decrease. It means that wheat is sensitive to the increase of nutrient availability, but the growth of wheat and yield are not directly proportional to the excess application of nutrients (125% to 150% RDF) [16].

The height of the plant grew steadily between T1 and T8, which indicated a high level of dependence on nitrogen supply to promote vegetative growth [17]. Nevertheless, the tall vegetation in T 5 did not become proportional in terms of the quantity of grains, which suggests the possibility of luxury intake of nutrients or redirection of assimilates towards the growth of a vegetative body instead of the reproductive organs [18]. The pattern was the same in dry matter accumulation, with T9 having the best biomass, although T5 (100% RDF) was more effective at converting into economic yield. This brings out the fact that the efficiency of nutrient use and not the particular nutrient uptake defines the yield performance [19].

The maximum LAI was 90 DAS, and the T5 had the best canopy growth. The T6 and T5 were further fed on, but their LAI was not higher than T5, implying that there should be an optimal amount of NPK applied to optimize photosynthetic surface, and excess fertilizers may disrupt physiological balance or accelerate senescence [20]. The nutrient application had a positive effect on yield attributes, including the number of spikes, the spike length, the number of grains per spike, and the test weight after T5; the effects were mostly even. This indicates that 100% RDF is a physiological threshold of maximization of the reproductive potential of DBW-187 under the specified soil and climatic conditions.

The fact that grain yield improved marginally after T5, as well as further, proved that over-application of fertilization does not necessarily increase productivity. The same findings in the case of straw and biological yield continue to confirm the fact that 100% RDF offers a balanced nutrient supply to both the vegetative and reproductive growth [21]. The protein level rose gradually with the rise in N levels, indicating the high effect of nitrogen on the quality of grain, but high protein in T9 was at the expense of low yield efficiency, which depicts the negative correlation between yield and protein in high nitrogen conditions [20].

The NUE of wheat, particularly in the DBW-187 variety, is profoundly influenced by the rates and balance of NPK fertilizer application, as well as by genetic, environmental, and management factors [16]. Nitrogen is the most yield-limiting nutrient in wheat production, and its inefficient use not only reduces crop productivity but also leads to significant environmental concerns, such as nitrate leaching and greenhouse gas emissions, since only about half of the applied nitrogen is typically utilized by the crop while the remainder is lost through volatilization, runoff, leaching, and denitrification [1, 5].

The response of wheat to increasing fertilizer doses observed in the present study is consistent with earlier findings that wheat exhibits a diminishing return curve in relation to nutrient input. Studies by Malinas *et al.* [2] and Govindasamy *et al.* [5] reported that NUE and grain yield increase with increasing nitrogen and balanced NPK supply up to an optimum level, beyond which NUE declines. In our experiment, the 100% RDF (T5) treatment produced the highest grain yield, NUE, and economic return, which agrees with previous reports that optimal fertilizer rates maximize nutrient recovery and biomass partitioning into grain [22].

The lack of further yield improvement at 125% and 150% RDF can be explained by physiological and soil-plant interaction mechanisms. At higher fertilizer levels, nutrient uptake becomes limited by root absorption capacity, enzyme activity, and sink strength in developing grains [23]. Excess nitrogen tends to promote vegetative growth rather than grain formation, leading to luxury consumption, lodging risk, and inefficient assimilate partitioning [22]. Moreover, excessive fertilizer availability can reduce nutrient recovery efficiency due to greater losses through leaching, volatilization, and immobilization in the soil, which has also been reported in wheat NUE studies previously [3, 9, 24, 25]. This explains why the 150% RDF treatment showed higher plant height and protein content but did not produce proportionately higher grain yield or NUE.

In addition, excessive fertilizer application may induce physiological stress by disrupting nutrient balance, accelerating leaf senescence, and reducing photosynthetic efficiency, thereby limiting yield gains despite higher nutrient availability. Thus, the superior performance of the 100% RDF treatment reflects a balance between nutrient supply, crop demand, and efficient physiological utilization, rather than maximum fertilizer input [26, 27].

The present study also has certain limitations that should be acknowledged. The experiment was conducted at a single location during one cropping season, and therefore, seasonal variability and long-term soil fertility dynamics were not assessed. The plot size and replication number, while sufficient for statistical analysis, may not capture all field-scale variability. In addition, environmental factors such as rainfall distribution and temperature fluctuations during the season may have influenced nutrient availability and crop response [28-30]. Future studies conducted across multiple seasons and locations, with additional physiological and soil measurements, would further strengthen the understanding of NUE in DBW-187 under varying fertilizer regimes [31].

The response of wheat to different NPK doses is characterized by an asymptotic yield curve, where increasing fertilizer rates initially boost yield and NUE, but excessive application results in diminishing returns and greater nutrient losses, highlighting the importance of optimizing fertilizer rates to match crop demand [3, 12]. Genetic variation among wheat varieties, including DBW-187, plays a crucial role in NUE, with some genotypes exhibiting superior uptake, assimilation, and remobilization of nutrients, especially under limited NPK supply [1, 2, 9]. For instance, traits such as root architecture, post-anthesis nitrogen uptake, and efficient remobilization of nitrogen from vegetative tissues to grain are associated with higher NUE and can be targeted in breeding programs [1, 5, 9].

Management practices that synchronize nutrient supply with critical growth stages—such as tillering and grain filling—are essential for maximizing both yield and grain quality, as these stages are particularly sensitive to nutrient availability [1]. The use of indices like partial factor productivity, partial nutrient balance, and recovery efficiency provides valuable metrics for assessing NUE, though each has limitations, such as not accounting for indigenous soil nutrient levels or requiring unfertilized control plots for accurate measurement [2, 32]. Furthermore, integrating micronutrients with NPK and employing advanced fertilizer technologies, such as slow-release formulations or split applications, can further enhance nutrient uptake and utilization efficiency [5, 11, 13]. Environmental factors, including drought and heat stress, can adversely affect nutrient uptake and assimilation, underscoring the need for resilient varieties and adaptive management strategies [1, 33]. Ultimately, improving NUE in DBW-187 under varying NPK doses requires a holistic approach that combines genetic selection, precise and balanced fertilizer management, and consideration of environmental conditions [21]. Such integrated strategies not only support higher yields and improved grain quality but also contribute to the sustainability of wheat production systems by reducing nutrient losses and mitigating environmental impacts, aligning agricultural productivity with environmental stewardship [1-5, 13].

5. Conclusions

This study demonstrated that the response of wheat variety DBW-187 to NPK fertilization follows an optimum-response pattern rather than a linear increase with higher fertilizer doses. Among the tested treatments, the recommended dose of fertilizers (100% RDF) produced the highest grain yield, superior yield attributes, improved nutrient uptake, and the greatest benefit–cost ratio, thereby confirming that balanced fertilization maximizes both productivity and NUE. Although higher fertilizer doses (125% and 150% RDF) increased plant height and grain protein content, they did not result in proportional yield or economic gains, indicating reduced nutrient recovery and physiological inefficiency at excessive nutrient supply levels. These findings directly address the main objective of the study by showing that optimizing NPK supply, rather than maximizing fertilizer input, is essential for improving NUE and yield performance in DBW-187. The results also highlight that excessive fertilization leads to diminishing returns due to limitations in nutrient uptake, assimilate partitioning, and increased nutrient losses.

From a practical perspective, this research provides clear guidance for wheat farmers and fertilizer managers. Applying NPK at the recommended rate (100% RDF) ensures optimal crop performance while avoiding unnecessary fertilizer costs and environmental losses. This recommendation is particularly relevant for irrigated wheat-growing regions with similar soil and climatic conditions to those of the Doon Valley. By adopting balanced and optimized fertilizer management, farmers can achieve higher profitability, improved grain quality, and more sustainable wheat production.

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