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Determination of Indigenous Nutrient Supplying Capacity of Soil through Omission Plot Technique in Wheat at Bhairahawa

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ABSTRACT

The rapidly expanding intensive cropping systems in the Terai region of Nepal, combined with imbalanced fertilization, are leading to significant nutrient depletion in agricultural soils, raising concerns about the sustainability of wheat production. To address this issue, a field experiment was conducted at the National Wheat Research Program (NWRP) in Bhairahawa, Rupandehi, during 2018-19 to evaluate the soil's nutrient-supplying capacity and its impact on wheat grain yield. The treatments included five different nutrient levels: N- omission (75:75:5:1 P_2O_5:K_2O:Zn:B kg ha^{-1}), P-omission (150:75:5:1 N:K_2O:Zn:B kg ha^{-1}), K-omission (150:75:5:1 N:P_2O_5:Zn:B kg ha^{-1}), adequate NPK (150:75:75, N:P_2O_5:K_2O kg ha^{-1}), and adequate NPK+Zn+B (150:75:75:5:1 N:P_2O_5:K_2O:Zn:B kg ha^{-1}). The trial was laid out in a randomized complete block design with five replications, planted in five different blocks of the National Wheat Research Program (NWRP), Bhairahawa, with each block treated as a replication. Data on growth, yield attributes, grain yield, and nutrient uptake were analyzed using the Genstat statistical package. The results showed that plant height, dry matter production, spike length, grains per spike, biological yield, and grain yield variables were significant ($P< 0.05$), while 1000 grain weight and harvest index were not significant ($P>0.05$). Total N, P, and K uptake were significant ($P<0.05$) in different treatments, with adequate NPK showing higher NPK uptake and significantly lower in N- omission treatment. Grain yield was higher in fully fertilized treatment than in nutrient omission treatments, with significantly lower grain yield in N- omission followed by P- omission treatments. Among the major nutrients, nitrogen was found to be the most limiting factor, followed by phosphorus and potassium for wheat. Based on these results, it can be concluded that a balanced amount of NPK nutrients should be supplied to enhance the indigenous nutrient-supplying capacity of the soil and improve wheat productivity in Bhairahawa.

Keywords: Indigenous nutrient supply, k-omission, N-omission, P-omission, and wheat productivity

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INTRODUCTION

Wheat (*Triticum aestivum* L.) is the third most important cereal in Nepal, following rice and maize. It plays a crucial role in national food security and contributes significantly to the country's agricultural gross domestic product (Devkota et al 2019, Adhikari et al 2014). However, wheat yields have either remained stagnant or decreased (Rawal et al 2017). Declining soil fertility and the loss of soil organic matter are major factors contributing to this stagnation (Adhikari et al 2014). Low and unbalanced fertilizer applications are key reasons for the low wheat yields (Devkota et al 2016, Sapkota et al 2014). Conventional blanket and imbalanced fertilizer applications have led to low nutrient use efficiency in wheat (Regmi et al 2002). It is crucial to implement improved nutrient management practices to maximize wheat yield, maintain soil fertility, and minimize environmental impacts. Understanding the potential yield and the gap between potential and actual yields obtained by growers is essential for improving nutrient management (Liu et al 2011). A significant and attainable yield gap of wheat was reported between the experimental station yield and farmers' management practices, leading to a lower national average yield due to low fertilizer application and poor crop management practices (Devkota et al 2018). There is a need for an improved understanding of crop yield response to nutrients, nutrient use efficiency, and the indigenous nutrient supply from soil and environmental sources. Differences in nutrient response are attributed to the variability in crop demand and soil nutrient supply and losses (Cui et al 2008). Indigenous nutrient supply refers to the cumulative quantity of nutrients from all non-fertilizer sources present in the soil solution surrounding the root system (Dobermann et al 2003). Quantifying the soil's capacity to supply major nutrients such as N, P, and K is essential for increasing yield and nutrient use efficiency (Adhikari et al 2014). There is a large variability in soil nutrient supply capacity among fields, and recommended doses of fertilizer may not be suitable for all fields (Regmi et al 2002). Each field must be evaluated for its nutrient-supplying capacity to determine the appropriate fertilizer needed to achieve targeted yields. Soil nitrogen supply is best determined by crop nitrogen uptake in N omission plots, where other nutrients are applied in sufficient amounts to limit plant growth only by nitrogen supply (Witt et al 2002). Similarly, the primary nutrients phosphorus (P) and potassium (K) can also be estimated using the same omission plot technique. This technique is a valuable tool for quantifying soil nutrient supply (Adhikari et al 1999). Therefore, this study aimed to quantify the native nutrient-supplying capacity of soil for wheat and its impact on wheat productivity in Bhairahawa.

MATERIALS AND METHODS

Experimental site:
A field experiment was conducted during the winter season of 2018/19 in blocks A, B, C, D, and E of the National Wheat Research Program (NWRP) in Bhairahawa, Rupandehi, Nepal. The site is located at 27° 32’ North latitude and 83° 25’ East longitude, with an elevation of 104 meters above sea level. The climate in the area is subtropical. Soil samples were collected diagonally from three spots in each block at a depth of 0-20 cm using a tube auger. A composite sample was prepared, air-dried, ground, and sieved through a 2.0 mm sieve for analysis. The soil samples were analyzed for texture, organic matter, pH, N, P_2O_5, and K_2O. The experimental soil pH was alkaline (7.84), low in organic matter (1.88%), low in total nitrogen (0.09%), high in available phosphorus (97.03 kg ha^{-1}), and medium in available potassium (179.12 kg ha^{-1}). The soil texture was silt loam (Table 1). Block-A has the highest organic matter (2.5%) and total nitrogen (0.10%) among the blocks, along with the greatest levels of available phosphorus (133.52 kg ha^{-1}) and potassium (320.4 kg ha^{-1}), with alkaline soil (pH 7.83) and a silt-loam texture. In comparison, Block-B has lower organic matter (1.5%) and nitrogen (0.08%) but the highest pH (7.92), while maintaining high phosphorus (142.41 kg ha^{-1}) and moderate potassium (188.8 kg ha^{-1}) in similar soil texture. Block-C mirrors Block-A in organic matter (2.5%) but has lower nitrogen (0.09%), phosphorus (90.74 kg ha^{-1}), and the lowest potassium (91.9 kg ha^{-1}) among the blocks, with a slightly lower pH (7.75). Block-D, with 1.5% organic matter and 0.09% nitrogen, has the lowest available phosphorus (43.12 kg ha^{-1}) but moderate potassium (172.5 kg ha^{-1}) and a pH of 7.78. Block-E exhibits the lowest organic matter (1.4%) and moderate nitrogen (0.09%), with the highest pH (7.95), lower phosphorus (75.39 kg ha^{-1}), and potassium (122.0 kg ha^{-1}), all with a silt-loam texture.

Table 1. Initial soil physicochemical properties in different blocks of NWRP, Bhairahawa

Locations	Organic matter (%)	pH	Total Nitrogen (%)	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})	Textural class
Block-A	2.5	7.83	0.10	133.52	320.4	Silt-loam
Block-B	1.5	7.92	0.08	142.41	188.8	Silt-loam
Block-C	2.5	7.75	0.09	90.74	91.9	Silt-loam
Block-D	1.5	7.78	0.09	43.12	172.5	Silt- loam
Block-E	1.4	7.95	0.09	75.39	122.0	Silt-loam
Mean	1.88	7.84	0.09	97.03	179.12	Silt-loam

The total rainfall during the research period was recorded as 138 mm, with weekly maximum and minimum temperatures ranging from 23 to 39°C and 7 to 25°C, respectively (Figure 1).

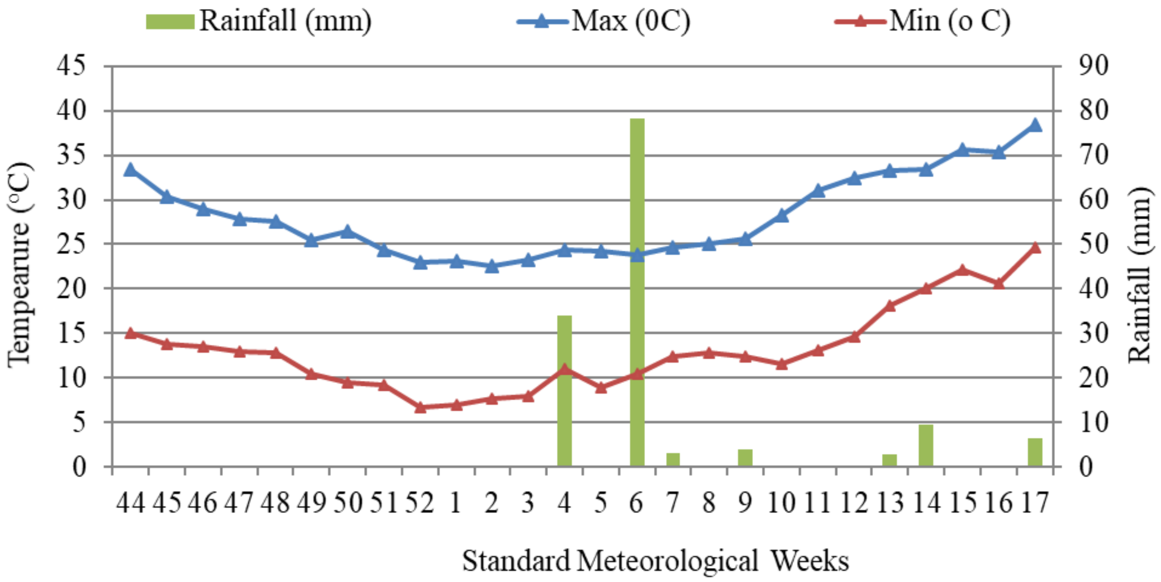

Figure 1. Meteorological data during the crop growing season of 2018/19.

Experimental details

The experiment was conducted in a randomized complete block (RCB) design. Treatments consisted of five different nutrient levels: : N- omission (75:75:5:1 P_2O_5:K_2O:Zn:B kg ha^{-1}), P-omission (150:75:5:1 N:K_2O:Zn:B kg ha^{-1}), K-omission (150:75:5:1 N:P_2O_5:Zn:B kg ha^{-1}), adequate NPK (150:75:75, N:P_2O_5:K_2O kg ha^{-1}), and adequate NPK+Zn+B (150:75:75:5:1 N:P_2O_5:K_2O:Zn:B kg ha^{-1}). The trial was planted in blocks A, B, C, D, and E at NWRP, Bhairahawa, with each block serving as a replication. The wheat variety Vijay was used in the experiment, which was planted on November 24, 2018. Each plot measured 4 m x 3 m (12 m^2) with 12 rows of 4 meters each sown at a spacing of 25 cm row to row. Herbicide 2, 4-D sodium salt 80 WP was applied at 35 days after sowing to control weeds. 50% of N and full doses of P, K, Zn, and B were applied as a basal dose, with the remaining nitrogen split into 25% at 30 DAS and 25% at 55 DAS.

Data colleciton

Ten plants were randomly selected in each plot to measure plant height, with the average height of ten plants used as the plant height in cm. Spike m^{-2} was recorded, grains per spike data were collected from 20 randomly selected spikes, and a thousand grains were counted and weighed. Total biomass and grain yields were recorded and expressed in kg ha^{-1} at 12% moisture content. The Harvest index was calculated as a percentage. Plant samples were collected randomly for plant analysis, with grain and straw samples oven-dried and ground for nutrient analysis. Nutrient content was determined using specific methods, and nutrient uptake was calculated based on the nutrient contents in grain and straw multiplied by their respective yield.

Statistical Analysis

All data were analyzed using the Genstat statistical package, with analysis of variance conducted for all variables and Duncan's multiple range test (DMRT) used for mean separations at $p<0.05$.

RESULTS AND DISCUSSION

Plant height at harvest

There was a significant effect of varying nutrient levels on plant height (Table 2), with a P-value of less than 0.05. The N-omission (-N) treatment resulted in significantly lower plant height compared to the P-omission (-P), K-omission (-K), adequate NPK, and adequate NPK+Zn,B treatments. Except for the N omission, all treatments showed similar plant heights. It is a well-known fact that adequate nutrients provide all the essential growth-promoting elements necessary for shoot growth, root development, photosynthesis, cell division, and cell enlargement. This results in increased meristematic activity, favoring the growth of wheat. Singh et al. (2010) also reported significantly lower plant height in N-omission treatments compared to adequately fertilized treatments.

Yield attributes

Yield attributes such as spike length, grains per spike, biological yield, and grain yield variables were found to be significant ($P<0.05$), while 1000 grain weight and harvest index variables were not significant ($P>0.05$) in different fertility level treatments (Table 2 and 3). The number of spikes per square meter is the lowest for the N omission, which was significantly lower than the P omission and all other treatments. Similarly, the P omission was responsible for a significantly higher number of spikes per square meter than the N omission but resulted in significantly fewer spikes than the other treatments. Spike length and number of grains per spike exhibited a similar trend. The N-omission treatment achieved a shorter spike length and lower number of grains per spike compared to other treatments (Table 2). P-omission (-P), K-omission (-K), adequate NPK, and adequate NPK+Zn+B treatments did not significantly differ in spike length and number of grains per spike but were superior to N-omission.

In this study, nitrogen (N) omission significantly reduced the number of spikes per square meter, highlighting its essential role in plant tillering and spike formation. Nitrogen plays a key part in cell division and elongation (MacAdam et al 1989), which are vital during the early vegetative and reproductive stages, leading to increased spike numbers (Luo et al 2020). Similar findings have been reported by Wang et al (2017), where N deficiency led to a substantial reduction in tiller formation and consequently fewer spikes per unit area. The number of grains per spike followed a similar trend, with N omission leading to a significantly lower grain count per spike. Nitrogen is heavily involved in protein synthesis and carbohydrate production, both of which are necessary for proper grain development (Wang et al 2023). Thus, insufficient nitrogen during the grain-filling stage limits the accumulation of carbohydrates, reducing the potential number of grains. On the other hand, the P omission treatment did not significantly affect grain numbers compared to treatments with adequate P, suggesting that P plays a lesser role during the later stages of grain formation compared to N.

Table 2. Effect of different fertility levels on plant height at harvest and yield attributes of wheat

Treatments	Plant height (cm)	No. of spike m^{-2}	Spike length (cm)	No. of grains per spike	Thousand-grain weight (g)
N-omission	78.3^{b}	207^{c}	81.0^{b}	21^{b}	51.5
P-omission	94.4^{a}	272^{b}	10.2^{a}	34^{a}	50.9
K-omission	94.8^{a}	312^{a}	10.1^{a}	34^{a}	50.2
Adequate NPK	96.5^{a}	327^{a}	10.1^{a}	34^{a}	49.2
Adequate NPK+B+Zn	96.5^{a}	332^{a}	10.6^{a}	35^{a}	49.1
P-value	<.001	<.001	<.001	<.001	0.404
SEm (±)	1.61	12.06	0.18	0.91	1.03
LSD (=0.05)	4.82	38.05	0.52	2.74	3.08
CV, %	3.9	9.8	4.0	6.4	4.6
Grand mean	92.1	289.90	9.8	31.8	50.2

Notes: N-omission: –N + P, K, Zn, B (75:75:5:1 P_2O_5:K_2O:Zn:B kg ha^{-1}); P-omission: -P + N, K, Zn, B (150:75:5:1 N:K_2O:Zn:B kg ha^{-1}); K-omission: -K+ N, P, Zn, B (150:75:5:1 N: P_2O_5:Zn:B kg ha-1); Adequate NPK: (150:75:75 N:P_2O_5:K_2O kg ha^{-1}); Adequate NPK + B, Zn: (150:75:75:5:1, N:P_2O_5:K_2O:Zn:B kg ha^{-1}). Treatment means in the column followed by the same letter(s) are not significantly different by DMRT at 0.05 level of significance.

The thousand-grain weight, often regarded as an indicator of grain size and filling, was not significantly different among the fertility treatments. This result suggests that once grain formation begins, thousand-grain weight becomes less sensitive to nutrient variations, particularly nitrogen. This could be because, by the grain-filling stage, nutrient remobilization from vegetative tissues takes precedence over continued nutrient uptake from the soil (Etienne et al., 2017). Previous studies, such as those by Guo (2021) and Zeng et al (2021), have noted that while N and P are crucial for early growth and spike formation, their impact on grain weight is often overshadowed by factors like water availability and photosynthetic activity during the grain-filling phase. Interestingly, the thousand-grain weight remained stable even in N-omission plots, which indicates that once the grains are set, the final grain size may be more dependent on assimilate partitioning rather than ongoing nutrient availability (Gasparis et al 2023). These findings align with studies that suggest thousand-grain weight is often more resistant to environmental stresses or nutrient limitations than other yield attributes like spike number or grain count (Melash et al 2023). The lack of significance in thousand-grain weight also suggests that the crop may have reached a compensation threshold, where the reduced grain number per spike was balanced by slightly larger grains, preventing a significant reduction in thousand-grain weight.

Yield and harvest index

The fertility treatments significantly impacted grain yield and total biological yield, with nitrogen omission (N-omission) resulting in the lowest values for both parameters. The N-omission treatment yielded only 1918 kg ha^{-1} of grain and 4737 kg ha^{-1} of biological yield, emphasizing the crucial role of nitrogen in maximizing yield. Phosphorus omission (P-omission) produced moderate results, with a grain yield of 3931 kg ha^{-1} and a biological yield of 9212 kg ha^{-1}. The highest grain and biological yields were observed in treatments with adequate NPK and the addition of zinc and boron (NPK+B+Zn), with grain yields of 4526 kg ha^{-1} and biological yields of 10402 kg ha^{-1}, respectively. However, there were no significant differences in total biological yield between the K-omission, Adequate NPK, and NPK+B+Zn treatments. Harvest index (HI) was not significantly affected by treatments, ranging from 40.6% for N-omission to 44.6% for K-omission, indicating that while nutrient supply influences yield, the efficiency of biomass partitioning to grain remains relatively consistent across treatments.

Table 3. Effect of different fertility levels on yield and harvest index of wheat

Treatments	Grain yield (kg ha^{-1})	Total biological yield (kg ha^{-1})	Harvest index (%)
N-omission	1918^{c}	4737^{c}	40.6
P-omission	3931^{b}	9212^{b}	42.7
K-omission	4442^{a}	9944^{ab}	44.6
Adequate NPK	4448^{a}	10140^{ab}	43.7
Adequate NPK+B+Zn	4526^{a}	10402^{a}	43.5
P-value	<.001	<.001	0.098
SEm (±)	124	301.7	0.99
LSD (=0.05)	372	904.5	2.97
CV, %	7.2	7.6	5.1
Grand mean	3853	8887	43.0

Notes: N-omission: –N + P, K, Zn, B (75:75:5:1 P_2O_5:K_2O:Zn:B kg ha^{-1}); P-omission: -P + N, K, Zn, B (150:75:5:1 N:K_2O:Zn:B kg ha^{-1}); K-omission: -K+ N, P, Zn, B (150:75:5:1 N: P_2O_5:Zn:B kg ha-1); Adequate NPK: (150:75:75 N:P_2O_5:K_2O kg ha^{-1}); Adequate NPK + B, Zn: (150:75:75:5:1, N:P_2O_5:K_2O:Zn:B kg ha^{-1}). Treatment means in the column followed by the same letter(s) are not significantly different by DMRT at 0.05 level of significance.

The significantly lower grain yield and biological yield in the N-omission treatment demonstrate nitrogen's essential function in plant growth, photosynthesis, and grain formation. Nitrogen is a key component of chlorophyll and enzymes involved in carbohydrate synthesis, which is necessary for optimal vegetative growth and spike development (Fathi 2022). The drastic reduction in yields under nitrogen omission suggests that without adequate nitrogen, wheat plants are unable to achieve their full yield potential. These findings align with previous research showing that nitrogen deficiency severely limits both grain and biomass production (Wang et al 2021). In contrast, the P-omission treatment, while negatively affecting both grain and biological yield, had a less severe impact compared to nitrogen omission. Phosphorus is crucial for energy transfer and root development, but its omission appeared to be partially compensated by the plant's ability to redistribute internal phosphorus reserves during the growth cycle (Khan et al 2021). Nevertheless, the moderate reduction in yields under phosphorus omission suggests that phosphorus is still necessary for optimizing growth, particularly in root establishment and early plant development stages. The highest grain and biological yields were observed in treatments receiving adequate NPK, with or without the addition of zinc and boron. These results highlight the importance of balanced nutrient management in ensuring optimal growth and yield. Potassium, along with micronutrients like zinc and boron, supports enzymatic functions, nutrient transport, and stress tolerance, all of which contribute to enhanced yield outcomes (Bashir et al 2023). The lack of significant differences between K-omission and adequate NPK treatments suggests that once nitrogen and phosphorus requirements are met, potassium and micronutrients provide supplementary benefits, but may not independently drive major increases in yield under certain conditions. Rawal et al (2017), Pathak (2014), and Singh (2016) reported higher wheat grain yield with full fertilized treatment.

The grain yield from the NPK+Zn+B fertilized treatment was higher compared to other treatments, but it was similar to the yields from the adequate NPK and K-omission treatments. However, these three fertility levels outperformed the N-omission and P-omission treatments. Notably, the N-omission treatment had lower grain yield than the P-omission treatment. Applying adequate and balanced fertilizer during critical physiological phases could have supported better assimilation of photosynthates towards grain production (Qureshi et al 2016). The increase in grain yield may also be attributed to a positive impact on growth and yield parameters.

Omitting nutrients from the fertilizer regimen led to a significant yield loss, underscoring the importance of replenishing nutrients to achieve high-yield targets.

Interestingly, the harvest index (HI) was not significantly affected by fertility treatments, remaining relatively constant across treatments. This suggests that while nitrogen, phosphorus, and potassium affect the overall biomass and grain yield, the partitioning of biomass into grain remains consistent (Laza et al 2023). The N-omission treatment, which showed the lowest HI, indicates inefficient biomass allocation toward grain production when nitrogen is deficient. However, in other treatments, the efficiency of converting biomass to grain was stable, indicating that once the plant reaches reproductive maturity, nutrient management may have less impact on biomass partitioning than environmental factors or plant genetics.
The lack of a significant difference in thousand-grain weight and harvest index among treatments suggests that once the crop reaches physiological maturity, the final grain filling may be less sensitive to fertility treatments. This is because it depends on the translocation of assimilates rather than nutrient supply during the reproductive stage. Ayoub et al (1994) also reported that a spike in population increased with an increase in nitrogen levels. Geleto et al (1995) reported that grain yield is closely related to the number of spikes per unit area.

Nutrient uptake
Total major nutrient uptake of N, P, and K, as well as grain yield variables, were significantly influenced by different fertility levels in wheat (Table 4). Total N and K uptake in P-omission, K-omission, adequate NPK, and adequate NPK+Zn+B treatments were not significant, but these treatments were significantly superior to the N-omission treatment. Parylak and Waclawowicz (2000) also noted that increasing N fertilizer rates increased its uptake, particularly by grain yield. Total P uptake was significantly higher in the adequate NPK treatment compared to others. A similar uptake of total P was found in K-omission and adequate NPK+Zn+B treatments, but these two treatments were superior to P-omission and N-omission treatments. P uptake was significantly lower in the N-omission treatment compared to the remaining treatments. The mean total N uptake ranged from 42 to 96.7 kg ha^{-1}, P uptake ranged from 3.51 to 16.15 kg ha^{-1}, and K uptake ranged from 46.5 to 102.4 kg ha^{-1}, respectively (Table 4). Grain yield increased with higher levels of nutrients, with N and K uptake showing a significantly more positive association with grain yield than P uptake. NPK uptake and grain yield decreased significantly in the N-omission treatment (Figure 2). The results indicated that the complete treatment maintained higher uptake values, most likely due to the higher yields recorded in these treatments (Sharma and Singhal 2014, Singh 2017). These results underscore the importance of balanced fertilization in providing adequate nutrition to plants. The N-omission treatment recorded the lowest uptake values, reflecting the lowest yield recorded in this treatment. Similar results were reported by Gupta et al (2009) and Singh (2016).

Table 4. Total nutrient uptake of wheat as influenced by different fertility levels

	Total nutrient uptake (kg ha^{-1})		
Treatments	**N**	**P**	**K**
N-omission	42.1^{c}	3.51^{d}	43.4^{b}
P-omission	88.0^{b}	6.14^{c}	93.7^{a}
K-omission	91.1^{ab}	8.13^{b}	92.5^{a}
Adequate NPK	101.1^{a}	16.15^{a}	106.2^{a}
AdequateNPK+B+Zn	89.4^{ab}	8.25^{b}	96.4^{a}
P-value	<.001	<.001	<.001
SEm (±)	3.82	0.51	5.24
LSD (=0.05)	11.44	1.53	15.71
CV, %	10.4	13.5	13.6
Grand mean	82.3	8.44	86.5

Notes: N-omission: –N + P, K, Zn, B (75:75:5:1 P_2O_5:K_2O:Zn:B kg ha^{-1}); P-omission: -P + N, K, Zn, B (150:75:5:1 N:K_2O:Zn:B kg ha^{-1}); K-omission: -K+ N, P, Zn, B (150:75:5:1 N: P_2O_5:Zn:B kg ha-1); Adequate NPK: (150:75:75 N:P_2O_5:K_2O kg ha^{-1}); Adequate NPK + B, Zn: (150:75:75:5:1, N:P_2O_5:K_2O:Zn:B kg ha^{-1}). Treatment means in the column followed by the same letter(s) are not significantly different by DMRT at 0.05 level of significance.

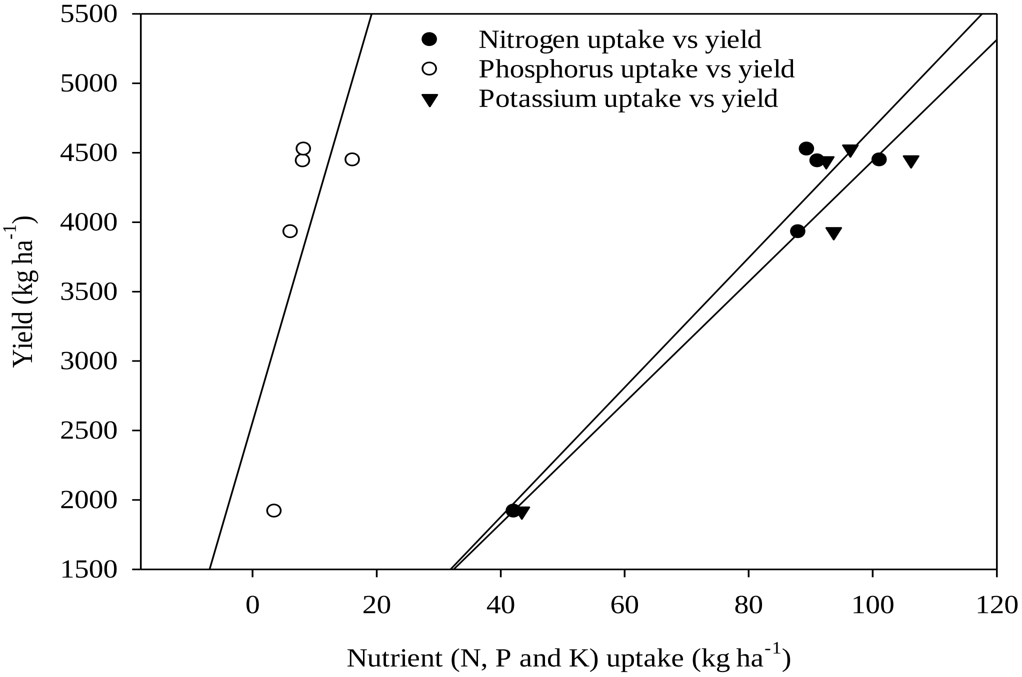

Figure 2. Relationship between nutrient uptake and yield

NDVI value

The NDVI values observed at various stages of crop growth illustrate the significant impact of fertility treatments on plant health and vigor. At 30 DAS, the significantly higher NDVI values in the Adequate NPK and Adequate NPK + B+Zn treatments reflect the early benefits of balanced nutrient availability. Nitrogen plays a crucial role in early vegetative growth by promoting chlorophyll content and overall plant vigor (Fathi 2022). The similarity between the Adequate NPK + B, Zn, and P- and K-omission treatments at this stage may suggest that early growth is less affected by the omission of individual nutrients like phosphorus or potassium, but strongly influenced by nitrogen deficiency, as seen in the N-omission treatment, which consistently had the lowest NDVI value.

At 45 DAS, the importance of both nitrogen and phosphorus becomes more evident, with N- and P-omission treatments showing significantly lower NDVI values than Adequate NPK and Adequate NPK+B+Zn treatments. This stage corresponds to the critical period of tillering and leaf expansion, which are heavily dependent on sufficient nitrogen and phosphorus (Vinod and Heuer 2011). The comparable NDVI values for K-omission to other treatments suggest that potassium's role becomes more prominent in the later stages of growth. As the crop approached 60, 75, and 90 DAS, the N-omission treatment consistently exhibited the lowest NDVI values, underscoring nitrogen’s ongoing importance in maintaining photosynthetic activity and biomass accumulation throughout the crop cycle.

Nitrogen deficiency is known to limit the plant's ability to form new tissues and sustain healthy leaf function, which is reflected in these lower NDVI readings (Zhao et al 2005). In contrast, the other treatments, including those omitting phosphorus or potassium, maintained similar NDVI values, indicating that while these nutrients are important, their deficiency is less immediately detrimental than nitrogen omission in wheat, especially at later stages of development.

The balanced nutrient management strategies, particularly those incorporating micronutrients like boron and zinc, further enhance plant growth and help sustain optimal NDVI values, leading to better overall plant health and potentially higher yields.

Table 5. Effect of different fertility levels on normalized difference vegetation index (NDVI) value at different growth stage

Treatments	NDVI value				
	30 DAS	**45 DAS**	**60 DAS**	**75 DAS**	**90 DAS**
N-omission	0.21^{c}	0.42^{c}	0.48^{b}	0.48^{b}	0.35^{b}
P-omission	0.27^{b}	0.56^{b}	0.67^{a}	0.67^{a}	0.46^{a}
K-omission	0.27^{b}	0.63^{ab}	0.69^{a}	0.68^{a}	0.45^{a}
Adequate NPK	0.32^{a}	0.66^{a}	0.72^{a}	0.69^{a}	0.48^{a}
Adequate NPK+B+Zn	0.3^{ab}	0.66^{a}	0.72^{a}	0.71^{a}	0.48^{a}
P-value	<.001	<.001	<.001	<.001	<.001
SEm (±)	0.01	0.03	0.02	0.02	0.01
LSD (=0.05)	0.04	0.08	0.06	0.06	0.033
CV, %	9.8	10	6.9	7.1	5.5
Grand mean	0.27	0.586	0.66	0.646	0.444

Notes: N-omission: –N + P, K, Zn, B (75:75:5:1 P_2O_5:K_2O:Zn:B kg ha^{-1}); P-omission: -P + N, K, Zn, B (150:75:5:1 N:K_2O:Zn:B kg ha^{-1}); K-omission: -K+ N, P, Zn, B (150:75:5:1 N: P_2O_5:Zn:B kg ha-1); Adequate NPK: (150:75:75 N:P_2O_5:K_2O kg ha^{-1}); Adequate NPK + B, Zn: (150:75:75:5:1, N:P_2O_5:K_2O:Zn:B kg ha^{-1}). Treatment means in the column followed by the same letter(s) are not significantly different by DMRT at 0.05 level of significance.

CONCLUSION

Based on the results obtained, it can be concluded that the inherent nitrogen and phosphorus-supplying capacity of the soil was low. Nitrogen was found to be the most limiting factor for wheat grain yield compared to phosphorus and potassium. The highest grain yield was found in the fully fertilized treatment with zinc and boron (150:75:75:5:1, N:P_2O_5:K_2O:Zn:B kg ha^{-1}). Therefore, it is recommended to apply the optimum doses of nitrogen, phosphorus, and potassium to enhance nutrient uptake efficiently, which will help to increase wheat productivity.

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AUTHORS' CONTRIBUTION

Mathura Yadav conducted the field experiment, collected and analyzed the data, and wrote the manuscript. Dr.Shrawan kumar Sah, Dr. Anant Prasad Regmi and Dr. Santosh Marahatta designed the research, helped to frame the manuscript and edited the manuscript.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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