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Site-Specific Fertilizer Management through Nutrient Expert: Productivity, Profitability and Efficiency of Wheat

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Abstract

A field experiment was conducted at Tikapur, Kailali located in Sudur-Pashim Province of Nepal from November 2021 to April 2022 to determine the effects of site-specific nutrient management practices on the yield, economics and resource use efficiency of wheat (cv: Vijay). Six fertilizer treatments were laid-out in a Randomized Complete Block Design. The treatment includes nitrogen omitted plot (N_0), blanket recommendation (BR), Nutrient Expert based-NPK (NE), Nutrient Expert based nitrogen recommendation and farmers fertilizer practice for other fertilizers (NE-N), leaf color chart-based nitrogen recommendation (LCC-N) and farmers fertilizer practice (FFP). NE produced the highest yield compared to BR and FFP. Grain yield between NE and LCC was similar ($p>0.05$). LCC-N produced the highest harvest index (0.46) and nitrogen use efficiency while they were the lowest in farmer-based practice. As with yield, NE produced higher gross revenue and benefit-cost ratio compared to farmers' practice. Similarly, the maximum nitrogen uptake by grain and straw and soil residual N was observed in NE treated plot. These results suggested that NE based NPK management could increase yields, NUE and farm profit. However, similar benefits could also be achieved using either LCC based N management with 25 to 40% less N compared to NE. So, the fertilizer recommendation using NE-Wheat model in combination with LCC (if available to farmers) for N management could be suggested to the farmers for successful wheat cultivation.

Keywords: fertilizer practices, nutrient expert, nitrogen use efficiency, site-specific nutrient management

Introduction

Wheat (*Triticumaestivum* L.) is a major food crop, and cultivated globally in 216 million ha with a total production of 765 million tons and an average yield of 3.5 t ha^{-1}, ranks second to maize and followed by rice (FAO, 2019; Houshyar et al., 2010). It is the third most important cereal crop in Nepal, both in terms of area and production (Bhatta et al., 2020). Although wheat is cultivated across all agro-ecological zones in Nepal, more than 60% wheat is grown in the Terai region (MoALD, 2017). Wheat accounts for approximately 7.14% of national AGDP (Pandey & Basnet, 2018). In Nepal, wheat is grown on 7,07,505 ha with a total production of 2,185,289 Mt and a yield of 3.09 t ha^{-1}. In Kailali district, wheat is cultivated in 35,950 ha with a total production of 140,545 Mt and a yield of 3.91 t ha^{-1} (MoALD, 2020). However, domestic production is not sufficient to meet the national demand.

There are several factors that contribute to Nepal's low wheat yield, the most important of which is improper and insufficient fertilizer use (Amgain et al., 2022; Bhatta et al., 2020). This causes a large yield gap between a genetic potential of 11-13 t ha^{-1} (Senapati & Semenov, 2020) and actual yield at farmer's field. Appropriate crop management technologies and approaches must be introduced to close the yield gaps and increase production (FAOSTAT, 2017). Among the nutrients, nitrogen is a key nutrient for increasing crop yield (Halitligil et al., 2000), but its utilization efficiency is very low as more than 50% of applied N is lost to the environment. According to a recent global review, the recovery rate of N fertilizer in wheat crop with current management practices is around 30% (Krupnik et al., 2004). It is reported that the cereal NUE is very low in Nepal compared to the SAARC countries (Singh et al., 2007). Nitrogen use efficiency in rice and wheat is low due to inefficient N application, including use of inappropriate rates, timing and application method (Krupnik et al., 2004). This necessitates to adopt improved methods which improve NUE and yields, while reduces environmental pollution. Some of the strategies include Site-Specific Nutrient Management (SSNM) through Nutrient Expert (NE) and real-time nitrogen management through Leaf Color Chart (LCC) (Jat & Gerard, 2014).

Previous studies show that adoption of NE based fertilizer application improved yields and fertilizer use efficiency because it helps to synchronize nutrient supply with the plant demand. In comparison to farmers' fertilizer practice (FFP), the NE-based wheat model increased yield and profitability through effective nitrogen use (Bhatta et al., 2020; Kunwar et al., 2019; Zhang et al., 2018). NE makes fertilizer recommendations based on yield responses and targeted agronomic efficiencies, as well as indigenous nutrient contributions. Similarly, the real-time N application guided by LCC enables farmers to apply fertilizer N in multiple doses to ensure a sufficient supply of N at critical growth stages; thus, improves yields and NUE. LCC, which is based on the

SSNM principle, also aids in nitrogen management in the soil by taking into account the inherent N-supplying capacity of different fields, ensuring consistent high yields with efficient use of N in both rice and wheat and increasing total productivity of the rice-wheat system and farmer profit (Shukla et al., 2004).

It has been reported that the efficiency of N use in wheat in South Asia could be improved by using fertilizer N management strategies that are responsive to temporal variations in which N demands and supply vary from field to field (Amgain et al., 2022; Singh et al. 2010). Improved synchrony of N supply with crop demand, N supply by soil, and applied N fertilizer at optimum dose appears to be more promising in wheat. The strategy combines preventive (applying fertilizer N as basal or at earlier fixed growth stages to prevent fertilizer N deficiency) and corrective (LCC guided) N management. The Terai region of Nepal is known as the "bread basket" of food crops, but farmers have been disappointed in recent days due to low profit margins. A preliminary survey conducted in Tikapur shows that the productivity of wheat is low due to lack of farmer awareness on the application of fertilizers including optimum rate, application time and methods, use of pesticides and miss-management of cultivation practices. In far-western region of Nepal, the research based on SSNM approaches including N management strategies in wheat is lacking. These problems are associated with lack of manpower and research funding, lack of credits and agricultural inputs, poor crop management practices and poor planning as compared to eastern region. Therefore, this study was conducted to determine Nutrient Expert-wheat recommendations to farmers' fertilizer practices (FFP) comparing with the government recommendations (GR) for increasing NUE and thereby production and profitability and providing an alternative option for improved nutrient management for wheat farmers in Nepal's diverse climatic regions.

Materials and Methods

Experimental Site, Soil and Weather

The experiment was conducted in the farmer's fields of Tikapur (28°31′30″N, 81°07′15″ E, 256 masl.) in Kailali district from November 2020-April 2021. The Rice was cultivated in experimental farm before conducting the experiment with wheat. The soil samples were collected from each field before start of the experiment (2020/2021) from 0–20 cm soil layer and analyzed. Soil texture was sandy loam, acidic in reaction (pH 6.53), low in organic matter (2.44%), total nitrogen (0.12%) and available potassium (162.40 kg ha^{-1}), but low in available phosphorus (29.49kg ha^{-1}). The average temperature recorded during crop growth period (November 2020 to April 202) ranged from 15 to 40^{0} C with relative humidity of 10% to 62%.

Experimental Design and Treatment Detail

Wheat cultivar Vijay (BL-3063) was sown in November after harvesting of rice. For farmers' fields were selected randomly. There was slight variation in soil physical and chemical characters. Each selected farmer was interviewed with the NE-Wheat embedded questionnaire, with the majority of wheat production techniques and nutrient management procedures as prescribed in the question sets. The data was entered into the NE ® Wheat model program. According to the Nutrient Expert tool, various nutrient dosages for nitrogen from Urea, phosphorus from Di-ammonium phosphate (DAP), and potassium from Muriate of Potash (MOP) were recommended for different farmers for different fields. The Nutrient-Expert Wheat model was used to predict wheat yield and profit at 14% moisture for all treatments, and the results were compared to the actual yield and profit to validate the model's estimation. Crop was grown following recommended agronomic package of practices wherein full dose of P and K through DAP, MOP applied basally (Reddy & Reddy, 2009).

Six fertilizer treatments (Table 1) were laid out in a randomized complete block design with 4 replications (a farmer field was considered as a replication), Treatments consisted N omission, blanket recommendation (BR), nutrient expert based NPK application (NE) and nutrient expert based N application (NE-N), real-time N following leaf color chart (LCC), and farmers fertilizer practice (FFP).

Table 1

Treatment Details Used in the Experiment

Treatment	Abbreviation	Treatment description	N: P_2O_5: K_2O: B kg ha^{-1}
T1	N0	N-omission, P (SSP), K and micronutrient (boron) as per government recommended rates	0:50:50:2
T2	BR	Government recommended rates (blanket application); N, P, K and micronutrients as per recommendation	120: 50:50:2
T3	NE	Nutrient Expert-wheat model recommended dose	Farmers 1: 125: 63: 82 Farmers 2: 110: 50: 83 Farmers 3: 95: 44: 65 Farmers 4: 125: 60: 88

T4	NE-N	Nutrient Expert based Nitrogen and farmer's practice-based P and K; Nitrogen applied according to Nutrient Expert wheat and P &K on the basis of farmer's dose	Farmers 1: 125: 23: 0 Farmers 2: 110: 23: 0 Farmers 3: 95: 23: 0 Farmers 4: 125: 23: 15
T5	LCC	N based on LCC and P, K and boron as per recommendations	65.56:50:50:2
T6	FFP	Farmers' fertilizer practices; Applied as a farmers' dose.	

Estimation of Yield, Nitrogen Use Efficiency and Economic Return

Wheat was harvested in its physiological maturity and recorded yield and yield components. Effective tillers m^{-2}, filled grains $spike^{-1}$, thousand grain weight (g) were recorded from 10 randomly selected plants of each plot. Grain, straw and biological yields (t ha^{-1}), were recorded from the net plot of 12 m^2 area and grain yield was adjusted at 14% moisture. Harvest index and sterility percentages were then calculated following the standard formula. Grain and straw samples were prepared for laboratory analysis of N content. Based on N content of grain and straw, the total N uptake by grain and straw, and NUE was determined.

Economic analysis was done for each treatment using cost of cultivation and gross revenue. Cost of cultivation was estimated (NRs ha^{-1}) based on cost of different agriculture inputs viz. labor, fertilizer, compost, and other necessary materials. Gross returns (NRs ha^{-1}) were calculated from economic yield (grain + straw) of wheat on the basis of local market price available in Kailali district of Nepal for the year 2020/21. Benefit-Cost ratio was calculated by dividing gross returns with cost of cultivation.

Nitrogen Use Efficiency (NUE)

NUE is the ratio of nitrogen utilized by plant in biomass production to the N total n applied. Plant uptake of nitrogen from the soil and its efficient translocation for sustainable production of biomass varies with crops and management practices. According to Fageria et al. (1997) following formulae were used to estimate NUE:

Agronomic Nitrogen Use Efficiency (ANUE)

Agronomic nitrogen use efficiency is yield increase per unit of Nitrogen applied. It more closely reflects the impact of applied Nitrogen on the yield because it measures the amount of grain yield gained by the nitrogen input (Snyder and Bruulsema, 2007).

$$\text{ANUE} = \left(\frac{\text{Grain yield in fertilized plot (Kg ha}^{-1}\text{)} \; - \; \text{Grain yield in unfertilized plot (Kg ha}^{-1}\text{)}}{\text{Nutrient rate (Kg ha}^{-1}\text{)}}\right)$$

Apparent Nitrogen Recovery Efficiency (ANRE)

Apparent Nitrogen recovery efficiency is defined as the increase in crop uptake of Nitrogen in the aboveground parts of the plant in response to the application of Nitrogen. Like AE, it can be measured when a nutrient omission plot has been implemented.

$$\text{ANRE} = \left(\frac{\text{TNU in fertilized plot (Kg ha}^{-1}) \;-\; \text{TNU in unfertilized plot (Kg ha}^{-1})}{\text{Nutrient applied in fertilized plot (Kg ha}^{-1})}\right)$$

Agro-physiological Nitrogen Use Efficiency (APE)

Agro-physiological efficiency (APE): It is the economic yield per nutrient uptake.

$$\text{APE}= \left(\frac{\text{Grain yield in fertilized plot (Kg ha}^{-1}) \;-\; \text{Grain yield inunfertilized plot (Kg ha}^{-1})}{\text{TNU infertilized plot (Kg ha}^{-1}) \;-\; \text{TNU inunfertilized plot (Kg ha}^{-1})}\right)$$

Internal Efficiency

Internal efficiency has been defined as the amount of grain yield produced per kilogram of nutrient accumulation in the aboveground plant dry matter expressed on an oven-dry basis. Internal efficiency is used to evaluate the ability of plants to transform nutrients acquired from all sources (soil and fertilizer) into economic yield (grain). A low IE suggests poor internal nutrient conversion due to stress (i.e., nutrient deficiencies, drought, heat, mineral toxicities, and disease)

$$\text{IE} = \frac{\text{Grain yield (Kg ha}^{-1})}{\text{TNU (Kg ha}^{-1})}$$

Partial Factor Productivity

The PFP is calculated in units of crop yield per unit of nutrient applied.

$$\text{PEP} = \frac{\text{Grain yield (Kg ha}^{-1})}{\text{Fertilizer applied (Kg ha}^{-1})}$$

Data Analysis

Data were entered into Microsoft Excel-2010. Analysis of variance for each response variable and their mean grouping was performed by using Gen-Stat package and treatment mean were compared by Least Significant Difference (LSD) at 0.05% level of significance.

Results and Discussion

Yield Attributing Characters

The effective tillers m^{-2}, no. of filled grains $spike^{-1}$, and thousand grain weights (g), are considered yield attributes of wheat (Table 2). The average effective tillers were recorded as 333.20 m^{-2}. Nutrient Expert based nutrient management produced the highest number of effective tiller (428.80 m^{-2}), followed by LCC-N (382.50 m^{-2}). Nitrogen omission plot had recorded the least number of effective tillers (251.50m^{-2}). The average number of filled grains spike^{-1} was 36.46 grains spike^{-1}. The NE treatment produced the highest number of number of grains spike^{-1} (40.43 grains spike^{-1}) followed by LCC-N (38.28 grains spike^{-}1), but the minimum grain number was recorded in Nitrogen omission plot (28.88grains spike^{-1}). The availability of nitrogen in soil promotes greater number of filled grains per spike, which is consistent with other findings (Shokri et al., 2009). Kunwar et al. (2019) and Dahal et al. (2018) reported that higher grains spike^{-1} for NE model as compared to the farmer's fertilizer practice.

The test weight was influenced by different nutrient management practice (Table 2). The test weight of wheat ranges from 48.12 g to 54.03g, with the average of 52.2g. The higher grain weight per spike is due to higher nitrogen uptake in grains that resulted in increased photosynthate and carbohydrate accumulation which is in consistent with (Siddik, 2010). Similarly, the sterility percentage was significantly varied among the treatments ranging from highest 46.37% in nitrogen omission plot followed by FFP (43.63%) and Nutrient Expert-N (40%) although recorded least at Nutrient Expert recommendation (33.13%). Pant et al. (2020) reported that highest sterility was observed in nitrogen omitted plot and the lowest in nutrient expert-based model in rice which might be due to the supply of nitrogen in adequate amount which then promoted the availability of other nutrients such as P and K in NE based model, which is in accordance to our finding.

Table 2

Effect of Different Nitrogen Management Practices on Yield Attributing Characters of Wheat at Tikapur, Kailali, Nepal during 2020/2021

Treatment	Effective tillers m^{-2}	Filled grains spike^{-1}	Thousand grain weight (g)	Sterility (%)
N Check (N0)	251.50^{d}	28.88^{c}	48.12^{c}	46.37
BR	303.00^{cd}	37.18^{ab}	52.50^{ab}	37.54
NE	428.80^{a}	40.43^{a}	54.03^{ab}	33.13
NE-N+FFP- P&K	341.20^{bc}	35.62^{ab}	51.84^{abc}	40.00
LCC-N	382.50^{ab}	38.28^{a}	53.81^{ab}	38.28
FFP	256.00^{d}	31.65^{bc}	50.31^{bc}	43.63
LSD (5%)	55.33(***)	5.27(**)	4.41(**)	NS
CV%	11.4	9.9	5.1	18.0

Grain and Biological Yields, and Harvest Index

Nutrient Expert recommendation produced significantly higher yield (4.59 t ha^{-1})

compared to BR and FFP, but statistically similar with LCC (4.07 t ha^{-1}). The minimum yield was recorded in nitrogen omission plot which was 2.65 t ha^{-1}, highlighting, N is the most critical nutrient to increase the wheat yield (Table 3).

The estimated yield for Nutrient Expert was 5.5 t ha^{-1} under favourable climatic condition and irrigation but due some crop damage at an earlier growth stage and scanty rainfall pattern the estimated and expected yield range i.e. 5.5 t ha^{-1} of wheat variety was not met. Generally, there is positive correlation between the grain yield and nitrogen uptake. However, sometimes the crop varieties produce different grain yield with the same amount of nitrogen uptake which is due to the difference in internal nitrogen use efficiency (IEN) (Singh et al., 1998; Tirol-Padre et al., 1996). Sapkota et al. (2014) found similar results on use of NE model. The grain yield was found significantly correlated with agronomic characters such as plant height, total tillers m^{-2}, effective tillers $plant^{-1}$, grain $spike^{-1}$, test weight and harvest index due to application of nitrogen fertilizer (Kader et al., 2013), which is in accordance to our finding. It was found that the grain yield was significantly increased by increasing the nitrogen level by applying the fertilizer at right time, amount and space which is in close agreement to other findings (Ahmad et al., 2011; He et al., 2009).

The maximum biomass yield was obtained in Nutrient Expert recommendation (10.39 t ha^{-1}) as compared to Nitrogen omission plot (7.058t ha^{-1}) and FFP (7.32 t ha^{-1}). Bhatta et al. (2020) and Sapkota et al. (2014) also found that higher biomass yield for NE over FFP. The dry matter production increased with the increase of nitrogen in wheat crop which might result in increment of the biomass yield. The results corroborate the findings of other authors Gupta et al. (1985) and Kumar et al. (2016), who also observed that biological yield increases with increasing fertilizer dosages. Nitrogen promotes vegetative growth by assimilation of more photosynthates into the crop, as well as increases in growth, yield and yield-attributed characteristics, which is supported by (Kumar et al., 2016).

The highest harvest index of 0.46 was recorded in LCC-N recommended doses of nutrient followed by and Nutrient Expert-N. Nitrogen omission had the lowest harvest index (0.38) due to differences in proportion of grain yield and biomass production. Findings of Kumar et al. (2017) and Sen et al. (2011) are in accordance with our result. An increase in the harvest index is the result of an increase in grain yield and biomass yield, both of which are significantly influenced by nitrogen application. A similar outcome was attained by (Farooq et al., 2012).

Table 3

Effect of Different Nitrogen Management Practices on Grain Yield, Biomass Yield and Harvest Index of Wheat at Tikapur, Kailali, Nepal during 2020/2021

Treatment	Grain yield at 14% moisture (t ha^{-1})	Biomass yield (t ha^{-1})	Harvest Index
N Check (N0)	2.65^{d}	7.05^{b}	0.38
BR	3.87^{b}	9.21^{a}	0.42
NE	4.59^{a}	10.39^{a}	0.44
NE-N	4.09^{ab}	8.99^{a}	0.45
LCC-N	4.07^{ab}	9.19^{a}	0.46
FFP	3.32^{c}	7.32^{b}	0.45
LSD (5%)	0.52(***)	1.49(***)	NS
CV%	9.0	11.2	11.5

Economic Analysis

The economic analysis suggested that the Nutrient Expert based fertilizer management produces higher economic return NRs. 1.42 lakhs ha^{-1} compared to N omission and FFP. Although the total cost was higher in Nutrient Expert recommendation (NRs.0.58lakhs ha^{-1}) and the lowest in nitrogen omission plot NRs. 0.50 lakhs ha^{-1} followed by farmer's fertilizer practice NRs. 0.51 lakhs ha^{-1} (Table 4), NE produced the higher return and cost benefit ratio.

Table 4

Effect of Different Nitrogen Management Practices on Total Cost, Revenue and BC Ratio of Wheat in the on-farm Experiment at Tikapur, Kailali, Nepal 2020/21

Treatment	Total Cost (NRs. lakhs ha^{-1})	Gross Revenue (NRs. lakhs ha^{-1})	B:C Ratio
N Check (N0)	0.50^{d}	0.92^{b}	1.82^{b}
BR	0.57^{b}	1.21^{a}	2.13^{ab}
NE	0.58^{b}	1.42^{a}	2.46^{a}
NE-N	0.46^{e}	1.26^{a}	2.71^{a}
LCC-N	0.53^{c}	1.22^{a}	2.29^{ab}
FFP	0.51^{d}	1.16^{ab}	2.24^{ab}
LSD (5%)	0.01(***)	0.26(*)	0.50(*)
CV%	1.90	14.30	15.10

The gross revenue among the treatments was found highest for NE based model NRs 1.42 lakhs ha^{-1} which is statistically similar with LCC and NE-N and the lowest for nitrogen omission plot NRs. 0.92 lakhs ha^{-1}. Bhatta et al. (2020) and Kunwar et al. (2019) also showed similar result that revenue through SSNM-Nutrient Expert is higher than farmer's practices and government recommendations in wheat. The gross return is higher in NE® is due to an increase in grain yields from adequate nutrient applications than other nutrient management practices. The B:C ratio of NE model in comparison to the farmer's practice was high. Kunwar et al. (2019) also reported higher BC ratio for NE-model (2.42) over FFP (1.37). The BC ratio for NE-model was high due to the high gross return over cost of cultivation compared to FFP (Fonsah et al., 2007, 2008), which is in accordance to our findings.

Nitrogen Content, Nitrogen Uptake, and Nitrogen Use Efficiency

Nitrogen concentration in grain is more than in straw ranging from 1.73 to 2.12 % in grain and 0.34 to 0.39 % in straw (Table 5).

Table 5

Effect of Different Nitrogen Management Practices on Nitrogen Uptake in Wheat at Tikapur, Kailali, Nepal during 2020/2021

Treatment	Grain N%	Straw N%	Grain N uptake (Kg ha^{-1})	Straw N uptake (kg ha^{-1})	Total N uptake (kg ha^{-1})
N Check (N0)	1.73^{d}	0.34	46.84^{d}	14.68^{b}	61.52^{c}
BR	1.85^{bcd}	0.39	74.20^{bc}	23.17^{a}	97.36^{b}
NE	2.08^{ab}	0.38	85.31^{ab}	21.86^{a}	107.11^{ab}
NE-N	1.91^{abcd}	0.35	85.25^{ab}	18.72^{ab}	104.02^{ab}
LCC-N	1.89^{abcd}	0.35	77.00^{b}	18.47^{ab}	95.47^{b}
FFP	1.84^{bcd}	0.37	62.16^{c}	14.89^{b}	77.05^{c}
LSD (5%)	0.21(*)	NS	13.99(***)	5.67(*)	15.71(***)
CV%	7.60	11.70	12.40	19.80	11.10

Fertilizer treatments significantly affected different component of NUE. The highest N uptake by grain was observed in Nutrient Expert recommendation (85.31 kg ha^{-1}), but lowest uptake was in Nitrogen omission plot (46.84 kg ha^{-1}). N uptake by straw was found higher in blanket recommendation (23.17kg ha^{-1}) and statistically par with Nutrient Expert recommendation (21.86 kg ha^{-1}). The least straw N uptake was found in nitrogen omission plot (14.68 kg ha^{-1}). The higher nitrogen concentration of grain and straw with increasing nitrogen rate might be due to the crop's having adequate nitrogen, which could enhance nitrogen concentration on biological yield, particularly straw, due to better roots and greater density. These is in line with the findings of Worku et al. (2007) and Astaneh (2018) who reported that increase in the supply of nitrogen increases straw nitrogen content gradually.

In our findings the highest partial factor productivity (PFP), Agronomic Nitrogen Use Efficiency (ANUE), Agronomic nitrogen recovery efficiency (ANRE) and Agro-physiological nitrogen use efficiency were seen in LCC-N and lowest in farmer's fertilizer practice (Table 6).

Table 6

Effect of Different Nitrogen Management Practices on Nitrogen Use Efficiency in Wheat at Tikapur, Kailali, Nepal during 2020/2021

Treatment	PEP	ANUE	ANRE	APE	IE-N
N Check (N0)					38.15
BR	37.80[cd]	15.72[bc]	0.48[a]	31.85	43.50
NE	40.86[c]	17.51[bc]	0.40[a]	42.21	44.03
NE-N+FFP- P&K	36.4[cd]	13.06[c]	0.37[a]	33.28	39.55
LCC-N	69.97[a]	24.84[a]	0.56[a]	45.85	43.82
FFP	28.95[d]	5.91[d]	0.13[b]	41.11	39.24
LSD (5%)	8.367(***)	6.415(***)	0.184(**)	NS	NS
CV%	13.1	27.8	30.8	28.5	8.20

These results are in close agreement with previous studies by Maiti and Das (2006) and Kundu et al. (2000), they observed that the LCC-N plots showed high PFP, ANUE, ANRE and APE against fixed-scheduling N splits. Singh et al. (2007) also reported high PFP in LCC-N than farmer's practice. Similarly, Haile et al. (2012) found a declining trend in nitrogen use efficiency as nitrogen rates increased, which is in accordance to our findings. With high nitrogen use efficiency, more of the applied nitrogen is absorbed by the crop, benefiting the ecosystem by reducing leaching and volatilization loss as well as enhancing the farmers' profits by increasing the yield and protein content in grain which increases the economic value of grain. The IE-N was found highest for Nutrient Expert recommendation (44.03). Ladha et al. (1998) and Zhang et al. (2007) reported that variation in IE-N may occur due to differences in internal N requirements for development and the plant's capacity to translocate, distribute and mobilize absorbed N to and from various organs, which support our findings.

Residual Soil Chemical Properties

The highest nitrogen residue was found on farmer field practice (0.56 %), which might be due to the application of large amounts of nitrogen (Johnkutty et al., 2000) as compared to the N omission plot (0.10%). Our result is accordance with the research conducted by Xu et al. (2020), who found that the residual effects of fertilizer N increased with the increase of previous N application rate and decreased over time due to the combination of N uptake and N loss pathways (Table 7). While lower N availability in N omission plot might be due to insufficient N application that was utilized for crop growth and uptake. These results were similar to the findings of Shukla et al. (2006).

Table 7

Effect of Different Nitrogen Management Practices on Residual Soil Chemical Properties and Total N Uptake at Tikapur Kailali, Nepal during 2020/2021

Treatment	N% in soil	Total Nitrogen uptake
N Check (N0)	0.10[e]	61.52[c]
BR	0.47[b]	97.36[b]
NE	0.21[de]	107.11[ab]
NE-N+FFP- P&K	0.27[cd]	104.02[ab]
LCC-N	0.39[bc]	95.47[b]
FFP	0.56[ab]	77.05[c]
LSD (5%)	0.15(***)	15.71(***)
CV%	27.2	11.1

Conclusion

The study suggests that N is the most limiting nutrient for wheat cultivation in Western Terai region of Nepal and special attention is needed to recommend site specific N recommendation to improve yield and nitrogen use efficiency. Site-specific nutrient management (SSNM) based on Nutrient Expert, real-time N management using leaf color chart (LCC) could help to minimize the yield gap and increase the fertilizer use efficiency compared to the government' blanket recommendation and farmer's practice. Nepalese farmers would be able to significantly improve the yield of wheat and also raise their income through the use of site-specific fertilizer recommendation using NE in combination with LCC.

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References

Ahmad, A., Ali, A., Asif, M., Aziz, M., Khaliq, T. Mubeen, M., & Syed, W.H. (2011). Effects of nitrogen on growth and yield components of wheat. (Report). In *Biol. Sci, 3*(6), 1004-1005.

Amgain, L. P., Devkota, K. P., Marahatta, S., Karki, T. B., Kafle, S., Dulal, P. R., Subedi, S, ThapaMagar, S., & Timsina, J. (2022). Conservation agriculture technologies for cropping systems sustainability and food and nutrition security in Nepal. *Agriculture, Natural Resources and Food Security: Lessons from Nepal*, 195-220.

Astaneh, N., Bazrafshan, F., Zare, M., Amiri, B., & Bahrani, A. (2018). Effect of nano chelated nitrogen and urea fertilizers on wheat plant under drought stress condition. *Nativa*, *6*(6), 587-593.

Bhatta, R. D., Amgain, L. P., Subedi, R., & Kandel, B. P. (2020). Assessment of productivity and profitability of wheat using Nutrient Expert®-Wheat model in Jhapa district of Nepal. *Heliyon*, *6*(6), 41-44.

Dahal, S., Shrestha, A., Dahal, S., & Amgain, L. P. (2018). Nutrient expert impact on yield and economic in maize and wheat. *International Journal of Applied Sciences and Biotechnology*, *6*(1), 45-52.

Faostat, F. A. O. (2017). Available online: http://www. fao. org/faostat/en/# data. *QC (accessed on January 2018)*.

FAO. (2019). Status of major cereals grain production. Bangkok, Thailand: Food and Agriculture Organization of the United Nations. 120.

Fageria, N. K., Santos, A. B. D., & Baligar, V. C. (1997). Phosphorus soil test calibration for lowland rice on an Inceptisol. *Agronomy Journal*, *89*(5), 737-742.

Farooq, M., Wahid, A., & Siddique, K. H. (2012). Micronutrient application through seed treatments: a review. *Journal of Soil Science and Plant Nutrition*, *12*(1), 125-142.

Fonsah, E. G., Adamu, C. A., Okole, B. N., & Mullinix, B. G. (2007). Field evaluation of Cavendish banana cultivars propagated either by suckers or by tissue culture, over six crop cycles in the tropics. *Fruits*, *62*(4), 205-212.

Fonsah, E. G., Krewer, G., Harrison, K., & Stanaland, D. (2008). Economic returns using risk-rated budget analysis for rabbiteye blueberry in Georgia. *Hort Technology*, *18*(3), 506-515.

Gupta, U. C., Jame, Y. W., Campbell, C. A., Leyshon, A. J., & Nicholaichuk, W. (1985). Boron toxicity and deficiency: a review. *Canadian Journal of Soil Science*, *65*(3), 381-409.

Haile, D., Nigussie, D., & Ayana, A. (2012). Nitrogen use efficiency of bread wheat: Effects of nitrogen rate and time of application. *Journal of Soil Science and Plant Nutrition*, *12*(3), 389-410.

Halitligil, M. B., Akın, A., Bilgin, N., Deniz, Y., Ogretir, K., Altınel, B., & Isık, Y. (2000). Effect of nitrogen fertilization on yield and nitrogen and water use efficiencies of winter wheat (durum and bread) varieties grown under conditions found in Central Anatolia. *Biology and Fertility of Soils*, *31*, 175-182.

He, P., Li, S., Jin, J., Wang, H., Li, C., Wang, Y., & Cui, R. (2009).Performance of an optimized nutrient management system for double-cropped wheat-maize rotations in north-central China. *Agronomy Journal*, *101*(6), 1489-1496.

Houshyar, E., Sheikh Davoodi, M. J., & Nassiri, S. M. (2010).Energy efficiency for wheat production using data envelopment analysis (DEA) technique. *Journal of Agricultural Technology*, *6*(4), 663-672.

Jat, M. L., & Gerard, B. (2014). Nutrient management and use efficiency in wheat systems of South Asia. *Advances in Agronomy*, *125*, 171-259.

Johnkutty, L., Kandawamy, O. S., & Palaniappan, S.P. (2000). Time course leaf N concentration in rice under different nitrogen application strategies and development of simulation models. *Journal of Tropical Agriculture, 37*, 40-45.

Kader, M. A., Sleutel, S., Begum, S. A., Moslehuddin, A. Z. M., & De Neve, S. (2013). Nitrogen mineralization in sub-tropical paddy soils in relation to soil mineralogy, management, pH, carbon, nitrogen and iron contents. *European Journal of Soil Science*, *64*(1), 47-57.

Krupnik, T. J., Six, J., Ladha, J. K., Paine, M. J., & Van Kessel, C. (2004). An assessment of fertilizer nitrogen recovery efficiency by grain crops. *Agriculture and the nitrogen cycle: Assessing the impacts of fertilizer use on food production and the environment*, 193-207.

Kumar, D., Singh, R. A., & Singh, Y. (2016). Influence of sowing dates and nitrogen scheduling on growth behaviour and productivity of late sown wheat (Triticumaestivum L.) in north Indian plains. *Annals of Agricultural Research. 37.*

Kumar, V., Kumar, T., Singh, G., & Singh, R. A. (2017). Effect of need based nitrogen management in wheat (Triticumaestivum). *Annals of Plant and Soil Research*, *19*(3), 243-247.

Kunwar, S. R., Bogati, S., Fonsah, E. G., & Amgain, L. P. (2019). Economic assessment of adopting nutrient Expert® wheat model vs conventional wheat fertilizer application management in Morang, Nepal. *Journal of Agricultural Studies*, *7*(3), 38-48.

Kundu, S., Barman, K. K., & Singh, M. (2000). Effect of fertilizer N rates on soil N uptake and recovery of applied N by wheat in a TypicHaplustert. *Journal of the Indian Society of Soil Science*, *48*(2), 287-291.

Ladha, J. K., Kirk, G. J. D., Bennett, J., Peng, S., Reddy, C. K., Reddy, P. M., & Singh, U. (1998). Opportunities for increased nitrogen-use efficiency from improved lowland rice germplasm. *Field Crops Research, 56*(1-2): 41-71.

Maiti, D., & Das, D. K. (2006). Management of nitrogen through the use of Leaf Colour Chart (LCC) and Soil Plant Analysis Development (SPAD) in wheat under irrigated ecosystem: (StickstoffbemessungmittelsBlattfarbungstabelle (LCC) und analyse der Boden-PflanzeEntwicklung (SPAD) in Bewasserungs-WeizenOkosystemen). *Archives of Agronomy and Soil Science*, *52*(1), 105-112.

MoALD. (2017). Statistical information of Nepalese agriculture 2015/2016. Agri Statistics Section, Monitoring, Evaluation and Statistics Division, Ministry of Agricultural Development, Singha Durbar, Kathmandu, Nepal

MoALD. (2020). Statistical information of Nepalese agriculture 2075/76.Ministry of Agriculture and Development, Singh Durbar, Kathmandu, Nepal.

Pandey, G., & Basnet, S. (2018). Objective agriculture book at a glance. *Kapil Group & Company Pvt. Ltd., Budhanilkantha, Kathmandu, Nepal*, 28-29.

Pant, C., Joshi, P. P., hariGaire, R., & Dahalc, B. (2020). Effect of Site Specific Nutrient Management Approach In Productivity Of Spring Rice In Kanchanpur, Nepal. *Malaysian Journal of Halal Research*, *3*(1), 24-30.

Reddy, T. Y., & Reddy, G. H. (2019). *Principles of agronomy*. Kalyani publishers, New Delhi.

Sapkota, T. B., Majumdar, K., Jat, M. L., Kumar, A., Bishnoi, D. K., McDonald, A. J., & Pampolino, M. (2014). Precision nutrient management in conservation agriculture based wheat production of Northwest India: Profitability, nutrient use efficiency and environmental footprint. *Field Crops Research*, *155*, 233-244.

Sen, A., Srivastava, V. K., Singh, M. K., Singh, R. K., & Kumar, S. (2011). Leaf colour chart vis-a-vis nitrogen management in different rice genotypes. *American Journal of Plant Sciences*, *2*(02), 223.

Senapati, N., & Semenov, M. A. (2020). Large genetic yield potential and genetic yield gap estimated for wheat in Europe. *Global Food Security*, *24*, 100340.

Shokri, S., Siadat, S. A., Fathi, G., Maadi, B., Gilani, A., & Mashhadi, A. A. (2009).Effect of nitrogen rates on dry matter remobilization of three rice cultivars. *International Journal of Agricultural Research*, *4*(6), 213-217.

Shukla, A. K., Ladha, J. K., Singh, V. K., Dwivedi, B. S., Balasubramanian, V., Gupta, R. K.,&Yadav, R. L. (2004). Calibrating the leaf color chart for nitrogen management in different genotypes of rice and wheat in a systems perspective. *Agronomy Journal*, *96*(6), 1606-1621.

Shukla, A. K., Singh, V. K., Dwivedi, B.S., Sharma, S. K., & Singh, Y. (2006). Nitrogen use efficiencies using leaf colour chart in rice (*Oryza saliva*)-wheat (*Triticumaestivum*) cropping system. *Indian Journal of Agricultural Science, 76*(11), 651-656.

Siddik, M. (2010). *Effect of placement of urea fertilizer on the yield of wheat* (doctoral dissertation, department of agronomy).

Singh, U., Ladha, J. K., Castillo, E. G., Punzalan, G., Tirol-Padre, A., & Duqueza, M. (1998). Genotypic variation in nitrogen use efficiency in medium-and long-duration rice. *Field Crops Research*, *58*(1), 35-53.

Singh,V., Singh, Y., Singh, B., Singh, B., Gupta, R. K., Singh, J., Ladha J. K., & Balasubramanian, V. (2007). Performance of site-specific nitrogen management for irrigated transplanted rice in northwestern India. *Archives of Agronomy and Soil Science*, *53*(5), 567-579.

Singh, V., Singh, B., Singh, Y., Thind, H.S., & Gupta, R.K. (2010). Need based nitrogen management using the chlorophyll meter and leaf color chart in rice and wheat in South Asia: A review. *Nutrient Cycling in Agroecosystems, 88*, 361-380.

Snyder, C. S., & Bruulsema, T. W. (2007). Nutrient use efficiency and effectiveness in North America. *Publ. Int. Plant Nutr. Inst. IPNI*.

Tirol-Padre, A., Ladha, J. K., Singh, U., Laureles, E., Punzalan, G., & Akita, S. (1996). Grain yield performance of rice genotypes at suboptimal levels of soil N as affected by N uptake and utilization efficiency. *Field Crops Research*, *46*(1-3), 127-143.

Worku, M., Bänziger, M., Erley, G. S. A. M., Friesen, D., Diallo, A. O., & Horst, W. J. (2007).Nitrogen uptake and utilization in contrasting nitrogen efficient tropical maize hybrids. *Crop Science*, *47*(2), 519-528.

Xu, A., Li, L., Xie, J., Wang, X., Coulter, J. A., Liu, C., & Wang, L. (2020). Effect of long-term nitrogen addition on wheat yield, nitrogen use efficiency, and residual soil nitrate in a semiarid area of the loess plateau of China. *Sustainability*, *12*(5), 1735.

Zhang, Y. H., Jian-Bo, F. H. N., Zhang, Y. L., Dong-Sheng, W. A. N. G., Huang, Q. W., & Qi-Rong, S. H. E. N. (2007). N accumulation and translocation in four japonica rice cultivars at different N rates. *Pedosphere, 17*(6), 792-800.

Zhang, J. J., He, P., Xu, X. P., Ding, W. C., Ullah, S., Wang, Y. L., & Zhou, W. (2018). Nutrient expert improves nitrogen efficiency and environmental benefits for winter wheat in China. *Agronomy Journal*, *110*(2), 696-706.