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Optimizing Nitrogen Fertilizer for Maximizing Potato Yield and Profits in Farmer's Field at Kaski District

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ABSTRACT

An experiment was conducted during 2020 and 2021 in farmer's fields at Machhapuchhre-06, Kaski, Nepal to determine the optimal amount of nitrogen for increasing potato yield, nutrient use efficiency (NUE) and net profits. Seven different levels of nitrogen (0, 25, 50, 75, 100, 125, and 150 kg/ha) were evaluated in a randomized complete block design with three replications. The effects of different levels of nitrogen on yield, yield-attributing traits, NUE, and production cost in potato cv. Janakdev were observed and recorded. It was found that applying nitrogen at the rate of 75 kg/ha, combined with 20 t farm yard manure (FYM)/ha produced the highest tuber yield and benefit-cost ratio. Application of nitrogen more than 75 kg/ha did not result any significant increase in yield and yield components. Considering agronomic, economic, and NUE factors, nitrogen application at 75 kg/ha along with 20 t/ha FYM was found to be optimal for the potato cultivation in Machhapuchhre, Kaski. This finding is also recommended for similar soil and agro-ecological conditions of Nepal.

Keywords: Nitrogen, nitrogen use efficiency, optimum nitrogen dose, potato, yield

सारांश

वातावरणमा पोषकतत्वको हानी कम गर्न र बाली उत्पादन, नाइट्रोजन उपयोग दक्षता र किसानहरूको नाफा बढाउन नाइट्रोजनजन्य मलको उपयुक्त मात्रा पहिचान गर्नु महत्वपूर्ण हुन्छ । माछापुच्छ्रे ०६ लाहाचोक, कास्की, नेपालमा कृषकको खेतमा आलुको उत्पादन, नाइट्रोजन उपयोग दक्षता र खुद नाफा बढाउनको लागि नाइट्रोजनजन्य मलको उपयुक्त मात्र निर्धारण गर्न सन् २०२० र २०२१ मा एक परीक्षण गरिएको थियो । नाइट्रोजनको सात विभिन्न स्तरहरू (०, २५, ५०, ७५, १००, १२५ र १५० के.जी./हे.) लाई तीन पटक दोहोराएर अनियमित पूर्ण ब्लक डिजाइनमा परीक्षण गरियो । आलको जात जनकदेबमा उत्पादन र उपज विशेषताहरुमा प्रत्येक नाइट्रोजनको मात्राको प्रभाव र उत्पादन लागत रेकर्ड गरियो । २० टन/हे. गोठेमल र ७५ के.जी./हे. नाइट्रोजनले आलु उत्पादन र खुद नाफा उल्लेखनीय रुपमा बृद्धि भएको देखियो । तर २० टन/हे. गोठेमल र ७५ के.जी./हे. भन्दा धेरै नाइट्रोजनको प्रयोगले उपज र उपज घटकहरूमा उल्लेखनीय रुपमा बृद्धि हुन सकेन । उक्त परिक्षणका कारकहरूलाई ध्यानमा राखि, माछापुच्छ्रे, कास्की र उस्तै हावापानी र माटो भएका नेपालका मध्य पहाडी क्षेत्रहरुमा आलु खेतीका लागि २० टन/हे. गोठेमलको साथै ७५ के.जी./हे. नाइट्रोजनको मात्रा प्रयोग गर्नु उपयुक्त देखिन्छ ।

INTRODUCTION

Potato (*Solanum tuberosum L.*) is an important food and the predominant tuber crop in Nepal. It plays a crucial role in maintaining national food security (Lama et al 2016). It ranks fifth in area coverage, second in production, and first in productivity (MoALD 2021). In Terai region of Nepal, potatoes are consumed as a supplementary food, mainly as a vegetable, while serving as a staple food in the Hill and Mountain regions. The growing demand for potato-based products have been expanded its market potential, enhancing the economic well-being of smallholder farmers. The country's diverse climate allows for yearround potato cultivation from the lowland plains of Terai to the high-altitude Mountains (Lama et al 2016). The yield potential of potato tubers is mostly influenced by nitrogen and nitrogenous fertilizers. However, enhancing the nitrogen uptake rate of the potato plant and maximizing the efficiency of absorbed nitrogen for tuber production has remained a significant challenge (Ospina et al 2014).

The low productivity of potatoes in Nepal is linked to various edapho-climatic and crop management limitations with one of the primary causes being the inefficient utilization of nutrients. The crop production and excellence quality largely depend on the availability of essential nutrients in soil. Declined soil fertility and poor management techniques, which are frequently ignored for management by farmers, are major causes of low potato yield (Timilsina et al 2022). Nitrogen is a crucial and vital element in determining the production potential of Potato (Muleta et al 2019). Applying nitrogen fertilizer to the soil helps for balancing the nitrogen supply with the crop's demands, promoting optimal plant growth and has a potential to increase the productivity of potato (Vos 2010). Higher rates of nitrogen fertilization in potatoes positively impacts plant growth characteristics and lead to an increase in both the number of tubers and overall yield (Ruza et al 2013). Adequate nitrogen availability positively influences plant growth and development by playing a key role in protein synthesis and chloroplast formation. However, excessive use of nitrogen can lead to excessive vegetative growth, which negatively impacts root and fruit development (Mengel et al 2001). Excess supply of nitrogenous fertilizers results in higher costs, lower returns, and an increased risk of environmental pollution (Timilsina and Vista 2022). Effective nitrogen management plays a crucial role in regulating potato growth and development while also reducing the risks of nitrate contamination in groundwater and the emission of nitrous oxide, a greenhouse gas. (Zebarth and Rosen 2007). Sustaining high crop yields with least nutrient losses to the environment is a major challenge to the potato producers (Westerman 2005). On the other hand, crop yields do not increase proportionally with the increased rate of nitrogen application leading to a reduction in nitrogen use efficiency (NUE) and increased nitrogen losses (Zhang et al 2012 and Moreno et al 2003).

The current fertilizer application rate by farmers for potato production have been found to be insufficient for achieving higher productivity, highlighting the need to revise these application rate to more balanced and optimal levels with improved nutrient use efficiency. Low nitrogen use efficiency (NUE) in potato production is primarily attributed to poor fertilizer management practices. Identifying the optimal nitrogen application rate is crucial for maximizing the efficient use of nitrogen by potato plants to enhance yields. Different potato varieties may have varying response to N- fertilizer depending on their agronomic traits, climate and soil properties. This study was undertaken to identify the optimal nitrogen dose to enhance potato production, improve nitrogen use efficiency (NUE), and maximize economic returns in farmer's field to be recommended for mid hill conditions in Nepal.

MATERIALS AND METHODS

Experimental site

A field experiment was carried out at Machhapuchhre Rural Municipality 06, Lahachowk, Kaski (28°31' N latitude, 83°92' E longitude) from November to March in two consecutive years 2020 and 2021. The soil at the experimental site was slightly acidic with a sandy loam texture containing a medium level of organic carbon and total nitrogen, a high concentration of available P_2O_5, and a medium level of available K_2O (**Table 1**).

Table 1. Physico chemical properties of the soil at the experimental site prior to the study

Soil parameter	Soil test value	Rating	Analysis Method
Soil texture class	Sandy Loam	-	Hydrometer (Bouyoucos 1927)
Soil pH	6.45	Slightly acidic	Potentiometric 1:2.5 (Jackson 1973)
Soil organic matter (%)	3.71	Medium	Walkely Black (Walkely and Black 1934)
Total nitrogen (%)	0.20	Medium	Kjeldahl (Bremner 1982)
Available P_2O_5 (kg/ha)	81	High	Modified Olsen's (Olsen et al 1954)
Extractable K_2O (kg/ha)	117	Medium	Ammonium acetate (Jackson 1967)

Experimental setup and crop management

The experiment included seven treatments with different nitrogen levels (0, 25, 50, 75, 100, 125, and 150 kg/ha) was arranged in a randomized complete block design with three replications (**Table** 2). The first treatment (T_1) was considered as control without nitrogen application. One of the popular potato varieties '*Janakdev*' was plated in second week of November in 7.2 m^2 plot size. Tubers weighing 30-50 g were planted in the furrows spaced at 60 cm × 25 cm with a depth of 3-5 cm, and finally covered with soil. A basal dose of 20 t/ha of farmyard manure (FYM) was incorporated during land preparation, along with 100 kg/ha of P_2O_5 and 60 kg/ha of K_2O, using single super phosphate (SSP) and muriate of potash (MOP), respectively and applied in rows before planting in all experimental units. The N fertilizer through urea was applied in rows as per the treatment in basal dose. Consistent plant protection and cultural management practices were maintained throughout the crop period.

Table 2. Details of the experiment

S.N	Symbol	Detail of the treatment
1	T1	0:100:60 N: P_2O_5:K_2O kg/ha and 20 t FYM /ha
2	T2	25:100:60 N:P_2O_5:K_2O kg/ha and 20 t FYM /ha
3	T3	50:100:60 N:P_2O_5:K_2O kg/ha and 20 t FYM /ha
4	T4	75:100:60 N:P_2O_5:K_2O kg/ha and 20 t FYM /ha
5	T5	100:100:60 N:P_2O_5:K_2O kg/ha and 20 t FYM /ha
6	T6	125:100:60 N:P_2O_5:K_2O kg/ha and 20 t FYM /ha
7	T7	150:100:60 N:P_2O_5:K_2O kg/ha and 20 t FYM /ha

Data recording and analysis

Yield and yield components such as tuber yield, number and weight tubers, plant height, plant vigor, and parameters used for measuring nutrient use efficiency were recorded at respective crop growth stages. Based on average yield divided by nitrogen application rate, average nitrogen use efficiency (ANUE) was estimated (Cassman et al 1996). In other words, it eliminates the contribution of indigenous N in soil to NUE.

$$\text{ANUE} = \frac{Y_N - Y_0}{\text{Nitrogen Rate}}$$

Where, ANUE= Agronomic nitrogen use efficiency

Y_N= Tuber yield in kg/ha for plots fertilized with nitrogen,

Y_0= Tuber yield in kg/ha of plots not fertilized with nitrogen and

Nitrogen rate = Amount of N used in kg/ha

A partial budgeting analysis of nitrogen and control treatments was done by accounting for cultural and fertilizer-related costs associated with cultivating potatoes on one hectare of land. Input and labor costs as well as prices for potato tubers and other related expenses were determined through a local market survey conducted in Lahachowk and Pokhara, Kaski. The benefit-cost (B:C) ratio was calculated using the formula provided by Badal et al 2023. All inputs, including seed, fertilizer, pesticides, land rental value, and labor wages, were assessed and priced at current market rates to estimate the total cost of production.

B: C ratio = Gross return/Total cost of cultivation

For the analysis of variance, the Statistical Tool for Agricultural Research (STAR) version 2.0.1 was used, while Jamovi (version 2.3) was employed for correlation analysis. The Significance was assessed using Fisher's least significant difference at a p-value of less than 0.05 (Gomez and Gomez 1984).

RESULTS

Plant height

Different nitrogen rates significantly influenced the potato plant height and increasing trend was observed as nitrogen rate increased. The tallest plant was recorded at a nitrogen level of 150 kg/ha, followed by 125 kg/ha and 100 kg/ha which were statistically similar but significantly taller than rest of other N Levels during both consecutive years. The correlation analysis showed that the plant height and plant vigor were significantly correlated with increased N levels (**Figure 3**). The combined analysis of plant height from both consecutive years of experiment revealed that applying nitrogen greater than 75 kg/ha did not significantly affect potato plant height.

Table 3. Effect of nitrogen levels on potato yield and yield-related characteristics, Kaski, 2020

Treatments	Plant height (cm)	Total Tuber/Plot		Yield (t/ha)
		Number	Weight(Kg)	
T1	46.27 d	420 bc	16.53 d	22.96 d
T2	51.20 cd	428 bc	21.26 c	29.53 c
T3	53.73 c	467 bc	25.28 b	35.11 b
T4	56.40 bc	495 b	28.72 a	39.89 a
T5	57.93 abc	581 a	27.91 a	38.76 a
T6	62.67 ab	452 bc	27.85 a	38.69 a
T7	63.67 a	407 c	25.07 b	34.82 b
Mean	55.98	464	24.66	34.25
CV%	6.95	9.24	5.30	5.30
P Value	0.001	0.005	0.001	0.001
$LSD_{0.05}$	6.92	76	2.32	3.22

Total tuber number and weight per plot

Increasing N dose increased total tubers number up to 100 kg/ha N during first year of experiment but N level did not have significant effect on total tubers count per plot during 2nd year of study. The total weight of tubers per plot was increased significantly up to 75 kg/ha N during first year and up to 100 kg/ha N during 2nd year of experiment. The combined analysis of data from two years showed that nitrogen doses exceeding 75 kg/ha did not have a significant effect on the total weight of tubers per plot.

The result of Pearson’s correlation analysis revealed that the tuber number and weight of large size tuber had significant positive correlation with increased N level, but significant negative correlation with number and weight of under size and seed size tubers per plot (**Figure 3**).

Table 4. Effect of nitrogen levels on potato yield and yield-related characteristics, Kaski, 2021

Treatments	Plant height (cm)	Total Tuber/Plot		Yield (t/ha)
		Number	Weight (kg)	
T1	39.40 e	405	12.52 d	17.39 d
T2	47.30 d	433	16.96 c	23.55 c
T3	54.50 c	470	18.98 b	26.36 b
T4	55.47 bc	415	20.54 b	28.53 b
T5	56.27 abc	427	23.61 a	32.79 a
T6	58.50 ab	421	24.25 a	33.68 a
T7	59.40 a	410	24.21 a	33.62 a
Mean	52.98	426	20.15	27.99
CV%	3.42	9.34	5.62	5.62
P Value	0.001	0.5	0.001	0.001
$LSD_{0.05}$	3.22	NS	2.01	2.79

Tuber Yield

Potato tuber yield showed significant variations with different level of nitrogen. The response of tuber yield was positively correlated with increasing nitrogen doses, ranging from 0 to 150 kg/ha, in both years of the experiment (**Figure 1**). However, in 2020, the yield increment rate became non-significant after applying 75 kg/ha of nitrogen (**Table 3**), while in 2021, it remained non-significant beyond 100 kg/ha of nitrogen (**Table 4**). The highest tuber yield of 36.22 t/ha was recorded with the application of 125 kg/ha of nitrogen, but this yield was statistically similar to those obtained with nitrogen applications between 75 and 150 kg/ha (**Figure 2**).

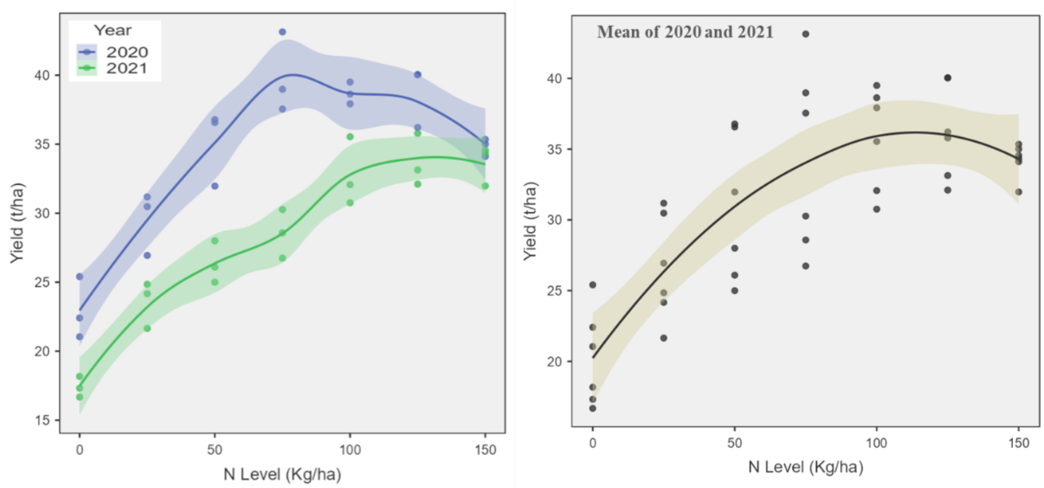


Figure 1. Correlation between mean tuber yield and N levels during 2020 and 2021

The result of Pearson's correlation analysis indicated a significant positive correlation between potato tuber yield and several factors, including nitrogen level, plant height, plant vigor, the number of large-sized tubers, and the weight of large-sized tubers per plot. This means that as these variables increased, the tuber yield also tended to increase suggesting that higher nitrogen levels and improved plant health directly contributed to greater productivity and larger tuber sizes (**Figure 3**). Conversely, the analysis showed a significant negative correlation between tuber yield and the number of relationship highlights the importance of nitrogen management and plant health in promoting not only higher yields but also the quality of the tubers produced. Overall, these correlations emphasize the interconnectedness of nitrogen application, plant growth characteristics, and tuber yield, providing valuable insights for optimizing potato cultivation practices (**Figure 3**).undersized tubers per plot. This implies that as the number of undersized tubers increased, the overall tuber yield decreased. This

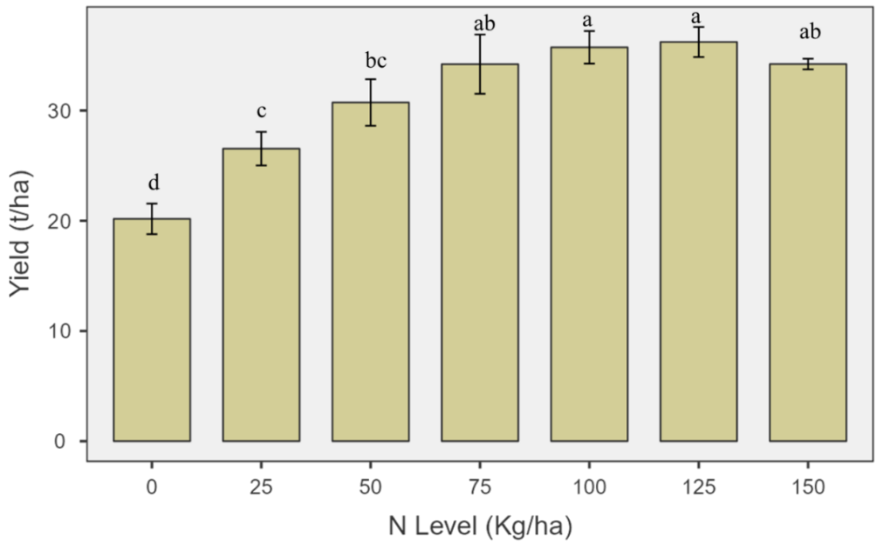
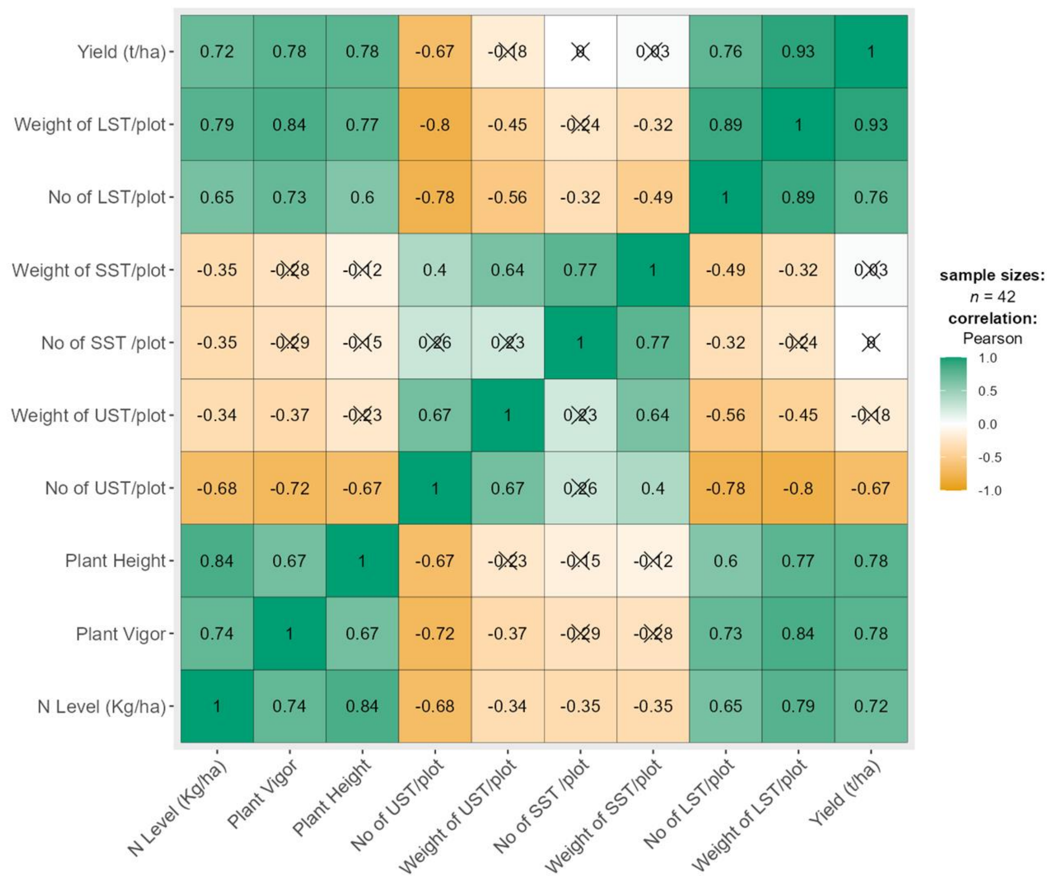


Figure 2. Mean tuber yield of potato as influenced by different N levels in 2020 and 2021



UST: Under size tuber (<25g), SST: Seed size tuber (25-50g) and LST: Large size tuber (>50g) X = non-significant at $p < 0.05$ (Adjustment: None)

Figure 3. Pearson's correlation matrix among different variables of potato as influenced by different N levels during 2020 and 2021

Agronomic N use efficiency (ANUE)

Increasing N dose decreased agronomic N use efficiency (ANUE) during both consecutive year of experiment (Figure 3). In 2020, the highest agronomic nitrogen use efficiency (ANUE) value of 263.11 was achieved with the application of 25 kg/ha of nitrogen, which was statistically comparable to values obtained with up to 75 kg/ha of nitrogen. However, the ANUE significantly decreased at nitrogen levels above 75 kg/ha. The maximum ANUE in the second year of the experiment also occurred with the lowest nitrogen application rate, while ANUE values for nitrogen applications ranging from 50 to 100 kg/ha were statistically similar. The lowest ANUE was recorded with the highest nitrogen rates.

The combined analysis of two years' data demonstrated that agronomic nitrogen use efficiency (ANUE) in potato production increased from 93.67 to 254.84 as nitrogen application rates decreased from 150 to 25 kg/ha. ANUE values from nitrogen applications between 25 and 75 kg/ha were statistically similar, while there was a significant decline in ANUE above 75 kg/ha, with the lowest ANUE occurring at 150 kg/ha of nitrogen. This pattern indicates that applying nitrogen above 75 kg/ha resulted in greater nitrogen losses to the environment rather than being effectively utilized by the potato plants.

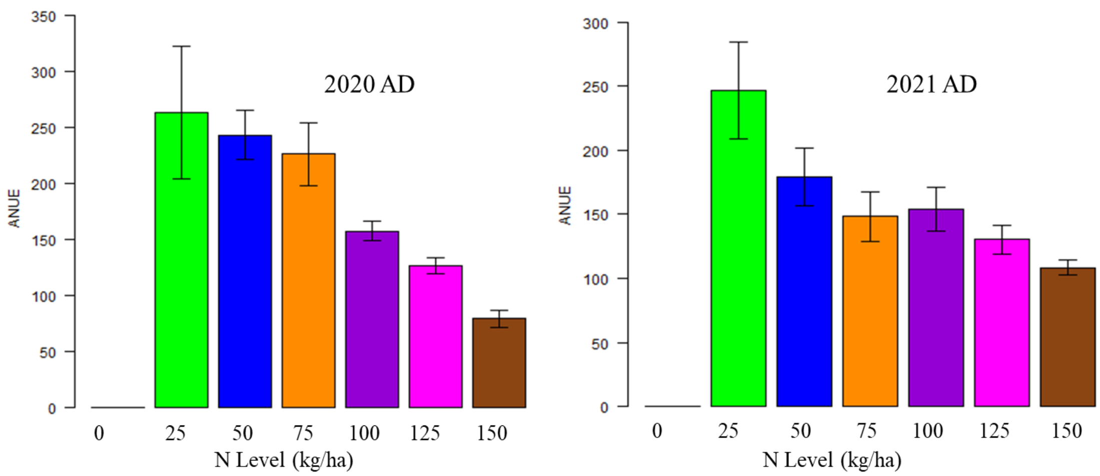


Figure 3. Effects of different N-levels on agronomic nitrogen use efficiency (ANUE) in potato production during 2020 and 2021

Economic analysis

The economic analysis of potato production (**Table 5**) provides a comprehensive overview of the total cost of production, net benefits, and benefit cost ratios recorded in different treatments. The data clearly illustrate that as the rate of nitrogen application increases, the total cost of production also rises. This increase in costs can be attributed to the higher expenses associated with purchasing and applying larger quantities of nitrogen fertilizer, along with any additional inputs required for managing the crop effectively at these higher nitrogen levels. The total cost of production increased as the rate of N increased but the net benefit increased up to N rate of 125 kg/ha. Based on partial budgeting analysis, the treatment that involved 125 kg/ha of nitrogen yielded, the highest net benefit of NRs 986,925 indicating that this level of nitrogen application was particularly effective in enhancing the overall economic return from potato production. Additionally, the benefit-cost ratio for this treatment was calculated to be 2.14. This ratio means that for every unit of currency spent on production, there was a return of approximately 2.14 units demonstrating a favorable economic outcome. Following the 125 kg/ha treatment, the next highest net benefits and B:C ratios were observed at the 100 kg/ha and 75 kg/ha nitrogen application rates. This data underscores the importance of finding an optimal nitrogen application rate that balances production costs with potential revenue, thereby maximizing profitability in potato cultivation. The insights from **Table 5** highlight the need for careful economic consideration when determining nitrogen fertilization strategies in agricultural practices.

Table 5. Partial economic analysis of potato production with different treatments (N levels) estimated for a hectare of land

N Level (Kg/ha)	Mean tuber Yield (t/ha)	Value of tuber yield (NRs/ha)	Cost of Production (NRs/ha)	Net Benefit (NRs)	B:C Ratio
0	20.17	806800	455000	351800	0.77
25	26.54	1061600	456375	605225	1.33
50	30.73	1229200	457750	771450	1.69
75	34.21	1368400	459125	909275	1.98
100	35.74	143000	460500	969500	2.11
125	36.22	1448800	461875	986925	2.14
150	34.21	1368400	463250	905150	1.95

NRs 132=$1

DISCUSSIONS

Optimizing nitrogen fertilization reduced the amount of N fertilizers, improved yields, and hence, increased N use efficiency in potato production. The yield and yield-related parameters were significantly better in nitrogen-fertilized plots up to a certain level compared to the control treatments. The application of N fertilizer significantly influenced the plant height of potato and increasing trend was obtained with the increase in nitrogen levels. This is because the plant grows vigorously when nitrogen is applied in relatively large amount. Similar results have also been reported by Adhikari (Madhikarmy 1979, Sharma and Upadhaya 1993). The application of nitrogen enhances various physiological processes, including cell division and elongation, which promote maximum vegetative growth and result in increased plant height and vigor (Rea et al 2019). Sufficient nitrogen likely supports cellular activities and development, contributing to improved plant vigor (Timilsina et al 2023).

The increase in tuber yield with increasing N fertilizer application might be increased dry matter production, accelerated growth rates, and fostered biomass production (Tolessa 2019). Higher nitrogen fertilization up to a certain threshold, positively impact plant growth parameters, leading to an increase in both the number of tubers and overall yield. This is primarily due to the fact that increasing nitrogen application within a certain limit can enhance potato yield, but going beyond this threshold has adverse effects, reducing tuber production (Ierna and Mauromical 2019). Higher nitrogen rates are linked to increased foliage, which enhances photosynthetic activity and subsequently leads to greater translocation of nutrients to the tubers (Kumar et al., 2007). Nitrogen application plays a crucial role in plant growth and development, as it directly influences tuber production by affecting the plant’s nitrogen allocation. It impacts the nitrogen uptake, transport to the leaves, and the processes of reduction and redistribution, which are key factors in tuber yield formation (Fang et al 2023). Conversely, the higher yields may be attributed to nitrogen's role in enhancing yield components (Tolessa 2019). When nitrogen is applied in optimal amounts, it promotes vigorous vegetative growth, leading to healthier plants that can effectively capture sunlight and photosynthesize. This increased photosynthetic capacity contributes to the development of more robust stems, larger leaves, and enhanced root systems, all of which are essential for supporting tuber formation. The results of Timilsina et al 2023, Shah et al 2013 and Adhikari 2009 also showed that increasing nitrogen rates increased yield and yield components of different crops. The research result from Fang et al 2023, Ruza et al 2013, Fontes et al 2010 and Adhikari 2009 reported the increased potato tuber yield with nitrogen application up to certain level. According to the findings of Adhikari (2009), in the sandy loam soils of Chitwan, Nepal, the potato cultivar Kufri Sindhuri achieves higher yields with an application of 150 kg/ha of nitrogen, while the Desiree variety produces greater yields at a rate of 100 kg/ha of nitrogen. While nitrogen is vital for plant growth, an excessive supply is detrimental to potato tuber development and dry matter buildup (Sattelmacher and Marschner 1979). Beyond a certain threshold, excessive nitrogen can lead to diminishing returns in terms of plant growth and tuber yield. At high nitrogen levels, plants may become overly lush, which can increase susceptibility to diseases and pests, and may also result in nutrient imbalances. Furthermore, excess nitrogen can leach into the environment, leading to potential pollution issues. To optimize production, it's essential to regulate nitrogen's internal metabolic effects on the crop that enhance the tubers' dry matter accumulation (Li et al 2016).

The experiment clearly revealed that the nitrogen application rate significantly influenced agronomic nitrogen use efficiency (ANUE) indicating that higher NUE was observed at lower nitrogen doses. When nitrogen doses are low, plants can utilize the available nitrogen more efficiently, leading to higher ANUE values. However, as nitrogen application rates increase beyond an optimal level, plants may not be able to absorb or utilize all of the additional nitrogen. This inefficiency can be attributed to several factors, including potential nitrogen leaching, volatilization, or other environmental losses that occur when nitrogen is applied in excess. Similar findings were reported by Liu et al (2016) and according to that result reduced N application rate improves ANUE in potato. Other studies have also confirmed a decrease in agronomic nitrogen use efficiency with increasing nitrogen rates (Darwish et al 2006, Kumar et al 2007, Fontes et al 2010, Lombardo 2020). Additionally, Tyler et al (1983) and Zvomuya et al (2002) found that when N fertilization rate increased, nitrogen use efficiency values decreased and that’s why, high N fertilizer application rates might have produced higher N losses to the environment. The decline in ANUE with increasing nitrogen doses suggests that there is a threshold beyond which additional nitrogen does not contribute proportionately to yield. Instead, excess nitrogen may lead to wastage, as plants cannot take up the surplus effectively. This observation underscores the importance of determining optimal nitrogen levels for maximizing crop yield while minimizing nitrogen losses to the environment. Overall, the trend highlights the need for careful nitrogen management in agricultural practices to ensure sustainable production and environmental protection. Higher nitrogen fertilization rates can positively influence plant growth parameters, tuber number, and yield; there is a delicate balance to maintain in order to optimize these benefits without encountering the negative consequences of over-fertilization. Proper nitrogen management practices are essential to achieve sustainable and productive potato cultivation.

CONCLUSION

Nitrogen dose of 75 kg/ha through chemical fertilizer along with 20 t/ha farm yard manure (FYM) was found optimum for the potato cultivation and N dose greater than 75 kg/ha from chemical fertilizer had no significant effects on potato tuber yield and yield related components at farmer’s field of Machhapuchhre 06 Kaski. Considering agronomic, economic, and NUE factors, 75 kg/ha N along with 20 t/ha FYM can be recommended to similar soil and agro ecology of Nepal for profitable potato production.

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