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Research Article

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Increasing Capsicum Yield, Nitrogen Use Efficiency and Profits through Optimal Nitrogen Fertilizer Application in Naturally Ventilated Polyhouse

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Abstract

Most of the farmers in mid-hill areas introduce plastic houses, naturally ventilated poly-houses or other types of protected structures for year-round vegetable production. Capsicum is a commonly cultivated crop inside these structures. Optimizing nitrogen (N) fertilization during capsicum production is critical for increasing crop yields, increasing nitrogen use efficiency (NUE), increasing net profit of farmers and minimizing the loss of nutrients into the environment. A study was carried out to identify the optimal nitrogen dose for enhancing Capsicum yield, nitrogen use efficiency (NUE), and net profits within a naturally ventilated polyhouse at the Directorate of Agriculture Research, Lumle, Kaski, Nepal, in two consecutive years; 2019 and 2020. Eight nitrogen levels (0, 100, 125, 150, 175, 200, 225, and 250 kg/ha) were evaluated using a randomized complete block design with three replications. Data were collected on each treatment's effect on yield, yield-related characteristics, nitrogen use efficiency (NUE), and production cost. Nitrogen application at 225 kg/ha resulted the highest fruit yield and net benefit; however, N levels between 200 and 250 kg/ha showed similar effect on yield, yield-related components and net benefit. Considering agronomic, economic, and NUE factors, an N dose of 200 kg/ha along with 30 t/ha farmyard manure (FYM) was found to be optimal for Capsicum cultivation in a naturally ventilated polyhouse at Lumle, Kaski, and this N dose can be recommended for similar soil and agroecological conditions in Nepal.

Keywords : Capsicum, naturally ventilated polyhouse, nitrogen, yield

Introduction:

Capsicum, also known as sweet pepper or bell pepper (*Capsicum annuum L.*), is an important high value vegetable crop from the Solanaceae family, widely cultivated in sub-temperate climates across the globe (Bhattarai et al., 2011; Verma and Mehta, 2019; Khanal et al., 2021). The fresh fruit, whether eaten raw in salads or cooked as a vegetable, is high in antioxidants, vitamin A and vitamin C, which protect the human body from oxidative damage that can contribute to heart disease, cancer, and aging. (Agarwal et al., 2007; CABI, 2019). The high nutritive value of Capsicum results in a high market demand year-round (Bhattarai and Poudyal, 2011). The ecological conditions in the mid-hills areas of Nepal are very favourable for producing high-quality fruits of Capsicum (Bhattarai et al., 2011). The government of Nepal has prioritized the strategic enhancement of agricultural production and productivity as part of its broader initiative to modernize the agricultural sector. This commitment is reflected in the launch of the Prime Minister Agricultural Modernization Project, which aims to transform the agricultural landscape of the country. The project has introduced many plastic tunnels, naturally ventilated poly-houses and other types of protected structures at the farm level for year-round vegetable production (Jha et al., 2022; Shrestha, 2022 and PMAMP, 2023). Capsicum is one of the most commonly cultivated crops inside these structures. Even though the Nepalese market has good retail prices, its productivity is quite low compared to that of other South Asian countries (Bhattarai et al., 2020). Several edaphoclimatic constraints contribute to low capsicum productivity, with one of the primary factors being the inefficient use of fertilizers. Balanced fertilization and scientific management practices can significantly enhance the productivity of Capsicum (Bhattarai et al., 2011).

Capsicum thrives most effectively when provided with ample organic matter and a balanced application of mineral fertilizers (CABI, 2019). Nitrogen is an essential nutrient that plays a fundamental role in the growth and development of crops, making it a crucial factor in determining their yield potential. As a primary component of amino acids, proteins, and nucleic acids, nitrogen is vital for several physiological and biochemical processes within plants. The application of N fertilizer directly influences the amino acid composition of protein and thereby the nutritional quality of economic produce and crop yield (Maheswari et al., 2017). Optimal N fertilization is a foremost agronomic practice that affects the productivity of crops and requires as much nitrogen as possible in appropriate amounts (Timilsina and Vista, 2022). Excess supply of nitrogenous fertilizers results in higher costs, lower returns, and an increased risk of environmental pollution. Conversely, a low nutrient supply limits the ability to raise the current nutrient levels to economically optimal levels, hindering the potential for greater production (Rakshit et al., 2015). Higher nitrogenous fertilizer application rates do not always result in proportional increases in crop yields. While nitrogen is essential for plant growth, there is a threshold beyond which additional nitrogen no longer boosts yield but instead leads to inefficiencies. Excess N application disrupts nitrogen use efficiency and leads to significant environmental, economic, and ecological challenges because plants can only absorb and use a limited amount of nitrogen; any excess nitrogen surpasses the plant's needs and capacity to utilize it effectively (Zhang et al., 2012). Applying insufficient and unbalanced fertilization to crops leads to low yields and degrades soil health (Uddin, 2003). The existing recommended fertilizer doses for major nutrients in vegetable production in Nepal are proving insufficient for achieving higher productivity and need adjustment to more optimal and balanced levels. It is crucial to determine the optimal nitrogen fertilization dose for the effective use of this nutrient by crops to achieve better yields. The response of different varieties to N fertilizer may vary depending on their agronomic traits. This study aimed to identify the optimal nitrogen dose for enhancing Capsicum production, nitrogen use efficiency (NUE), and economic returns in naturally ventilated polyhouses, with recommendations tailored for mid- to high-hill regions in Nepal.

Materials and methods:

Experimental Site

A field experiment was carried out over two consecutive years (2019 and 2020) at the Directorate of Agricultural Research, Gandaki Province, Lumle, Kaski (28°17' N latitude, 83°49' E longitude, 1740 meters above sea level) inside a naturally ventilated polyhouse with sandy loam soil. The soil was moderately acidic, with 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).

Figure 1 illustrates the monthly variations in rainfall (mm) as well as the maximum, minimum, and average temperatures (°C) recorded during the study period. The temperature data for both years show an upward trend from March to August, with the highest temperatures recorded in August, followed by a slight decline in September. Rainfall significantly increases during the monsoon season, peaking in July and August, while drop in March and April, indicating lower rainfall in those months.

Table 1: Physical and chemical properties of the soil at the experimental site prior to the study

Soil parameter	Soil test value	Analysis Method
Soil texture class Soil pH	Sandy Loam 5.9	Hydrometer (Bouyoucos, 1927) Potentiometric 1:2.5 (Jackson, 1973)
Soil organic matter (%)	5.0	Walkely Black (Walkely and Black, 1934)
Total nitrogen (%)	0.20	Kjeldahl (Bremner, 1982)
Available P2O5 (kg/ha)	220	Modified Olsen's (Olsen et al., 1954)
Extractable K2O (kg/ha)	109	Ammonium acetate (Jackson, 1967)

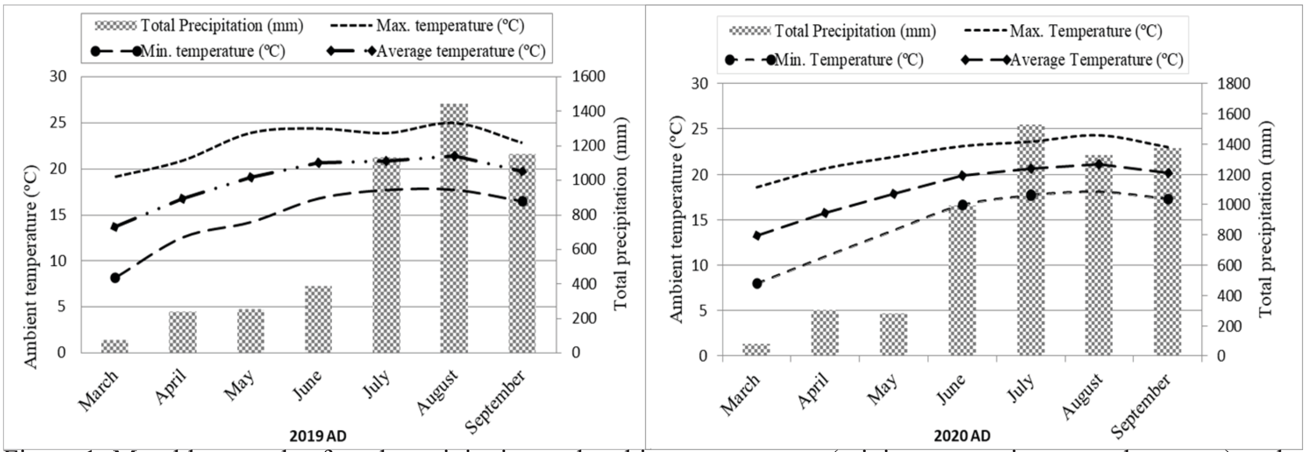

Figure 1: Monthly records of total precipitation and ambient temperature (minimum, maximum, and average) at the experimental site, Lumle, Kaski

Experimental setup and crop management

The experiment included eight treatments (Table 2) featuring various N fertilizer doses (0, 100, 125, 150, 175, 200, 225, and 250 kg/ha), arranged in a randomized block design with three replications. California Wonder, a widely grown Capsicum variety, was transplanted in the second week of March at a spacing of 60 cm × 45 cm, with each experimental plot (4.05 m²) containing 15 plants. At the final field preparation, all plots received a basal application of 30 t/ha farmyard manure (FYM), 100 kg/ha phosphorus (P2O5) in the form of single super phosphate (SSP), and 100 kg/ha potassium (K2O) as muriate of potash (MOP).

Nitrogen was applied in three split doses: ½ as a basal application, ¼ at 25 days after transplanting, and the final ¼ at 45 days after transplanting. Recommended plant protection measures and other cultural practices were consistently followed throughout the crop growth period.

Table 2: Treatment details of the experiment

S.N	Treatment symbol	Treatment details
1	N_0	0:100:100 $N:P_2O_5:K_2O$ kg/ha and 30 t ha−1 FYM
2	N_{100}	100:100:100 $N:P_2O_5:K_2O$ kg/ha and 30 t ha−1 FYM
3	N_{125}	125:100:100 $N:P_2O_5:K_2O$ kg/ha and 30 t ha−1 FYM
4	N_{150}	150:100:100 $N:P_2O_5:K_2O$ kg/ha and 30 t ha−1 FYM
5	N_{175}	175:100:100 $N:P_2O_5:K_2O$ kg/ha and 30 t ha−1 FYM
6	N_{200}	200:100:100 $N:P_2O_5:K_2O$ kg/ha and 30 t ha−1 FYM
7	N_{225}	225:100:100 $N:P_2O_5:K_2O$ kg/ha and 30 t ha−1 FYM
8	N_{250}	250:100:100 $N:P_2O_5:K_2O$ kg/ha and 30 t ha−1 FYM

of nitrogen applied, following the method outlined by Cassman et al. (1996).

$$ANUE = (Y_N - Y_0)/\text{Nitrogen rate}$$

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

Y_0= Fruit yield in kg/ha of plots not fertilized with nitrogen;

Nitrogen rate = Amount of N used in kg/ha

A partial budgeting analysis was conducted for both the N-treated and control plots, taking into account costs associated with cultural practices and fertilizers for cultivating Capsicum on a per-hectare basis. Input costs, labor expenses, Capsicum fruit prices, and other relevant prices were determined based on local market surveys in Lumle and Pokhara, Kaski. The benefit-cost (B-C) ratio was calculated following the formula provided by Badal et al. (2023). All cultivation inputs including seeds, fertilizers, pesticides, and labor were valued at current market rates to determine the overall production costs.

B-C ratio = gross return/total cost of cultivation

Data recording and analysis

Data on yield and yield components—including plant height, number of fruits per plant, individual fruit weight, and total fruit yield—were collected at relevant growth stages. Nutrient use efficiency metrics were also recorded. Agronomic nitrogen use efficiency (ANUE) was used in this study to assess nitrogen use efficiency (NUE) and was calculated as the yield increase per unit

To perform the analysis of variance, STAR (Statistical Tool for Agricultural Research) version 2.0.1 and Jamovi version 2.2.28 were used. Statistical significance was assessed at $p<0.05$ using Fisher's least significant difference method, following the guidelines of Gomez and Gomez (1984).

Results:

Plant height

Different nitrogen levels significantly influenced the plant height of Capsicum, and an increasing trend was observed with increasing nitrogen levels. In the first year of the experiment, the tallest plant height was recorded at a nitrogen level of 225 kg/ha; however, nitrogen levels above 125 kg/ha had a statistically similar effect on plant height (Table 3). In the second year, plant height remained statistically similar with nitrogen application at 150 kg/ha and above (Table 4). The combined analysis of plant height from both consecutive years of the experiment revealed that the application of N above 125 kg/ha did not have any significant effect on the plant height of Capsicum.

second year (Table 4), but the effect was similar above that of the N level. The combined analysis of two years data revealed that the total weight of fruits per plot and average fruit weight was significantly greater at 200 kg/ha N and above that level had similar effects (Figure 2).

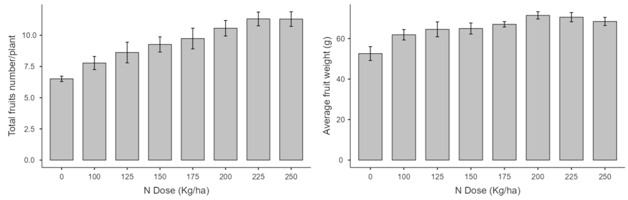

Figure 2. Total number of fruits per plant (left) and average fruit weight of Capsicum (right) as influenced by nitrogen levels during 2019 and 2020 at Lumle, Kaski

Table 3: Yield and yield parameters of Capsicum influenced by N level in a naturally ventilated polyhouse at Lumle, Kaski, 2019

Treatments	Plant height (cm)	Total no of fruits/plant	Total fruit weight (kg/plot)	Average fruit weight (g)	Yield (t/ha)
N_0	77.3^c	6^d	5.79^e	56.10^d	14.31^e
N_{100}	81.53^{bc}	8^c	8.01^d	63.68^c	19.79^d
N_{125}	90.60^{ab}	10^b	8.95^{cd}	61.91^{cd}	22.10^{cd}
N_{150}	92.40^a	10^b	9.65^c	64.56^c	23.82^c
N_{175}	89.47^{ab}	10^b	10.04^c	67.60^{bc}	24.78^c
N_{200}	89.60^{ab}	11^{ab}	11.75^b	73.34^{ab}	29.02^b
N_{225}	94.73^a	12^a	13.23^a	75.00^a	32.66^a
N_{250}	92.27^a	12^a	12.61^{ab}	71.64^{ab}	31.13^{ab}
Mean	**88.49**	**10**	**10.00**	**66.73**	**24.70**
CV%	**16.74**	**8.17**	**16.85**	**5.91**	**16.85**
P Value	**0.03**	**0.001**	**0.001**	**0.006**	**0.001**
$LSD_{0.05}$	**10.45**	**1.40**	**1.20**	**6.90**	**2.96**

Total number of fruits per plant

The results from both years indicated significant variation in the number of fruits per plant across different nitrogen levels. In the first year, the total number of fruits increased with N doses up to 200 kg/ha (Table 3), while in the second year, the increase was observed up to 175 kg/ha. Higher N doses beyond these levels showed similar effects without further increases in fruit count. Combined analysis of the two years data confirmed that nitrogen doses above 200 kg/ha did not significantly increase the total number of fruits per plant (Figure 2).

Fruit Yield

The fruit weight of Capsicum significantly varied with different N levels. Increasing the N dose increased the total fruit weight per plot up to 225 kg/ha N during the first year of the experiment and up to 200 kg/ha during the second year, but increasing the N dose above that level had a similar effect. The average fruit weight increased with increasing N dose up to 200 kg/ha in the first year of the experiment (Table 3) and 100 kg/ha in the

The fruit yield of Capsicum varied significantly with different levels of nitrogen. The yield response was positively correlated with increasing N doses from 0 to 250 kg/ha N in both years of the experiment (Figure 3). However, after 225 kg/ha N in 2019 (Table 3) and after 200 kg/ha N in 2020 (Table 4), the yield increase rate was not significant. The combined analysis of two consecutive years of the experiment revealed that the highest fruit yield (29.6 t/ha) was achieved with 225 kg/ha N but was statistically similar from 200 to 250 kg/ha N (Figure 3).

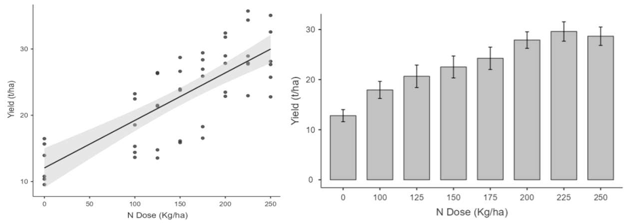

Figure 3. Correlations between Capsicum yield and N levels (left) and mean Capsicum yield in two consecutive years influenced by nitrogen levels (right) in 2019 and 2020 at Lumle, Kaski

Table 4: Yield and yield parameters of Capsicum influenced by the N level in a naturally ventilated polyhouse at Lumle, Kaski, 2020

Treatments	Plant height (cm)	Total no of fruits/plant	Total fruit weight (kg/plot)	Average fruit weight (g)	Yield (t/ha)
N_{0}	68.73^{c}	6^{e}	4.57^{e}	49.05^{b}	11.28^{e}
N_{100}	74.97^{c}	7de	6.51^{d}	60.01^{a}	16.09^{d}
N_{125}	83.57^{b}	8^{cd}	7.78^{c}	67.15^{a}	19.21^{c}
N_{150}	86.60^{ab}	9^{bc}	8.59^{c}	65.30^{a}	21.20^{c}
N_{175}	88.93^{ab}	10^{ab}	9.60^{b}	66.43^{a}	23.71^{b}
N_{200}	90.83^{ab}	11^{a}	10.84^{a}	69.48^{a}	26.76^{a}
N_{225}	93.47^{a}	11^{a}	10.75^{a}	66.07^{a}	26.54^{a}
N_{250}	92.20^{a}	11^{a}	10.61^{a}	65.20^{a}	26.19^{a}
Mean	**84.91**	**9**	**8.66**	**63.59**	**21.37**
CV%	**14.9**	**8.98**	**9.62**	**8.74**	**9.62**
P Value	**0.001**	**0.001**	**0.001**	**0.012**	**0.001**
$LSD_{0.05}$	**7.30**	**1.39**	**1.01**	**9.73**	**2.47**

Agronomic N use efficiency (ANUE)

Increasing the nitrogen level increased the agronomic N use efficiency (ANUE) during both consecutive years of the experiment up to 200 kg/ha N. In 2019, the application of 225 kg/ha of nitrogen resulted the highest agronomic nitrogen use efficiency (ANUE) value of 81.58, which was statistically similar to the values obtained with nitrogen doses ranging from 125 kg/ha to 250 kg/ha (Figure 4). The highest ANUE value in the second year of the experiment was recorded with the application of 200 kg/ha of nitrogen. However, the ANUE values for nitrogen applications between 125 kg/ha and 225 kg/ha were statistically similar. The combined analysis of data from the two years showed that the agronomic nitrogen use efficiency (ANUE) of Capsicum increased from 51.42 to 75.48 as nitrogen application rates increased from 100 to 200 kg/ha. However, the ANUE values for nitrogen applications between 125 kg/ha and 250 kg/ha were statistically similar. (Figure 4). From the pattern of ANUE with different levels of N, it was evident that the application of N above 200 kg/ha resulted in greater losses to the environment than did its actual utilization by Capsicum. Apart from the loss to the environment, there can be some antagonistic effect of N overuse on other nutrients that might have reduced the yield of capsicum.

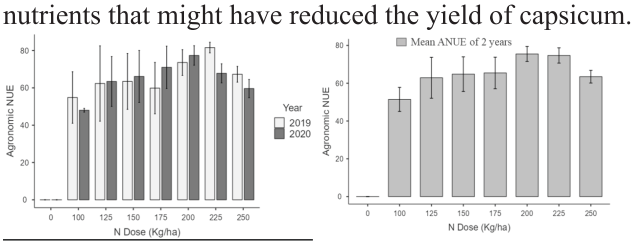

Figure 4. Agronomic N use efficiency (ANUE) as influenced by nitrogen levels in Capsicum production during 2019 and 2020 at Lumle, Kaski

Economic analysis

Table 5 shows the details of the total cost of production, net benefits, and benefit-cost ratios recorded in the different treatments. Based on partial budgeting, the greatest net benefit (NRs 1352825) and B-C ratio (3.2) was observed with 225 kg/ha N, followed by 250 and 200 kg/ha N, respectively. The results suggest that utilizing up to 225 kg of nitrogen per hectare maximizes both profitability and efficiency, making it a recommended practice for achieving better economic outcomes in the production process.

Discussion:

Optimizing nitrogen doses in Capsicum production has led to a reduction in the amount of nitrogen fertilizers used while simultaneously improving yields and enhancing nitrogen use efficiency. Yields and yield-related parameters were notably higher in nitrogen-fertilized plots compared to control plots, up to a certain optimal level. The application of nitrogen fertilizer significantly affected Capsicum plant height, which exhibited an increasing trend with higher nitrogen levels. This growth response can be attributed to the vigorous growth of plants when relatively large amounts of nitrogen are applied, resulting in greater nitrogen availability and subsequent increases in plant height. Similar findings have been reported by Mahmud et al. (2020), Lohani et al. (2020), Khan et al. (2010), Sharma et al. (2004), and Naeem et al. (2002), all noting that plant height improves with increased nitrogen application up to a specific level. The application of nitrogen enhances various physiological processes, including cell division and elongation, which promote maximum vegetative growth and contribute to increased plant height (Rea et al., 2019). Additionally,

Table 5: Partial economic analysis of different treatments (N levels) estimated for a hectare of land

Treatments	Mean capsicum yield (t/ha)	Value of capsicum (NRs/ha)	Cost of Production (NRs/ha)	Net Profit (NRs)	B:C Ratio
N0	12.79	767400	410800	356600	0.87
N100	17.94	1076400	416300	660100	1.59
N125	20.66	1239600	417675	821925	1.97
N150	22.51	1350600	419050	931550	2.22
N175	24.25	1455000	420425	1034575	2.46
N200	27.89	1673400	421800	1251600	2.97
N225	29.6	1776000	423175	1352825	3.2
N250	28.66	1719600	424550	1295050	3.05

1 USD: 133.48 NRs

sufficient nitrogen likely supports cellular activities and development, leading to enhanced plant vigour (Timilsina et al., 2023).

Significant variations were observed across different treatments in terms of the number of fruits per plant, fruit weight, and overall yield of Capsicum, attributed to varying nitrogen doses. The increases in these parameters can be linked to nitrogen application, which enhances dry matter production, accelerates growth rates, and promotes biomass accumulation (Tolessa, 2019). Numerous studies have established a relationship between nitrogen supply and photosynthesis (Mu and Chen, 2021). Nitrogen deficiency adversely affects plant growth and development, leading to reduced photosynthesis and lower productivity (Mu et al., 2016). Conversely, excessive nitrogen can result in excessive vegetative growth, imbalanced nutrient composition, and weakened reproductive growth, which are significant factors contributing to yield decline at high nitrogen levels (Han et al., 2021).

While higher nitrogen fertilization rates have positive effects on plant growth parameters, increasing fruit numbers per plant, fruit weight, and yield, there is an optimal range for these applications. Increased nitrogen rates also promote more foliage, enhancing photosynthetic activity and facilitating greater translocation (Kumar et al., 2007). The enhancement of yields can be attributed to nitrogen's role in improving yield components (Tolessa, 2019). Additionally, Mahmud et al. (2020), Lohani et al. (2020), Khan et al. (2010), Sharma et al. (2004), and Naeem et al. (2002) found that higher nitrogen application rates led to increased yields and yield components in Capsicum. Similarly, research by Timilsina et al. (2023), Timilisna and Vista (2022), Ruza et al. (2013), Fontes et al. (2010), and Adhikari (2009) demonstrated that the yields of various crops increased with higher nitrogen rates, up to a specific optimal level.

Our study clearly showed that the nitrogen application rate significantly influenced agronomic nitrogen use efficiency (ANUE), with the highest efficiency observed at the optimal nitrogen level of 200 kg/ha. This finding aligns with the results of Timilsina et al. (2023), Timilsina and Vista (2022), Lombardo (2020), and Liu et al. (2016), who reported that an optimal nitrogen application rate enhances ANUE across various crops. Most research indicates that cultivating Capsicum with an appropriate nitrogen fertilizer dose is economically beneficial. Among the various inputs in the production process, fertilizers play a crucial and positive role in determining the returns from the enterprise (Badal et al., 2023). Despite this, resources are not yet being utilized to their full potential, indicating opportunities for better management of production costs to maintain optimal levels and enhance profitability. According to Badal et al. (2023), fertilizer application should be optimized to maximize returns.

Conclusion:

A nitrogen dose of 200 kg/ha through chemical fertilizer along with 30 t/ha farmyard manure (FYM) was found to be optimal for Capsicum cultivation under naturally ventilated polyhouse conditions, and N dose above 200 kg/ha from chemical fertilizer did not have a significant effect on the yield or yield components of Capsicum at Lumle, Kaski. Considering agronomic, economic, and NUE factors, 200 kg/ha N along with 30 t/ha FYM can be recommended for similar soil and agro-ecological conditions in Nepal for profitable capsicum production inside naturally ventilated polyhouses.

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Declaration of conflict of interest and ethical approval:

S. Timilsina was responsible for designing and conducting the experiments, as well as preparing the manuscripts. A. Khanal contributed to data collection, data analysis, and the finalization of the manuscript. The authors declare that there are no conflicts of interest.

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