Effect of different nitrogen levels on growth, yield, and nitrogen use efficiency (NUE) of Hardinath Hybrid Dhan-1 in Madhesh Province, Nepal

ABSTRACT

Determining the optimum dose of nitrogen fertilizer application for hybrid rice is vital for boosting production and productivity of rice. Therefore, this study examines the effect of different nitrogen levels on the growth, yield, and nitrogen use efficiency (NUE) of Hardinath Hybrid Dhan-1 in Madhesh Province, Nepal. A field experiment conducted in 2020 at the National Rice Research Program, Hardinath, Dhanusha tested six nitrogen levels (0, 75, 100, 125, 150, and 175 kg ha^{-1}) with four replications under Randomized Complete Block Design during rainy season (June-September). The results showed that nitrogen application significantly improved plant growth and yield, with the highest grain yield (4.99 t ha^{-1}) achieved at 150 kg N ha^{-1}. Increasing nitrogen beyond this level did not further boost yield, indicating that excessive nitrogen does not improve productivity. Nitrogen use and agronomic efficiency were also highest at 150 kg N ha^{-1}, marking it as the ideal rate for optimal rice performance. Soil health, in terms of organic matter and nutrient availability, improved with higher nitrogen levels, while the highest nitrogen uptake occurred at 175 kg N ha^{-1}. In conclusion, 150 kg N ha^{-1} is recommended as the optimal nitrogen level to enhance hybrid rice yield and NUE, promoting sustainable rice production in the region. These findings highlight the need for optimal nitrogen management to improve crop yield and soil properties while minimizing environmental impact.

Keywords: *hybrid rice, nitrogen levels, nitrogen use efficiency, yield, Hardinath Hybrid Dhan-1*

INTRODUCTION

"Rice is the staple food for nearly half of the world's population, with about 90% of global rice production concentrated in Asia" (Firdaus et al., 2020). In Nepal, rice is the main staple food crop and contributes significantly to the Agricultural Gross Domestic Product (AGDP), with maize and wheat coming in second and third. In Nepal, rice is grown in a variety of ecological zones, from 3,050 meters above sea level in Jumla to 60 meters above sea level in the Terai region. "With an average yield of 3.87 tons per hectare, it is grown on about 1.48 million hectares, yielding an annual production of 5.724 million tons" (MoALD, 2024). "20% of the Agricultural Domestic Product and 7% of the Gross Domestic Product of the nation are derived from rice, which has a substantial economic impact" (Dhungel & Acharya, 2017). "Furthermore, rice accounts for roughly 53% of all grain production and provides 33% of Nepalese people's daily caloric consumption" (Tripathi et al., 2019). With a population of 29 million, the only way to ensure food security in the face of declining agricultural land is to increase production per unit area. One of the option available to increase production and productivity of rice in Nepal is the introduction of hybrid rice whose yield is 15-20% more than the promising commercial varieties. Gyawali et al., 2023 revealed that the judicious and proper use of fertilizers can markedly increase the yield of rice. One of the most significant factors limiting crop/rice output is nitrogen. Rice productivity can be increased by using rice types that are responsive to nitrogen and by figuring out the ideal nitrogen content.

"Lower rice productivity and poor returns are largely caused by inadequate or unbalanced nutrient usage, in addition to a variety of biotic and abiotic stressors" (Zafar et al 2018).

Nitrogen is a main component for cereal growth and metabolism to achieve the highest grain production (Ladha et al., 2005). Prior to recommending a nitrogen fertilizer dose for any crop, it is important to assess the effectiveness and optimal rate of various nutrient levels for each prospective rice genotype to maximize development and production (Noor 2017). One crucial management technique that helps boost hybrid rice output is proper fertilization. "Prior research revealed that hybrid rice had optimal development and growth when the right amount of N was applied, resulting in the highest proportion of full grains and 1000-grain weight, straw and grain yield of rice" (Kumar et al., 1995). Agronomic and cultural approaches can help achieve the efficient use of nitrogen fertilizer. "But if too much nitrogen is applied, a lot of post-harvest residual soil nitrogen accumulates and becomes available for the crop the next season" (Fagaria and Baligar 2003). The low fertility of the soils used to cultivate rice and the excessive or insufficient use of inorganic fertilizers along with lack of high yield hybrid rice variety by farmers are the main obstacles to increasing rice yield in Nepal.

Thus, the present research work was undertaken to identify the optimum dose of nitrogen on growth, productivity and agronomic nitrogen use efficiency of newly released hybrid rice variety in Madhesh province under Hardinath condition.

METHODOLOGY

A field experiment was conducted during the rainy seasons of 2020 at National Rice Research Program (NRRP), Hardinath, Dhanusha. The experimental site was in 26° 48' E latitude and 85° 59' N longitude with an elevation of 75 meter above sea level and has a sub-tropical climate. The average maximum and minimum temperature during rice growing season, 2020, at NRRP was 31 °C and 21 °C respectively. Likewise, the total rainfall during crop growing period was 775 mm (Figure 1). In general, the site receives ample rainfall during the monsoon, which starts in June and continues up to September. The initial soil status of the field where experiment was conducted is as follows:

SN	Parameters	Methods	Value
1	Soil texture	Hydrometer (Bouyoucos 1962)	Sandy loam (55.8% sand, 31.3 silt and 12.9 clay)
2	pH	Potentiometric 1:2 (Jackson, 1958)	6.72
3	Soil organic matter (%)	Walkley and Black, (1934)	0.81%
4	Available N (kg ha^{-1})	Subbiah and Asija (1956)	145 kg ha^{-1}
5	Available P_2O_5 (kg ha^{-1})	Olsen (Olsen et al., 1954)	35 kg ha^{-1}
6	Available K_2O (kg ha^{-1})	Ammonium acetate (Jackson, 1958)	115 kg ha^{-1}

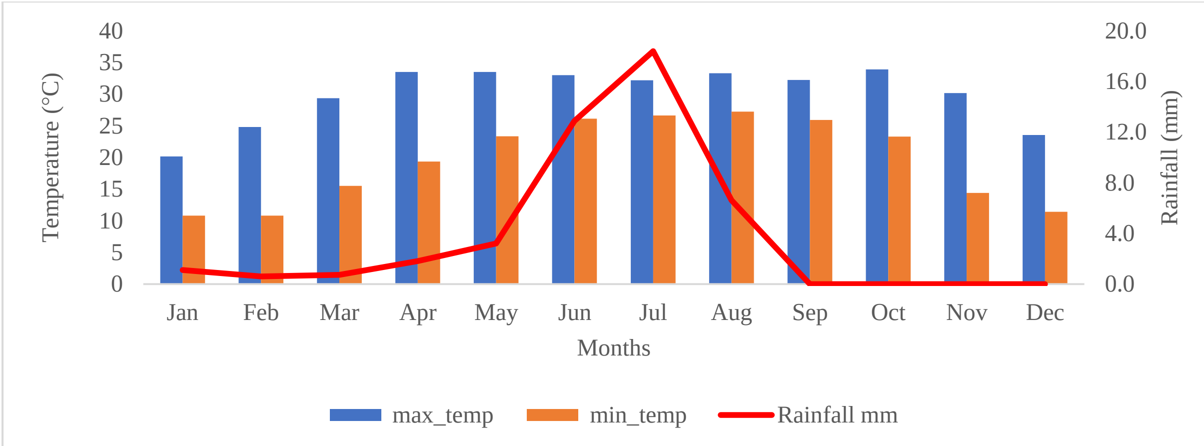

Figure 1. Average monthly temperature and rainfall of NRRP, Hardinath Dhanusha during 2020

The experiment was laid out in randomized block design with four replications. Hardinath Hybrid Dhan-1 was used as the hybrid rice which was recently released. Different nitrogen levels were included as the treatments. The plot size of experiment was 5 X 4 m^2.

Half dose of nitrogen, full dose of phosphorus (50 kg P_2O_5 ha^{-1}) and muriate of potash (50 kg K_2O ha^{-1}) were applied as basal dose in hybrid rice. Remaining half dose of nitrogen fertilizer was applied as top dress in two-split doses i.e. $1/4^{th}$ at active tillering stage and $1/4^{th}$ at panicle initiation stage. Fertilizers were applied through Urea, DAP and Muriate of Potash. Twenty-three days old seedlings were transplanted in well puddled soil with the spacing of 20 cm x 20 cm and seed rate of 20 kg ha^{-1} for newly released hybrid rice. Plant protection measures were applied as per requirement and standard crop management practices were followed apart from the treatments. Statistical analysis was done to evaluate different parameters using the R studio program.

RESULTS

Days to heading

The data from table 1 revealed that across a range of nitrogen levels, the days to heading were statistically at par, suggesting that nitrogen availability has little effect on when plants head. Moreover, the treatment where nitrogen was not applied showed an earlier heading (90.33 days) while the treatment where highest dose of nitrogen fertilizer was applied showed the late heading (92.33 days). However, days to heading were statistically at par for all the nitrogen levels (Table 1).

Days to maturity

With varying nitrogen levels, the days to maturity exhibit slight changes but the changes were not statistically significant. The days to maturity increase somewhat when the nitrogen level rises, but this variation was statistically similar, indicating that nitrogen levels have little effect on the hybrid rice maturity days. The control plot matured earlier (117.33 days) while that having highest dose of nitrogen matured at 118.67 days as shown in table 1.

Table 1. Days to heading, Days to maturity, Plant height and Effective tillers per square meter of hybrid rice as affected by different levels of Nitrogen during 2020.

Nitrogen levels (kg ha^{-1})	Days to heading	Days to maturity	Plant height (cm)	Effective tillers/m2
0	90.33	117.33	110.33	178.67c
75	91	117.67	117.33	181c
100	90.67	117.67	116.33	186.33c
125	91	118.33	115	189.67c
150	92	118.33	114.67	227a
175	92.33	118.67	112.33	208.67b
CV %	**1.21**	**1.09**	**2.29**	**3.19**
p-value	**0.71**	**0.78**	**0.07**	**<0.01**
SEM	**0.9**	**1.05**	**2.13**	**5.08**
$LSD_{0.05}$	**NS**	**NS**	**NS**	**11.32**

Plant height

Plant height increases with nitrogen levels up to 75 kg ha^{-1} but shows a slight decrease at higher nitrogen levels, but the changes were statistically insignificant. The lowest plant height was obtained with control plot while highest plant height was found with 75 kg N ha^{-1} (Table 1). This suggests that while moderate nitrogen application promotes plant growth, excessive nitrogen might not further enhance plant height.

No of effective tillers

The number of effective tillers per square meter increases with higher nitrogen levels up to 150 kg N ha^{-1} but further increase in dose of nitrogen decreased the effective tillers per square meter statistically. The lowest number of tillers per square meter were observed with control plot while the highest was obtained at 150 kg N ha^{-1} and the increase was statistically significant. This indicates that nitrogen positively affects tillering, which could potentially lead to better crop yields as more tillers can result in more grain heads (Table 1).

Grain moisture percentage

Nitrogen levels were statistically at par with regard to grain moisture percentage. The control plot recorded the lowest grain moisture percentage while the highest level of nitrogen contained greater grain moisture percentage. The moisture percentage was statistically at par for various levels of Nitrogen (Table 2).

Panicle length

Nitrogen application significantly increased panicle length in hybrid rice and 75, 100, 125 and 175 kg N ha^{-1} were at par and significantly higher than control while significantly lower than 150 kg N ha^{-1}. The lowest panicle length was found in control plot while highest was obtained at 150 kg N ha^{-1} while further increase in nitrogen level reduced the panicle length (Table 2).

Number of filled grains

The application of nitrogen significantly increased numbers of filled grains per 5 panicles. The lowest number of grains were obtained at the control plot which was statistically significant with other nitrogen levels. With subsequent increase in nitrogen level, the number of filled grains increased but was statistically at par for 75, 100, 125 kg N ha^{-1}. The highest number of grains were observed with 150 kg N ha^{-1} which was significantly different with other levels of Nitrogen but statistically at par with 175 kg N ha^{-1} (Table 2).

Thousand grain weight

Nitrogen application increased the weight of a thousand grain in hybrid rice, but the increase was statistically at par for each level of nitrogen. However, the lowest thousand grain weight was observed in control plot whereas highest was observed with 150 kg N ha^{-1}. Furthermore, the increase in nitrogen level beyond 150 kg N ha^{-1} decreased the thousand grain weight but this decrease was statistically at par (Table 3).

Table 2. Moisture percentage, Panicle length, Number of filled grains per 5 panicle, Number of unfilled grains per 5 panicles of hybrid rice as affected by different Nitrogen levels during 2020.

Nitrogen levels (kg ha^{-1})	moisture percentage	Panicle length	filled grains/5 panicle
0	12.43	27.33c	514c
75	12.33	29.33b	594b
100	12.57	29b	624b
125	12.47	29.33b	649b
150	12.47	30.67a	774.67a
175	12.6	28.67b	724.67a
CV %	2.1	2.41	5.24
p-value	0.84	0.004	<0.01
SEM	0.21	0.57	27.65
LSD $_{0.05}$	ns	1.272	61.6

Grain yield

Application of nitrogen created significant variation in grain yield of rice. Application of 150 kg N ha^{-1} gave the highest yield (4.99 t ha^{-1}) which was statistically at par with 175 kg N ha^{-1} (4.77 t ha^{-1}) but was significantly higher than other levels of nitrogen including the control (Figure 2). The increase in yield with application of 150 kg N ha^{-1} was 33.06 % over the control (Table 3).

Straw yield

Straw yield in rice increased significantly for each level of nitrogen as compared to control. However, the increase in straw yield was statistically at par for various levels of nitrogen apart from the control. Highest straw yield (7.3 t ha^{-1}) was obtained with 125 kg N ha^{-1} and lowest was found with control (5.14 t ha^{-1}).

pH

As per the data presented in Table 4, pH of post-harvest soil shown the subsequent and continuous depletion with the increased rate of Nitrogen application as per the treatment allocated. The highest pH was seen in the control plot (6.85). As compared to the control plot, the lowest pH was seen in the plot with application of 175 kg N ha^{-1}.

Soil Organic Matter

Application of varied levels of nitrogen caused significant variation in the organic matter of soil. Application of 150 kg N ha^{-1} increased the soil organic matter significantly (0.88%) which was statistically at par with application of 125 kg N ha^{-1}. These values were however significantly higher than control plot where there was no application of N fertilizer.

Table 3. Effect of different levels of nitrogen in 1000 grain weight, Grain yield and Straw yield of hybrid rice during 2020.

Nitrogen levels (kg ha^{-1})	1000 grain weight	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
0	24.67	3.75^{e}	5.14^{b}
75	24.83	4.2^{d}	6.73^{a}
100	24.83	4.34^{cd}	6.97^{a}
125	25.17	4.6^{bc}	7.3^{a}
150	25.5	4.99^{a}	6.99^{a}
175	25	4.77^{ab}	7.04^{a}
CV %	**1.21**	**3.22**	**6.88**
p-value	**0.07**	**<0.01**	**0.002**
SEM	**0.25**	**0.12**	**0.38**
LSD $_{0.05}$	**NS**	**0.26**	**0.84**

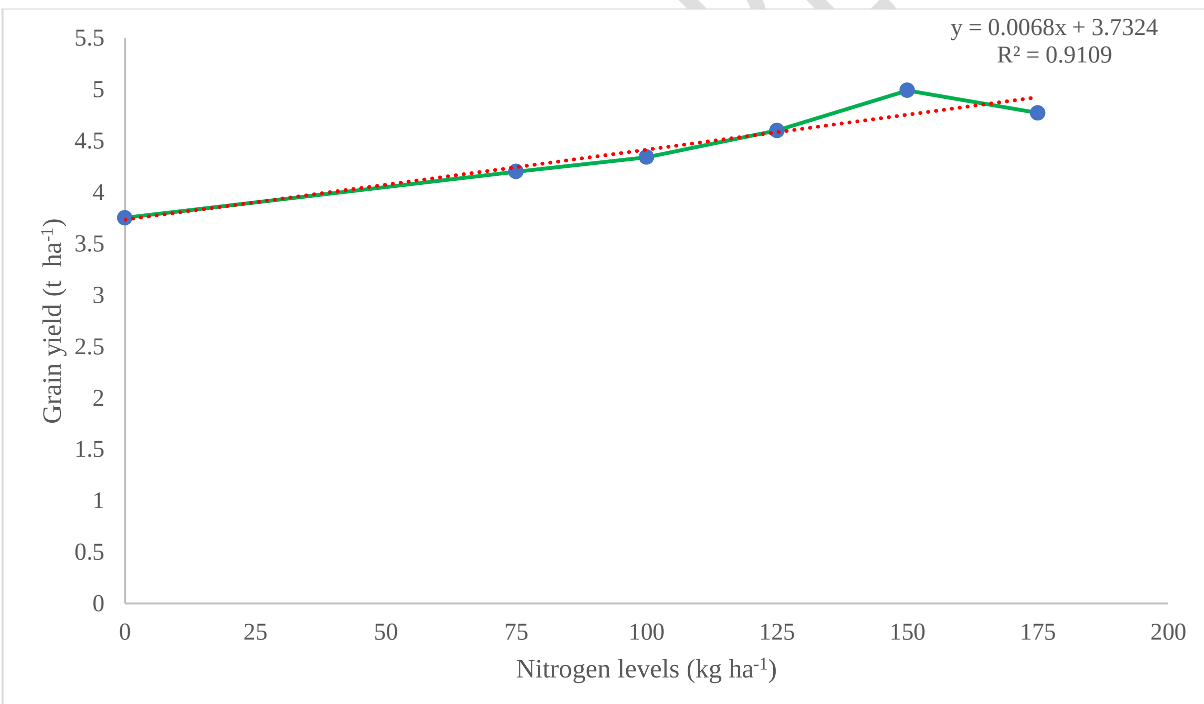

Figure 2. Grain yield of hybrid rice under different levels of Nitrogen

Table 4. Effect of different levels of nitrogen in pH, Soil Organic Matter and availability of NPK during 2020.

Nitrogen levels (kg ha-1)	pH	SOM	Available N	Available P	Available K
0	6.85^{a}	0.79^{d}	134^{f}	33^{d}	108
75	6.77^{b}	0.83^{c}	146.33^{e}	36^{c}	113.67^{c}
100	6.71^{c}	0.84^{bc}	160^{d}	39^{b}	116.67^{bc}
125	6.67^{d}	0.86^{ab}	174.67^{c}	41^{b}	119.67^{ab}
150	6.61^{e}	0.88^{a}	185.33^{b}	46.67^{a}	122.67^{a}
175	6.54^{f}	0.84^{bc}	192.33^{a}	46.67^{a}	123^{a}
CV %	**0.24**	**1.29**	**2.05**	**3.98**	**1.84**
p-value	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**
SEM	**0.013**	**0.01**	**2.77**	**1.31**	**1.76**
$LSD_{0.05}$	**0.03**	**0.031**	**6.17**	**2.92**	**3.93**

Available N

Increased application of N caused the significant increment in the availability of N in post-harvest soil as shown in Table 4. Application of 175 kg N ha^{-1} yielded the highest availability of N in soil whereas the lowest was observed in the control plot. The availability of N was significantly different for each and every plot with different treatments involved.

Available P

Application of N in the field significantly varied the availability of P in post-harvest soil of experimental field. Application of 150 kg N ha^{-1} and 175 kg N ha^{-1} shown the highest available P and these values were significantly similar whereas these values differed significantly higher than the control plot which shown the lowest availability of P. (Table 4)

Available K

N application in the field had a considerable impact on the availability of K in the experimental field's post-harvest soils. The application of 150 kg N ha^{-1} and 175 kg N ha^{-1} resulted in the maximum available K, and these values were statistically indifferent. Application of 125 kg N ha^{-1} resulted to the availability of K which was statistically at par with the application of 150 and 175 kg N ha^{-1}. Although these values increased much more than the control plot, which had the lowest available P. (Table 4)

Nitrogen Content

The trend of highest value of N content was seen in both grain and straw of rice. The highest value of nitrogen content was observed in the application of 175 kg N ha^{-1} both in grain and rice (1.2% and 0.63%). These values were significantly higher than the observation of control plot. Nitrogen content in straw for 175 kg N ha^{-1} was statistically at par with 150 kg N ha^{-1}.

Nitrogen Uptake

Application of 150 kg N ha^{-1} resulted to the highest N uptake (59.06 kg ha^{-1}) in rice grain whereas the value of N uptake by 175 kg N ha^{-1} (57.09 kg ha^{-1}) was statistically similar. The lowest uptake of N in rice grain was observed in the control plot (40.88 kg ha^{-1}).

The application of 175 kg N ha^{-1} resulted in the maximum N absorption (44.08 kg ha^{-1}) in rice straw, whereas the value of N uptake from 125 kg N ha^{-1} (43.79 kg ha^{-1}) was statistically equivalent. The control plot showed the lowest nitrogen absorption in rice grain (40.88 kg ha^{-1}). However, the values for N uptake in rice straw for application of 100, 125, 150 & 175 kg N ha^{-1} were found out to be statistically at par with each other but were significantly higher than the control plot. (26.99 kg ha^{-1}).

Table 5. Effect of different levels of nitrogen in content and uptake of N during 2020.

Nitrogen levels (kg ha-1)	**N content in grain (%)**	**N content in straw (%)**	**N uptake in rice grain (kg ha-1)**	**N uptake in rice straw (kg ha-1)**	**Total N uptake (kg ha-1) {grain +straw}**
0	1.09^{f}	0.53^{e}	40.88^{d}	26.99^{c}	67.87^{c}
75	1.12^{e}	0.57^{d}	47.15^{c}	38.34^{b}	85.48^{b}
100	1.14^{d}	0.58^{cd}	49.53^{c}	40.69^{ab}	90.21^{b}
125	1.16^{c}	0.6^{bc}	53.33^{b}	43.79^{a}	97.12^{a}
150	1.18^{b}	0.62^{ab}	59.06^{a}	43.08^{ab}	102.14^{a}
175	1.2^{a}	$.63^{a}$	57.09^{a}	44.08^{a}	101.17^{a}
CV %	**0.55**	**1.69**	**2.62**	**6.61**	**3.24**
p-value	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**
SEM	**0.005**	**0.008**	**3.84**	**2.13**	**2.4**
LSD $_{0.05}$	**0.011**	**0.02**	**2.44**	**4.75**	**5.35**

Table 6. Effect of different levels of nitrogen in partial factor productivity and agronomic efficiency during 2020.

Nitrogen levels (kg ha-1)	**Partial factor productivity (kg grain kg-1 N applied)**	**Agronomic efficiency (kg grain increased kg-1 N applied)**
0		
75	55.96	5.96b
100	43.43	5.93b
125	36.77	6.77ab
150	33.27	**8.27a**
175	27.26	5.83b
CV %	**4.67**	**18.19**
p-value	**<0.01**	**<0.01**
SEM	**1.25**	**0.811**
LSD $_{0.05}$	**2.78**	**1.81**

Partial Factor Productivity & Agronomic Efficiency

Table no 6 reflects the effect of variable N rates over the study parameter of partial factor productivity as well as the agronomic efficiency. As per the data, application of 75 kg N ha^{-1} results in the highest partial factor productivity. Agronomic efficiency (kg grain increased kg^{-1} N applied) was observed to be the highest when the application of 150 kg N ha^{-1} was done.

DISCUSSION

Jahan et al. 2022, Y. S. Shivay et al. 2016, Chaturvedi 2005 also shared similar results of increased plant height with the application of increased dosage of N fertilizer. The increase in plant height in response to application of N fertilizers is probably due to enhanced availability of nitrogen which enhanced more leaf area resulting in higher photo assimilates and thereby resulted in more dry matter accumulation. These results are supported by the findings of Mandal et al. (1992). Rupp and Hubner (1995) also reported increased level of leaf N with applied N.

Jahan et al. 2022 found a similar trend of increased number of tillers with the application of N fertilizer. The increased tiller with N fertilization was due to the increased availability of N which played a vital role in cell division.

The result of our research concurs with the result shown by Yoseftabar (2013), Gewaily et al. (2018), Manzoor et al. (2006) and Jahan et al. (2022) for panicle length. Nitrogen contributes to rice panicle formation by stimulating cell division in the reproductive stage of crop growth.

Singh et al. (2022), Singh and Gangwer (1989) during their research reported that number of filled grains increased significantly with increasing dose of nitrogenous fertilizer upto certain level but further increase in nitrogen level decreased number of filled grains as compared to optimum.

The application of nitrogen increased the protein percentage, which in turn increased the grain weight. Kausar et al. (1993) and Chaturvedi (2005) also reported similar results. Grain weight is a genetically controlled trait, which is greatly influenced by the environment during the process of grain filling.

Metwally and Gewaily (2011) had similar results of our current study as they also found out the increased grain yield with the increased dosage of N fertilizer applied. Manzoor et al. (2006) noted that higher paddy yield with 150 and 250 kg N ha-1, respectively. The higher paddy yield at higher nitrogen rates was also reported by other workers (Dixit and Patro 1994 and Meena et al. 2003).

Similarly, He et al. (2024) reported higher yield with 150 kg N ha and decreasing yield and efficiency with increasing in nitrogen level as compared to the optimum level of fertilization. Likewise, Zhao et al. (2022) also noted decrease in rice yield with increasing nitrogen level beyond the optimum level.

Similar results supporting the current study were also reported by Zaidi and Tripathi (2007), Ramiah et al. (1987) and Subbiah et al. (2001) for the increase in straw yield.

Sikdar et al. (2008) found out that N level showed significant effect on all the parameters of the post-harvest soil under study which was in accordance with our study. The research showed that the soil pH, organic matter, available phosphorus and exchangeable potassium in post-harvest increased with increasing levels of Nitrogen.

Several researchers have reported an increased N concentration in rice plant tissue and grain due to N fertilization (Panda et al. 1993 and Kumar and Prasad 2004). The higher N content of nitrogen in treated plants could relate to the positive effect of nitrogen in some important physiological processes. The lower N content of the straw at maturity in comparison with the content in the grain clearly indicates N remobilization from the vegetative parts. Mae and Shoji (1984) reported that remobilized N from the vegetative organs to the panicles accounted for 70%–90% of the total N, with the leaf blade alone contributing 60% of the remobilized N.

Lin et al. (2009) found that increased dosage of nitrogen fertilizer significantly increased the total nitrogen uptake which was similar to our finding of nitrogen application and nitrogen uptake.

CONCLUSION

The study revealed that varying nitrogen levels had minimal impact on the days to heading and maturity of hybrid rice, as these parameters remained statistically similar across treatments. However, plant height peaked at a moderate nitrogen level (75 kg ha^{-1}), suggesting excessive nitrogen does not further enhance growth. The number of effective tillers and grain yield significantly increased with higher nitrogen levels up to 150 kg ha^{-1}, indicating optimal nitrogen application can improve rice productivity.

Soil pH, organic matter, and nutrient availability were positively influenced by increased nitrogen levels. Nitrogen content and uptake in both grain and straw also increased with higher nitrogen application, with the highest values observed at 175 kg ha^{-1}. These findings underscore the importance of optimizing nitrogen application for enhancing hybrid rice growth, yield, and nutrient uptake.

Disclaimer (Artificial intelligence)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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