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Nitrogen physical optimum rate for hybrid and open-pollinated maize varieties under Chitwan conditions

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ABSTRACT

Nitrogen (N) is a critical limiting nutrient, and its optimization is essential for sustainable maize production. Pipeline maize varieties developed at the National Maize Research Program (NMRP) require evaluation of nitrogen application rates based on their production potential. This study was conducted in the research fields of NMRP during 2022 and 2023 to optimize nitrogen rates for two pipeline maize varieties: a hybrid variety (CAH1511) and an open-pollinated variety (ZM627). This field experiment utilized a Randomized Complete Block Design (RCBD) with eight nitrogen application rates, each replicated three times. The physical optimum nitrogen rate was determined through the first derivative of the quadratic yield function, using pooled data and yield correction methods. In 2022, the hybrid maize demonstrated the highest grain yield (10.93 t/ha) at a nitrogen application rate of 200 kg/ha, which was statistically comparable to yields achieved with 240, 160, and 120 kg N/ha. The lowest yield (4.45 t/ha) was recorded in the nitrogen omission plot. In 2023, the hybrid maize achieved its highest mean yield (14.85 t/ha) at 200 kg N/ha, whereas the lowest mean yield (3.50 t/ha) was observed in the nitrogen omission plot. For the open-pollinated maize, the highest grain yield in 2022 (8.61 t/ha) was recorded at 160 kg N/ha, which was statistically similar to yields at 240 and 120 kg N/ha. The lowest yield (3.80 t/ha) occurred in the 0 kg N/ha nitrogen omission plot. In 2023, the highest grain yield (9.91 t/ha) for open-pollinated maize was obtained with 240 kg N/ha, which was at par with 60 kg N/ha, while the lowest yield (3.80 t/ha) was again observed in the nitrogen omission plot. A significant correlation was observed between grain yield and key yield attributes for both maize types, including plant height ($r = 0.782$, $p < 0.001$), cob length ($r = 0.964$, $p < 0.001$), cob diameter ($r = 0.836$, $p < 0.001$), number of rows ($r = 0.508$, $p < 0.001$), number of grains per row ($r = 0.951$, $p < 0.001$), and thousand-grain weight ($r = 0.630$, $p < 0.001$). The pooled quadratic regression analysis revealed that the physical optimum nitrogen rate was 216 kg N/ha for hybrid maize and 164 kg N/ha for open-pollinated maize. In conclusion, the study demonstrates that hybrid and open-pollinated maize varieties respond differently to nitrogen fertilizer, with distinct optimum nitrogen rates. These findings can contribute to minimizing nitrogen loss, preventing yield reductions in maize, and promoting environmental sustainability.

Keywords: Maize yield sustainability, nitrogen management, nutrient response, physical optimum N rate, yield response

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INTRODUCTION

Nitrogen (N) is a vital nutrient that is fundamental to maize growth and development, influencing various physiological and biochemical processes within the plant (Mu et al 2021). Nitrogen availability affects key aspects of maize production, including plant height, ear formation, grain yield, and nutrient utilization efficiency. Proper management of nitrogen fertilization is crucial for ensuring optimum growth and achieving high yields in maize crops (Sainju et al 2019). In maize, plant growth is adversely affected due to N deficiency as it restricts the formation of enzymes, chlorophyll, and proteins necessary for growth and development, which can lead to stunted growth, reduced leaf area, delayed maturity, and lower grain yields (Khan et al 2011). On the other hand, excessive N application can result in vegetative overgrowth, delayed maturity, lodging, and reduced grain quality (Aziiba et al 2019).

Optimizing N management practices is crucial for achieving sustainable maize production. Hybrid maize, in particular, has gained significant attention due to its superior yield potential and adaptability to various growing conditions (Balko and Russell 1980). However, achieving optimal yields necessitates an in-depth understanding of the crop's response to key agronomic factors, notably N fertilization. Physical N rate optimization is a concept to calculate the required N rate above which the crop starts to show a negative yield (Havlin et al 2013). Understanding the impact of different nitrogen levels on soil fertility is essential for developing sustainable nutrient management strategies that enhance crop productivity while preserving soil health, cost-effectiveness, and ecosystem integrity.

Understanding the response of different hybrid and open-pollinated maize varieties to different N levels is essential for developing effective N management strategies and maximizing maize productivity (Aziiba et al 2019). This knowledge can help farmers make informed decisions regarding N fertilization, optimizing input usage, reducing costs, minimizing environmental impacts, and enhancing overall crop performance (Liu et al 2023). In Nepal, many farmers indiscriminately apply varying rates of nitrogen (N) fertilizer due to the lack of information regarding appropriate doses and timing of nitrogen application in rice-maize cropping systems (Baral et al 2020). Previous studies at NMRP reported that the released hybrid maize showed a mean response N rate at 200 kg N/ha, and the OP varieties responded around 120 kg N/ha (Annual Report, 2021, 2022, and 2023; Dhakal et al 2021). However, the physical optimum N rate has not been calculated by any other studies. By addressing this knowledge gap, the study will provide valuable insights into the effects of N levels on maize growth and soil fertility in the inner Terai region of Nepal.

The optimal nitrogen levels for hybrid and open-pollinated maize varieties are crucial to maximize crop yield. By evaluating the effects of different nitrogen levels, the study can provide valuable insights into the appropriate doses and timing of N application for hybrid and open-pollinated maize cultivation. This information will enable farmers to adopt precise and targeted N management practices, ensuring efficient fertilizer use and optimal crop growth. Evaluating the effects of N levels on maize growth, the study can provide evidence-based recommendations that help farmers improve their productivity and profitability.

MATERIALS AND METHODS

Description of the experimental site

Two field experiments were conducted at National Maize Research Program (NMRP), Rampur Chitwan research field. The study site has sub-tropical humid climate and altitude of the site is 225 m above the mean sea level. The experimental site lies at $27^0 37'$ North latitude and $84^0 29'$ east longitude.

Soil properties and climate of the experimental site

Soil samples were taken randomly from four different spots of each plot at a depth of (0-20 cm) using tube auger to record the initial physio-chemical properties of the soil. Composite soil sample of 500 g was taken by the quartering method. The soil samples were dried, ground and passed through 2 mm sieve and analyzed for different properties (Table 1).

Table 1. Physio-chemical properties of soil of the experimental plot before field layout at NMRP, Rampur, Chitwan.

S.N.	Properties	Values	Interpretation
1	**Physical properties**		
	Sand (%)	61	
	Silt (%)	29	
	Clay (%)	10	
	Textural class		Sandy loam
2	**Chemical properties**		
	Soil pH	6.4	Slightly acidic
	Soil organic matter (%)	2.97	Medium
	Total N (%)	0.12	Medium
	Available P2O5 (kg ha^{-1})	263	Very high
	Available K2O (kg ha^{-1})	275	Medium

The meteorological data for cropping season was recorded from the meteorological station of National Maize Research Program (NMRP), Rampur Chitwan. The maximum (24.79^0C to $32.26.3^0$ C) and minimum (9.91^0C to 20.88^0 C) temperature were recorded during the growing season (October to April). The highest relative humidity (83 %) was recorded in November and minimum (55%) in April. Similarly, the highest rainfall (10.21 mm) was recorded in October, 2.17 mm rainfall occurred in April and there was no rainfall during other months during the experiment.

Experimental details

The experiments were laid out in Randomized Complete Block Design (RCBD) with three replications and eight treatments with different levels of nitrogen (0, 60, 90, 120, 160, 200, 240 kg N/ha) for both hybrid and open pollinated maize. All the treatments were supplied with 60:60 P_2O_5:K_2O kg/ha. The dimension of the individual plot was 6 m in length and 3.5 m in breadth, resulting in a 21 m^2 area. The spacing between the plots was 1.5 m, while the spacing between replications was 2 m. Row to row distance was maintained at 75 cm while plant to plant distance was 25 cm, which allowed a total of eight rows in each plot. Out of eight rows, six central rows were used as net plot rows for collecting data on the biometrical and phonological features of the test crop. The outermost rows on either side of the plot were used as borderlines to avoid any biases and experimental errors.

Field preparation, fertilizer application, and seed rate
The land was plowed one month before seed sowing. Nitrogen (N), Phosphorus and potassium were supplied through inorganic fertilizers such as Urea, Single super phosphate (SSP) and Muriate of potash (MOP). Full doses of Phosphorus and Potash were applied as basal doses while Nitrogen was applied in split doses, 1/3rd at basal dose, 1/3rd at knee high stage, and 1/3rd at tasseling. Irrigation was done by flooding when it was necessary.

The seed rate of 25 kg/ha was used for each treatment. Seed was planted manually using Zabler seed planter, maintaining the 2 seeds per spot with a spacing of 75 cm x 25 cm apart for row to row and plant to plant distances. The seeds were covered with a thin layer of soil immediately after sowing, manually. Both the cultivars ZM627 (OP), CAH 1511 (Hybrid) were shown in October 2022 and 2023.

Intercultural operations
The first hand weeding was at 30 DAP and the second weeding at 45 DAP. Thinning unwanted plants maintained only one plant per hill 20th days after planting, followed by earthing up. Infection of fall armyworm was prevented by spraying Spinosad and spinetoram, which were applied at 3-4 leaf stage and knee-high stage.

The harvesting time of maize crop was judged by routinely observing the physical appearances of plants such as the husk of maize ears was changed into yellowish, black tip of seed caps, silks were changed into brown and leaves and stover starting to dry and brown. After harvesting, the cobs were separated, and the remaining biomass was weighed. The number of cobs per plot was counted and weighed. The cobs were dehusked after drying on the threshing floor.

Observations

Soil parameters
Soil samples were collected randomly from four spots of each plot at a depth of 0 – 20 cm using screw auger after crop harvest. These soil samples were air dried, ground and sieved through a 2 mm sieve and subjected to analyses (Organic matter, N, P_2O_5, K_2O and pH) to determine the initial and final physicochemical properties of soil. Soil samples were analyzed in the laboratory using the standard operating protocols developed by Digital Soil Map Working Guidelines of Nepal (DSM, 2020).

Biometric and yield parameters
Biometric parameters such as plant height (cm), biomass weight (fresh, kg) were recorded. Other yield attributes such as days to 50% tasseling and silking, cob length, cob diameter, number of rows per cob, number of grains per cob, thousand grain weight (g), and grain moisture content (in %) were recorded. The moisture content of grains of each plot was measured by an automated grain moisture meter and the final grain yield was adjusted at 12% moisture level by using the formula as given below:

$$\text{Grain yield (kg/ha)} = \frac{\text{Fresh ear weight (kg/plot)} \times (100\text{-MC}) \times 0.8 \times 10000\ (m^2)}{(100-12) \times \text{Area harvested or net plot size}}$$

where, MC= moisture content in grains at harvest (%), 0.8= shelling coefficient, Area harvested /plot, 1 hectare = 10,000 m^2, 88%= Grain moisture standard value at 12% MC, 12% moisture content required for maize grain at storage.

Statistical analysis

Statistical analysis was done using R studio (R core team, 2021). The analysis was done for the Analysis of Variance (ANOVA), mean comparison, and correlation among the parameters. Data were subjected to ANOVA assumptions, and they satisfied the assumptions. The significance of the treatment was tested by using Tukey's Honest Significant Difference at a 5% level of significance.

RESULTS

In year 2022, the highest hybrid maize cob yield (10.59 t/ha) was obtained with the nitrogen level 200 kg N/ha which was statistically similar with 160 kg N/ha, 240 kg N/ha, and 120 kg N/ha while the lowest yield (4.45) was obtained in 0 NPK plot (Table 2) which was similar with nitrogen level 0 kg N/ha (4.72 t/ha). The highest yield (8.61 t/ha) was obtained with nitrogen level 160 kg N/ha in open pollinated maize which was statistically similar with 120 kg N/ha, 200 kg N/ha, and 90 kg N/ha and 60 kg N/ha while the lowest yield (3.8 t/ha) was obtained with 0 kg N/ha nitrogen and in 0 NPK plot (4.21 t/ha). The data showed the optimum mean response rate of nitrogen for open pollinated maize was 60 kg N/ha, which was found similar to higher N rates (Table 2). Other yield attributes such as cob length, cob diameter, number of rows per cob, number of grains per cob and thousand grain weight was found significant for both hybrid and OP maize with the similar significance response to that of the yield.

In year 2023, the significant highest mean yield was obtained from 200 N kg/ha (14.85 t/ha) which was similar to 120 kg N/ha (11.92 t/ha) and 160 kg N/ha (11.92 t/ha) (Table 3). The lowest mean yield was obtained from treatment 0 NPK/ha (2.87 t/ha) which is similar with 0 N kg/ha (3.50 t/ha). So, the optimum mean N response for hybrid maize was obtained from 120 kg N/ha. The yield increases significantly with the application of nitrogen till 200 kg N/ha, if nitrogen application increase more than 200 kg N/ha then yield decrease, which may not result in further yield gains. Similarly, the significant highest mean yield in OP maize was obtained from 240 kg N/ha (9.91 t/ha) which was similar to 60 kg N/ha (5.66 t/ha), 120 kg N/ha (11.92 t/ha) 160 kg N/ha (9.63t/ha) and 200 kg N/ha (9.59 t/ha) (Table 3). The lowest mean yield was obtained from 0 kg NPK/ha (1.93t/ha) which is similar with 0 kg N/ha (2.23 t/ha). So, the optimum rate of nitrogen for OP maize was 60 kg N/ha. The yield increases significantly with the application of nitrogen till 120 kg N/ha. The mean performances of different yield attributes of hybrid and OP maize under various nitrogen rates are presented in Table 4. The parameters measured include plant height, cob length, cob diameter, row number, grain number, and thousand-grain weight. The results present the mean values along with the lower and upper confidence intervals (CI at 95% confidence interval) for each parameter, providing an understanding of the impact of nitrogen application on maize yield attributes.

There was no significant difference in residual soil nutrients (Table 5) among the plots with different levels of nitrogen application. There was no significant difference in residual nitrogen and potassium in the plots with different levels of nitrogen application. The highest residual potassium (298.4 kg N/ha) was found in the plot with nitrogen level 60 kg N/ha and the lowest residual potassium (200.8 kg N/ha) was found in the plot with 120 kg N/ha.

Table 2. Mean yield and yield attributes of hybrid and OP maize in the year 2022.

Hybrid Maize

Treatments Kg N/ha	**Length of Cob (cm)**	**Diameter of Cob (cm)**	**Number of Rows/cob**	**Number of grains/cob**	**Thousand grain wt (g)**	**Yield (t/ha)**
0 NPK	$8.97^{b}\pm0.71$	$3.32^{d}\pm0.13$	$12.4^{c}\pm0.62$	$15.47^{e}\pm1.33$	$429.33^{bc}\pm15.20$	$4.45^{d}\pm0.89$
0	$10.09^{b}\pm0.69$	$3.55^{cd}\pm0.12$	$13.0^{bc}\pm0.43$	$18.0^{de}\pm0.88$	$375.33^{c}\pm13.46$	$4.72^{d}\pm0.38$
60	$13.49^{a}\pm0.60$	$3.95^{abc}\pm0.09$	$14.8^{a}\pm0.14$	$22.2^{bcd}\pm0.89$	$453.33^{ab}\pm14.45$	$7.81^{bc}\pm0.64$
90	$13.28^{a}\pm0.48$	$3.81^{bc}\pm0.04$	$13.6^{abc}\pm0.01$	$21.07^{cd}\pm0.58$	$475.33^{ab}\pm18.63$	$7.55^{c}\pm0.32$
120	$15.427^{a}\pm0.65$	$3.99^{ab}\pm0.03$	$15.07^{a}\pm0.36$	$25.13^{abc}\pm1.06$	$468.00^{ab}\pm1.87$	$10.24^{ab}\pm0.46$
160	$16.07^{a}\pm0.31$	$3.99^{ab}\pm0.05$	$14.67^{ab}\pm0.22$	$27.47^{a}\pm1.26$	$475.33^{ab}\pm19.14$	$10.59^{a}\pm0.31$
200	$14.97^{a}\pm0.68$	$4.07^{ab}\pm0.02$	$14.00^{abc}\pm0.14$	$28.80^{a}\pm0.49$	$500.00^{a}\pm14.61$	$10.93^{a}\pm0.08$
240	$15.39^{a}\pm0.27$	$4.24^{a}\pm0.05$	$14.53^{ab}\pm0.16$	$26.47^{ab}\pm0.88$	$485.33^{ab}\pm2.16$	$10.06^{ab}\pm0.15$
P value	0.0008173***	0.004835**	0.04199*	0.0005457***	0.01540*	0.0001313***

Open Pollinated Maize

Treatments Kg N/ha	**Length of Cob (cm)**	**Diameter of Cob (cm)**	**No. of Rows/cob**	**No. of grains/cob**	**Thousand grain wt (g)**	**Yield (t/ha)**
0 NPK	$7.23^{b}\pm0.15$	$3.26^{d}\pm0.12$	$11.67^{c}\pm0.29$	$14.00^{b}\pm0.85$	$273.33^{bc}\pm8.28$	$4.21^{bc}\pm0.62$
0	$8.08\ ^{b}\pm0.14$	$3.62^{cd}\pm0.11$	$13.06^{bc}\pm0.27$	$14.33^{b}\pm0.54$	$270^{c}\pm6.82$	$3.80^{c}\pm0.37$
60	$11.51^{a}\pm0.17$	$4.12^{bc}\pm0.04$	$14.67^{ab}\pm\pm0.08$	$21.33^{a}\pm0.50$	$360.67^{a}\pm18.23$	$6.86^{a}\pm0.20$
90	$12.42^{a}\pm0.39$	$3.97^{bc}\pm0.19$	$12.80^{bc}\pm0.86$	$22.26^{a}\pm0.18$	$332.67^{abc}\pm15.20$	$6.62^{a}\pm0.86$
120	$12.17^{a}\pm0.38$	$4.02^{bc}\pm0.04$	$14.67^{ab}\pm0.33$	$21.73^{a}\pm1.35$	$349.33^{ab}\pm21.94$	$6.94^{a}\pm0.59$
160	$11.15^{a}\pm0.47$	$4.03^{bc}\pm0.18$	$15.06^{a}\pm0.39$	$23.67^{a}\pm0.36$	$398.67^{a}\pm9.09$	$8.61^{a}\pm0.08$
200	$12.21^{a}\pm0.28$	$4.70^{a}\pm0.08$	$15.06^{a}\pm0.43$	$20.40^{a}\pm0.86$	$362.00^{a}\pm15.51$	$6.87^{a}\pm0.22$
240	$12.38^{a}\pm0.72$	$4.18^{b}\pm0.02$	$14.00^{ab}\pm0.24$	$22.26^{a}\pm1.24$	$361.33^{a}\pm14.74$	$6.22^{ab}\pm0.57$
P value	0.0001127***	0.001625**	0.01351*	0.000722***	0.02923*	0.01433*

There was no significant difference in organic matter content among the plots with different levels of nitrogen. The highest organic matter content (4.65%) was found in the plot with nitrogen level 240 kg N/ha, the lowest (3.81%) in the plot with 60 kg N/ha nitrogen. The pH of the soil was statistically similar at all months but it decreased gradually from 30 days to harvesting. Initially, the highest pH was observed in the plot with 0 kg N/ha, while the lowest pH was observed with 240 kg N/ha nitrogen. At the harvesting time, the highest pH was observed in the plot with 160 kg N/ha nitrogen and the lowest pH of around 4.8 with 60 kg N/ha nitrogen. Overall, the graph showed (Figure 1) the decrease in pH of soil with time period on all levels of nitrogen.

Table 3. Yield of hybrid and OP maize variety recorded in the year 2023.

Treatment (Kg N/ha)	Hybrid mean yield (t/ha)	Standard error	OP mean yield, (t/ha)	Standard error
0 NPK	2.87[a]	0.22	1.93[a]	0.34
0	3.50[ab]	0.89	2.23[a]	0.41
60	8.57[bc]	0.62	5.66[ab]	0.90
90	9.03[c]	0.46	4.02[a]	0.32
120	11.92[cd]	1.11	9.82[b]	1.45
160	11.92[cd]	1.94	9.63[b]	1.36
200	14.85[d]	1.07	9.59[b]	0.82
240	14.79[d]	1.45	9.91[b]	0.79
P-value	<0.01		<0.01	

Table 4. Mean performance of different yield attributing parameters of hybrid and OP maize in the year 2023 (CI represents 95% confidence interval).

Hybrid Maize

Treatment Kg N/ha	Plant height, cm			Cob length, cm			Cob diameter, cm		
	Mean	Lower CI	Upper CI	Mean	Lower CI	Upper CI	Mean	Lower CI	Upper CI
0 NPK	152.00	149.01	154.99	5.68	5.01	6.35	3.25	3.06	3.45
0	164.00	152.08	175.92	6.95	5.49	8.40	3.27	2.53	4.02
60	181.33	155.52	207.15	9.97	8.57	11.36	3.91	3.73	4.08
90	176.67	170.04	183.30	10.63	9.65	11.62	4.23	4.12	4.35
120	220.33	201.05	239.61	13.01	11.13	14.89	4.31	4.09	4.54
160	217.33	190.17	244.50	12.69	11.10	14.29	4.35	4.11	4.60
200	226.67	193.94	259.39	15.86	14.20	17.52	4.47	4.23	4.70
240	229.00	210.47	247.53	15.77	15.49	16.06	4.53	4.46	4.60

Treatment	Row number			Grain number			Thousand grain weight, kg		
Kg N/ha	Mean	Lower CI	Upper CI	Mean	Lower CI	Upper CI	Mean	Lower CI	Upper CI
0 NPK	12.00	11.00	12.00	10.00	10.00	11.00	0.34	0.33	0.35
0	12.00	9.00	14.00	13.00	9.00	18.00	0.31	0.26	0.37
60	13.00	13.00	14.00	17.00	14.00	20.00	0.34	0.30	0.37
90	14.00	14.00	15.00	19.00	17.00	21.00	0.36	0.33	0.39
120	13.00	13.00	14.00	24.00	20.00	29.00	0.37	0.31	0.42
160	14.00	14.00	14.00	22.00	17.00	27.00	0.39	0.38	0.40
200	14.00	12.00	15.00	28.00	24.00	32.00	0.38	0.37	0.40
240	14.00	14.00	15.00	29.00	25.00	33.00	0.38	0.35	0.42

Open pollinated Maize

Treatment Kg N/ha	Plant height, cm			Cob length, cm			Cob diameter, cm		
	Mean	Lower CI	Upper CI	Mean	Lower CI	Upper CI	Mean	Lower CI	Upper CI
0 NPK	136.67	93.82	179.51	4.98	4.04	5.91	3.18	2.73	3.62
0	165.00	150.03	179.97	4.61	4.42	4.80	3.08	2.40	3.76
60	178.33	164.09	192.57	8.29	6.66	9.92	4.12	3.89	4.35
90	205.00	199.34	210.66	7.22	6.88	7.56	3.63	3.24	4.02
120	206.67	192.43	220.91	10.19	8.08	12.30	4.55	4.34	4.75
160	208.33	188.46	228.20	11.44	9.50	13.38	4.49	4.41	4.56
200	206.67	200.13	213.20	11.77	10.16	13.37	4.57	4.39	4.74
240	205.00	175.60	234.40	11.97	11.40	12.54	4.50	4.24	4.76

Treatment	Row number			Grain number			Thousand grain weight, kg		
Kg N/ha	Mean	Lower CI	Upper CI	Mean	Lower CI	Upper CI	Mean	Lower CI	Upper CI
0 NPK	12.00	10.00	14.00	9.00	7.00	11.00	0.23	0.15	0.32
0	12.00	9.00	14.00	9.00	6.00	12.00	0.22	0.09	0.35
60	15.00	14.00	15.00	16.00	12.00	21.00	0.33	0.29	0.37
90	14.00	11.00	17.00	15.00	13.00	17.00	0.35	0.30	0.39
120	14.00	13.00	15.00	23.00	18.00	27.00	0.39	0.37	0.41
160	15.00	13.00	16.00	23.00	17.00	29.00	0.37	0.31	0.43
200	15.00	14.00	16.00	23.00	21.00	25.00	0.38	0.36	0.40
240	14.00	13.00	16.00	24.00	20.00	28.00	0.39	0.36	0.41

Table 5. Changes in soil organic matter, total nitrogen, and available potassium influenced by the uptake of hybrid and OP maize varieties

Treatments Kg N/ha	OM	N	K
0 NPK	4.42^{ab}±0.17	0.075^{a}±0.03	277.2^{a}±20.58
0	4.47^{ab}±0.26	0.065^{a}±0.02	244.8^{a}±22.96
60	3.81^{b}±0.13	0.080^{a}±0.03	298.4^{a}±10.26
90	4.18^{ab}±0.11	0.055^{a}±0.02	244^{a}±12.99
120	4.00^{ab}±0.19	0.065^{a}±0.02	200.8^{a}±10.54
160	4.25^{ab}±0.12	0.055^{a}±0.02	232.8^{a}±22.88
200	4.38^{ab}±0.13	0.077^{a}±0.03	271.2^{a}±34.85
240	4.64^{a}±0.09	0.057^{a}±0.02	209.6^{a}±3.21
P value	0.25890^{ns}	0.8017^{ns}	0.4850^{ns}
SEM (±)	0.08	0.001	12.01
CV	8.96	36.6	23.79

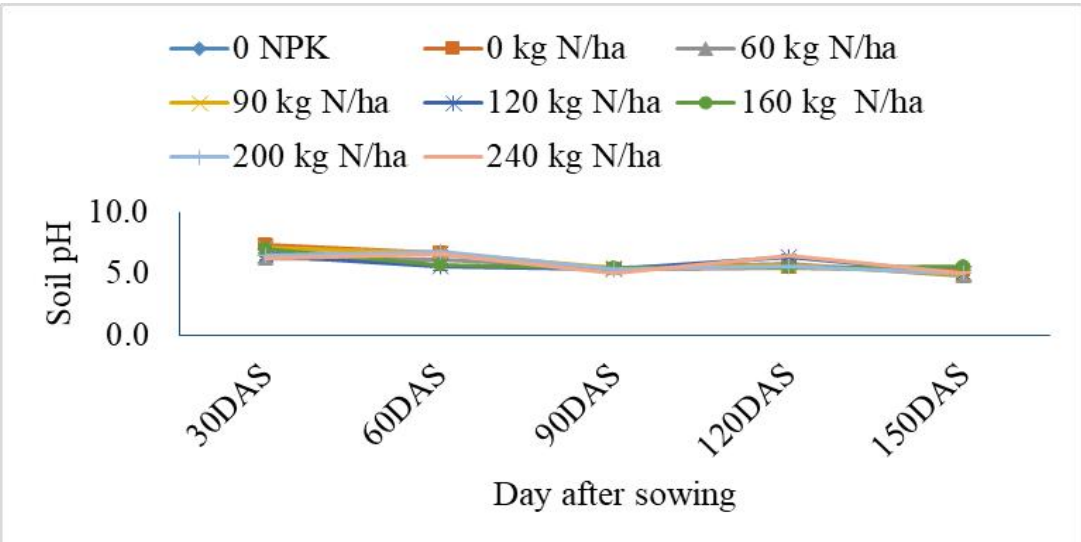

Figure 1. Periodic changes in soil pH after N application.

There is a significant correlation between yield and yield attributes of both hybrid and OPV maize (Figure 2). The significant correlation between yield and plant height ($r = 0.782^{***}$, $p < 0.001$), length of cob ($r = 0.965^{***}$, $p < 0.001$), diameter of cob ($r = 0.836^{***}$, $p < 0.001$), number of row ($r = 0.508$, $p < 0.001$), number of grains per row ($r = 0.951$, $p < 0.001$), thousand grain weight ($r = 0.630$, $p < 0.001$). The segregated correlation between the Hybrid and OP maize varieties also showed a similar correlation. A significant correlation can also be observed between the yield-attributing traits of both hybrid and OP maize. This showed a significant contribution of each of the yield traits in determining the yield of both hybrid and OP maize. The scatter diagram on the lower left-hand side of the correlogram showed a clear linear relationship between yield and yield attributing traits and the density plot showed the centric data distribution around the mean values indicating a parametric data distribution and the correlation obtained showed a strong relationship between yield and yield attributing traits in both hybrid and OP maize.

The second-order regression analysis on the relationship between hybrid maize yield and nitrogen application rate yielded a quadratic equation $y = -0.0002x^2 + 0.0865x + 2.572$ with an adjusted R^2 value of 0.98 (Figure 3a). The quadratic coefficient signified a curvilinear connection, suggesting an optimal nitrogen application rate for yield optimization. The positive linear coefficient demonstrated a direct positive relationship between yield and nitrogen application, while the constant term represented the baseline yield without nitrogen. The high R^2 value indicates a strong fit, explaining 98.32% of yield variability through the quadratic model. The equation provided an optimum physical yield of 216 kg N/ha ($dy/dx=0$). This analysis highlights a significant nitrogen-yield interaction, aiding in understanding N management in hybrid maize production practices.

Figure 2. Pooled correlogram showing the relationship between the yield and yield attributes of Hybrid and OP maize variety

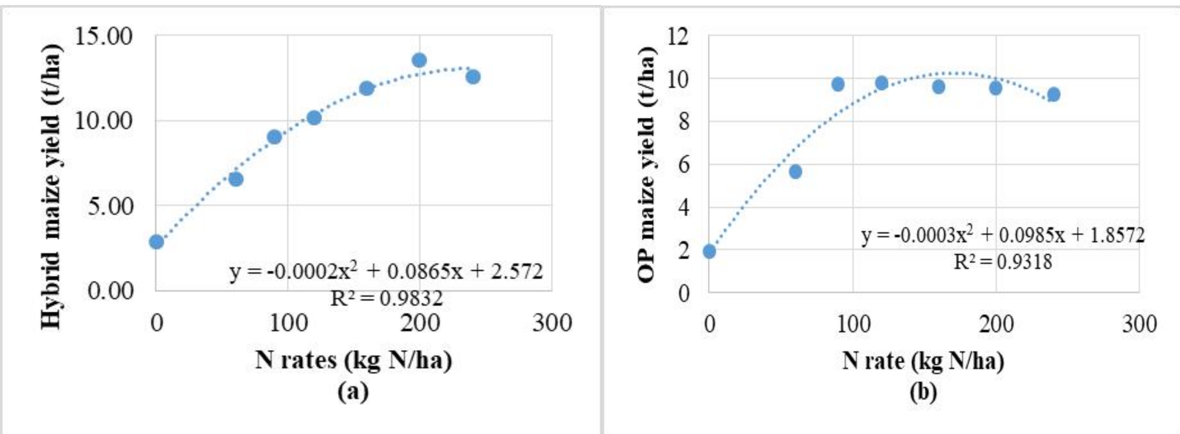

Figure 3. Pooled yield response of hybrid (a) and OP maize (b) with various rates of N

The second-order regression analysis on the relationship between OP maize yield and nitrogen application rate yielded a quadratic equation $y = -0.0003x^2 + 0.0985x + 1.8572$ with an adjusted R^2 value of 0.93 (Figure 3b). The quadratic coefficient signified a curvilinear connection, suggesting an optimal nitrogen application rate for yield optimization. The positive linear coefficient demonstrated a direct positive relationship between yield and nitrogen application, while the constant term represented the baseline yield without nitrogen. The high R^2 value indicates a strong fit, explaining 98.32% of yield variability through the quadratic model. The equation provided optimum physical yield of 164 kg N/ha (dy/dx=0).

Table 6. Physical optimum N rate calculation for hybrid and OP maize variety in 2 years pooled data

Hybrid maize	**OP maize**
$y = 2.572 + 0.0865x - 0.0002x^2$	$y = 1.8572 + 0.0985x - 0.0003x^2$
Differentiating with x and equating the first derivative to zero	Differentiating with x and equating the first derivative to zero
Here, $\frac{dy}{dx} = 0$	Here, $\frac{dy}{dx} = 0$
Or, $\frac{d(2.572 + 0.0865x - 0.0002x2)}{dx} = 0$	Or, $\frac{d(1.8572 + 0.0985x - 0.0003x2)}{dx} = 0$
Or, 0.0865 – 0.0004 x = 0	Or, 0.0985 – 0.0006 x = 0
X = 216 kg N	X = 164 kg N
So, the physical optimum N rate for the hybrid maize is 216 kg N	So, the physical optimum N rate for OP maize is 164 kg N

DISCUSSION

Nitrogen rates significantly responded to hybrid and open-pollinated (OP) maize varieties. The increase in yield is attributed to the significant correlation of yield-attributing traits such as thousand grain weight, grains per row, and the number of rows per cob. The vegetative growth, measured in terms of plant height, was also associated with nitrogen (N) rates, showing remarkable growth with increasing N rates up to certain levels (120 – 160 kg N/ha) in both hybrid and OP maize. Given hybrid maize's higher biomass and yielding nature, its nitrogen requirement is higher. Consequently, the physical optimal N dose for hybrid maize is 216 kg N/ha, while for OP maize, it is 164 kg N/ha. The increase in yield can be further attributed to the positive effects of nitrogen on several physiological and morphological traits, including chlorophyll content, photosynthesis, plant height, number of leaves per plant, leaf area index (LAI), and dry matter accumulation (Rammu and Reddy 2007).

Higher nitrogen supply facilitated better above-ground and root development, resulting in an improved sink size. Adequate nitrogen conditions also enhanced pollination, reducing barrenness and promoting sink development. The higher number of leaves per plant and increased leaf area index at higher nitrogen levels indicated prolonged photosynthate translocation. These factors collectively contributed to better sink filling and ultimately higher grain yield. Similar findings have been reported by Khanday and Thakur (1991) and Rammu and Reddy (2007). The increase in yield as a result of increasing nitrogen fertilizer levels may be due to the importance of nitrogen as a macronutrient essential for plant nutrition (Dhital et al 2022). Nitrogen plays a crucial role in increasing vegetative growth by enhancing leaf initiation and increasing chlorophyll concentration in leaves, which improves the process of photosynthesis (Abdallah and Mekdad 2012).

Other yield attributes such as plant height, cob diameter, and cob length showed significant improvements with each successive increment of nitrogen. This can be attributed to the fact that nitrogen is an integral part of proteins and chlorophyll, which are essential for better plant height (Singh et al 2000). Similar results were found by Kandil (1902), who observed enhanced plant growth with increased nitrogen levels. Khan et al (2011) also reported a significant effect of nitrogenous fertilization on plant height, corroborating these findings. Adhikari et al (2023) found similar results concerning yield attributes, indicating that nitrogen plays a crucial role in enhancing plant growth.

The increase in carbohydrates, which enhances the early transition from the vegetative phase to the reproductive phase, might also contribute to these improvements (Ahmad et al 2018). Moderate nitrogen levels promote optimal cob development by facilitating cell division and elongation. However, inadequate or excessive nitrogen can lead to shorter or malformed cobs in maize. This observation aligns with the findings of Balko and Russell (1980). Selvaraju and Iruthayaraj (1994) reported an increase in cob length up to a nitrogen level of 150 kg N/ha.

Dhital et al (2022) observed that the number of grains per cob increased with increasing rates of nitrogen. This result may be due to the higher accumulation of photosynthates at higher nitrogen levels, as nitrogen is a central element of chlorophyll and protein. The increase in the number of grains with increased nitrogen levels was also reported by Edalat et al (2009) and Subramanian and Muthukrishnan (1987). Ahmad et al (2018), Dhital et al (2022), and Sharma et al (2019) found similar results regarding thousand grain weight, reporting an increase in yield-attributing characters with higher nitrogen levels.

This study highlights that the importance of nitrogen rates varies with the biomass yield of both grain and crop. It is crucial to manage nitrogen levels carefully to optimize yield, as excessive nitrogen can lead to yield loss and environmental harm. The negative yield impact will certainly occur after a certain limit of nitrogen rate, emphasizing the need for careful nitrogen management.

CONCLUSION

The findings of this study revealed that the optimal nitrogen rate for hybrid maize is 216 kg N/ha, which yielded a significant grain output. Conversely, the open-pollinated maize variety demonstrated the best performance at a lower nitrogen rate of 164 kg N/ha. The yield for hybrid maize increased significantly with nitrogen application rates up to 200 kg N/ha; however, exceeding this threshold resulted in reduced yields, potentially leading to economic inefficiencies and environmental losses. For open-pollinated maize, the significantly highest mean yield (9.91 t/ha) was obtained with 240 kg N/ha, which was statistically similar to the yields achieved at nitrogen levels of 60 kg N/ha (5.66 t/ha), 120 kg N/ha (11.92 t/ha), 160 kg N/ha (9.63 t/ha), and 200 kg N/ha (9.59 t/ha). Notably, the yield increased significantly with nitrogen application rates up to 120 kg N/ha in open-pollinated maize. Additional yield-contributing parameters such as cob length, cob diameter, number of rows per cob, number of grains per cob, and thousand-grain weight also exhibited positive correlations with increasing nitrogen rates. Appropriate nitrogen levels promoted vigorous plant growth, as reflected in traits such as plant height and thousand-grain weight. This study also highlighted a significant correlation between grain yield and various yield attributes for both hybrid and open-pollinated maize varieties. Parameters including plant height, cob length, cob diameter, number of rows per cob, number of grains per row, and thousand-grain weight emerged as critical contributors to maize yield. The high correlation coefficients (r) and significant p-values ($p < 0.001$) underscore the potential of enhancing these attributes to boost overall maize productivity. The optimization of nitrogen fertilization methods presents an opportunity for farmers to improve crop yields, foster healthy plant growth, and maintain soil fertility. Nevertheless, it is crucial to consider specific factors such as soil type, climatic conditions, and crop requirements to tailor nitrogen management practices to diverse agricultural contexts. Future research should emphasize the refinement of nitrogen management strategies, addressing their ecological impacts, therefore, advancing the long-term sustainability of farming systems.

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Authors' Contributions
KK–fieldwork, lab analysis, data analysis, writing–reviewing and editing; RBO–conceptualization, methodology, writing original draft; JB–Data recording, formal analysis, writing–reviewing and editing.

Conflicts of Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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