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OPTIMIZING NITROGEN USE AND GENOTYPE SELECTION FOR SUSTAINABLE FORAGE MAIZE PRODUCTION IN BIHAR

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SUMMARY

A field experiment was conducted during the *Kharif* season of 2023 at Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India, to assess the productivity, profitability, and nitrogen use efficiency of forage maize genotypes under varying nitrogen levels. The study was laid out in a factorial randomized block design with three replications, involving seven maize genotypes and three nitrogen (N) levels (60, 100, and 140 kg N ha^{-1}). Results revealed significant variation among genotypes and nitrogen levels for green fodder yield, crude protein yield, nitrogen use efficiency, and economic returns. The genotype FSM-2021-1 produced the highest green fodder and crude protein yields, while the application of 140 kg N ha^{-1} was most effective among N treatments. The highest partial factor productivity of nitrogen (PFPN) was recorded in genotype J-1006 (104.7 kg DF kg^{-1} N) and under the 60 kg N ha^{-1} treatment (114.2 kg DF kg^{-1} N). Economic analysis indicated that FSM-2021-1 achieved the highest net return (Rs. 55,479 ha^{-1}) and benefit-cost ratio (2.86), followed closely by the 140 kg N ha^{-1} treatment (Rs. 56,003 ha^{-1} and B:C ratio of 2.86). The study highlights the potential of selecting suitable genotypes and optimizing nitrogen application to enhance forage maize productivity and profitability.

Key words: Forage maize, genotype, nitrogen application, nitrogen use efficiency, green fodder

Agriculture and animal husbandry are closely interlinked in rural India, particularly in states like Bihar, where nearly one-third of the rural economy depends on livestock rearing (Samal *et al.*, 2023; ICAR-IGFRI, 2022). Bihar has a livestock population of 36.5 million, accounting for 6.8% of India's total livestock population, and stands as the leading milk producer in eastern India. Green fodder serves as a cost-effective and nutrient-rich feed source for dairy animals, significantly lowering milk production costs when integrated into feeding systems (Prajapati *et al.*, 2023). However, the state suffers from a substantial green and dry fodder deficit of 82.73% and 27.59%, respectively (ICAR-IGFRI, 2022). To bridge this gap, there is a pressing need to enhance forage production through improved crop management and the identification of suitable genotypes (Samal *et al.*, 2024) and nutrient strategies, particularly nitrogen (N) management (Nanda *et al.*, 2021).

Maize (*Zea mays* L.), often referred to as the "queen of cereals," is a highly productive and versatile fodder crop due to its superior palatability, nutritional value, and adaptability to different seasons as a day-neutral crop (Nanda *et al.*, 2024). It is widely preferred for silage making and offers high biomass yield within a short duration. The fodder yield of maize can be significantly influenced by genotype selection and agronomic practices such as plant population, irrigation, and nutrient management. Nitrogen, in particular, plays a crucial role in enhancing biomass and forage quality (Maman *et al.*, 2006; Bramhaiah *et al.*, 2018; Sarkar *et al.*, 2022). Production potential of fodder maize can be altered with changes in agronomic practices like nutrient management (Satpal *et al.*, 2024). Previous studies have demonstrated that nitrogen application improves both yield and quality of fodder maize (Satpal *et al.*, 2022; Nanda *et al.*, 2024). Nitrogen use efficiency is an important indicator for resource saving which is impacted by genotype, nitrogen dose, method and time of application (Yadav *et al.*, 2023; Sarkar *et al.*, 2024).

In this context, the present investigation was undertaken to evaluate the productivity, and profitability and nitrogen use efficiency of forage maize genotypes under varying nitrogen levels.

MATERIALS AND METHODS

A field experiment was conducted during the *Kharif* season of 2023 under the AICRP on Forage

Crops and Utilization at Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India. The study employed a factorial randomized block design with three replications, evaluating seven forage maize genotypes (J-1006, PJHM-1, CMH-12-686, African Tall, FSM-2021-1, COHM-8, and MFM-18-2) and three nitrogen levels (60, 100, and 140 kg N ha^{-1}). Genotypes and nitrogen levels were assigned as the first and second factors, respectively. Sowing was carried out on July 18, 2023 using a seed rate of 50 kg ha^{-1} with 30 cm row spacing. Nitrogen was applied in two splits: half as basal and the remainder at 30 days after sowing (DAS). A uniform basal dose of phosphorus (60 kg P_2O_5 ha^{-1}) and potassium (40 kg K_2O ha^{-1}) was also applied. Urea, DAP, and MOP were the fertilizer sources for nitrogen, phosphorus and potassium. All other agronomic practices followed standard recommendations. Forage maize was harvested at 50% tasselling. Green fodder yield (GFY) was recorded from the net plot. A 500 g subsample was oven-dried at 70 ± 2°C to determine dry matter content and calculate dry fodder yield (DFY). Nitrogen uptake was estimated by analyzing total nitrogen content in the dried sample and multiplying by DFY. Crude protein (CP) content was derived by multiplying nitrogen content by 6.25, and crude protein yield (CPY) was calculated by CP% × DFY. Nitrogen use efficiency was assessed using partial factor productivity of nitrogen (PFPN) as per Nanda and Nilanjaya (2022):

PFPN (kg DF/kg N applied) = DFY (kg/ha)/ ANA (kg ha^{-1})

Where, DFY is dry fodder yield in fertilized plot (kg ha^{-1})

ANA is the amount of fertilizer nitrogen applied (kg ha^{-1})

The nitrogen utilization efficiency (NutE) was worked out as per Rostamza *et al.* (2011) and Nanda and Nilanjaya (2022) as follows:

NUtE (kg DF/kg N uptake) = DFY (kg ha^{-1})/ NU (kg ha^{-1})

Where, DFY is the dry fodder yield (kg ha^{-1}) and NU is the nitrogen uptake (kg ha^{-1}).

Economic analysis was performed based on input costs and prevailing market prices of green fodder. Data were statistically analyzed using ANOVA for factorial RBD as outlined by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Growth parameters

The results revealed that forage maize genotypes had a significant effect on plant height, leaf:stem ratio (LSR), and dry matter content (Table 1). Among the genotypes, J-1006 exhibited the tallest plants (262.2 cm), while CMH-12-686 recorded the highest LSR (0.48) and dry matter content (24.06%). However, the plant height of J-1006 was statistically at par with MFM-18-2, indicating similar vegetative growth potential. The superior LSR of CMH-12-686 suggests a greater proportion of leaf biomass, which is a desirable trait in forage crops as it improves digestibility and nutritional quality. Additionally, the dry matter content of CMH-12-686 was statistically comparable to that of J-1006, suggesting better biomass accumulation in both genotypes. These results highlight the influence of genotypic variation on key morphological and quality traits of fodder maize. Similar genotypic differences in plant height and LSR have been reported by Satpal *et al.* (2022), Nanda *et al.* (2024) and Banik *et al.* (2025), affirming that genetic potential plays a critical role in determining fodder yield.

Nitrogen application also had a significant effect on these parameters (Table 1). The highest plant height and LSR were observed with the application of 140 kg N ha^{-1}, indicating that increased nitrogen availability promotes vegetative growth and enhances the proportion of leaf biomass. However, the maximum dry matter content was recorded with the 100 kg N ha^{-1} treatment. Although the values for plant height, LSR, and dry matter content at 100 and 140 kg N ha^{-1} were statistically at par, both were significantly superior to the 60 kg N ha^{-1} treatment. This trend suggests that while increasing nitrogen levels beyond 100 kg ha^{-1} may not significantly enhance dry matter accumulation, it does support improved vegetative traits such as height and LSR. The enhancement of plant growth characteristics with nitrogen fertilization is well-documented and aligns with previous findings by Satpal *et al.* (2022), who also reported increased plant height, LSR, and dry matter content with higher nitrogen application.

Fodder yield, productivity and quality

Significant differences were observed among forage maize genotypes for green fodder yield (GFY), dry fodder yield (DFY), production efficiency (both

TABLE 1
Growth parameters of forage maize as affected by genotypes and nitrogen application.

Treatments	Plant height (cm)	L:S ratio	Dry matter (%)
Genotypes			
J-1006	262.2	0.33	23.84
PJHM-1	195.6	0.35	20.28
CMH-12-686	202.1	0.48	24.06
African Tall	233.2	0.30	19.01
FSM-2021-1	222.9	0.32	22.35
COHM-8	194.9	0.35	20.00
MFM-18-2	261.3	0.25	19.51
SEm ±	2.8	0.01	0.39
LSD (P= 0.05)	7.9	0.02	1.10
N levels (kg/ha)			
60	213.2	0.31	19.69
100	228.0	0.35	22.15
140	232.6	0.36	22.04
SEm ±	1.8	0.00	0.25
LSD (P= 0.05)	5.2	0.01	0.72

green and dry fodder), and fodder quality parameters including crude protein (CP) content and crude protein yield (CPY) (Table 2). The genotype FSM-2021-1 produced the highest green fodder yield (426.6 q ha^{-1}), while J-1006 recorded the highest dry fodder yield (96.4 q ha^{-1}), green fodder production efficiency (7.57 q ha^{-1} day^{-1}), and dry fodder production efficiency (1.81 q ha^{-1} day^{-1}). The GFY of FSM-2021-1 was statistically comparable with MFM-18-2, J-1006, and COHM-8, indicating these genotypes also had good potential for fresh biomass production. Similarly, the DFY of J-1006 was at par with FSM-2021-1 and CMH-12-686, showing consistent dry matter accumulation across these genotypes. In terms of production efficiency, J-1006 showed comparable performance with FSM-2021-1 and COHM-8 for green fodder, and with CMH-12-686 for dry fodder. These findings highlight the role of genotype in influencing biomass production dynamics over time.

Regarding fodder quality, the highest crude protein content was recorded in FSM-2021-1 (7.23%), which also produced the maximum crude protein yield (6.97 q ha^{-1}). This CPY value was significantly superior to most other genotypes, except J-1006 and CMH-12-686, which showed comparable performance. These results align with earlier reports by Satpal *et al.* (2022) Banik *et al.* (2023) and Nanda *et al.* (2024), which also indicated significant genotypic variation in green and dry fodder yields as well as crude protein yield in maize.

Nitrogen application had a pronounced effect on all measured parameters. The application of 140 kg N ha^{-1} resulted in the highest GFY (430.4 q ha^{-1}), DFY (94.8 q ha^{-1}), green fodder production efficiency (7.58 q ha^{-1} day^{-1}), dry fodder production efficiency (1.67 q ha^{-1} day^{-1}), crude protein content (7.18%), and crude protein yield (6.82 q ha^{-1}). However, all these values were statistically comparable with those observed under the 100 kg N ha^{-1} treatment, suggesting that increasing nitrogen beyond 100 kg ha^{-1} may not result in significant additional benefits. These observations are consistent with the findings of Banik *et al.* (2023) and Nanda *et al.* (2024), who also reported improved yield and quality of forage maize with higher nitrogen levels up to a certain threshold.

TABLE 2
Yield, production efficiency and quality of forage maize as affected by genotypes and nitrogen application

Treatments	GFY (q/ha)	DFY (q/ha)	GFY (q/ha/day)	DFY (q/ha/day)	CP (%)	CPY (q/ha)
Genotypes						
J-1006	403.6	96.4	7.57	1.81	6.94	6.70
PJHM-1	370.4	75.1	6.59	1.34	6.87	5.16
CMH-12-686	384.9	93.3	6.96	1.69	7.08	6.64
African Tall	388.0	74.6	5.68	1.09	6.91	5.19
FSM-2021-1	426.6	95.8	7.49	1.68	7.23	6.97
COHM-8	400.4	80.0	7.42	1.48	7.09	5.68
MFM-18-2	411.0	80.4	6.85	1.34	7.01	5.66
SEm ±	10.4	2.6	0.19	0.05	0.11	0.19
LSD (P= 0.05)	29.7	7.4	0.53	0.13	NS	0.53
N levels (kg/ha)						
60	348.5	68.5	5.99	1.19	6.76	4.63
100	414.6	91.9	7.25	1.61	7.12	6.54
140	430.4	94.8	7.58	1.67	7.18	6.82
SEm ±	6.8	1.7	0.12	0.03	0.07	0.12
LSD (P= 0.05)	19.4	4.8	0.35	0.09	0.21	0.35

Economics and nitrogen use efficiency

The economic performance of forage maize genotypes varied significantly in response to genotype and nitrogen levels (Table 3). Among the genotypes, FSM-2021-1 recorded the highest gross returns (Rs. 85,326 ha^{-1}), net returns (Rs. 55,479 ha^{-1}), and benefit-cost ratio (2.86). These values were statistically at par with those recorded for MFM-18-2, J-1006, and COHM-8, indicating that these genotypes also hold potential for economic returns under similar agro-ecological conditions. This is consistent with earlier findings by Satpal *et al.* (2022) and Nanda *et al.* (2024), who also reported notable genotypic differences in economic traits among forage maize cultivars. In terms of partial factor productivity of nitrogen (PFPN), significant variation was observed among genotypes (Table 3). The genotype J-1006 recorded the highest PFPN (104.7 kg DF/kg N applied), which was significantly superior to all other genotypes, indicating its efficient use of applied nitrogen in producing dry biomass. In contrast, African Tall exhibited the lowest PFPN (78.2 kg DF/kg N applied), suggesting less efficient nitrogen utilization. These findings align with Nanda *et al.* (2024) and Satpal *et al.* (2022), who also reported genotypic variability in nitrogen use efficiency traits in forage maize.

Nitrogen application significantly influenced profitability (Table 3). The application of 140 kg N ha^{-1} resulted in the highest gross returns (Rs. 86,087 ha^{-1}), net returns (Rs. 56,003 ha^{-1}), and B:C ratio (2.86), closely followed by the 100 kg N ha^{-1} treatment. These two nitrogen doses were statistically similar, suggesting that beyond 100 kg N ha^{-1}, economic gains may plateau. This highlights the potential for optimizing nitrogen inputs to balance productivity and cost-effectiveness. Among nitrogen levels, the highest PFPN (114.2 kg DF/kg N applied) was achieved with the lowest nitrogen dose of 60 kg N ha^{-1} which gradually declined with increasing nitrogen levels, reaching the lowest at 140 kg N/ha (Table 3). A similar trend was observed in nitrogen utilization efficiency (NUtE), which peaked at 92.6 kg DF/kg N uptake under 60 kg N ha^{-1} and declined to 87.3 kg DF/kg N uptake at 140 kg N ha^{-1}. This inverse relationship between nitrogen dose and NUE indices supports the observations of Nanda and Nilanjaya (2022) in forage pearl millet and Nanda *et al.* (2024) in maize, where excessive nitrogen inputs led to diminishing returns in biomass per unit of nitrogen utilized. The decline in PFPN and NUtE with increased N levels can be attributed to a reduced incremental biomass gain per unit of applied nitrogen, underscoring the importance of optimizing N application rates for efficient and sustainable fodder production.

TABLE 3

Production economics and nitrogen use efficiency of forage maize as affected by genotypes and nitrogen application.

Treatments	Economics			Nitrogen use efficiency	
	Gross returns (Rs./ha)	Net returns (Rs./ha)	B:C ratio	PFPN (kg DF/kg N applied)	NUtE (kg DF/kg N uptake)
Genotypes					
J-1006	80722	50875	2.70	104.7	90.3
PJHM-1	74085	44238	2.48	80.4	91.3
CMH-12-686	76980	47133	2.58	98.7	88.5
African Tall	77603	47756	2.60	78.2	90.6
FSM-2021-1	85326	55479	2.86	102.6	86.8
COHM-8	80073	50225	2.68	87.4	88.3
MFM-18-2	82199	52352	2.75	86.9	89.3
SEm ±	2075	2075	0.07	3.6	1.4
LSD (P= 0.05)	5930	5930	0.20	10.2	NS
N levels (kg/ha)					
60	69699	40089	2.35	114.2	92.6
100	82924	53077	2.78	91.9	88.0
140	86087	56003	2.86	67.7	87.3
SEm ±	1358	1358	0.05	2.3	0.9
LSD (P= 0.05)	3882	3882	0.13	6.7	2.6
Interaction	NS	NS	NS	NS	NS

CONCLUSION

Genotype FSM-2021-1 in combination with 100 kg N ha^{-1} demonstrated the highest potential for achieving both high yield and profitability, making it an ideal choice for forage maize cultivation in Bihar.

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