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Integrating Nitrogen Levels and Green Manuring for Sustainable Basmati Rice Production

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ABSTRACT

Background: Nitrogen is a vital macronutrient critical for plant tissues and development, making a substantial contribution to the synthesis of proteins, chlorophyll and other essential cellular components. Green manuring, combined with varying nitrogen levels, provides an integrated approach to enhancing soil health and enhancing nutrient cycling. This study evaluates the influence of green manuring and various amounts of nitrogen were studied on the basmati rice for crop production, concerning on growth, grain yield.

Methods: The field experiment was conducted during the *kharif* season 2023 at LPU, Punjab. A split-plot experimental design was used, with three replications for each treatment. The experimental treatments include four main plots: M_0: Control (no green manuring), M_1: *Sesbania aculeata*, M_2: *Crotalaria juncea*, M_3: *Vigna unguiculata* and four sub plots: N_1: 0 kg ha^{-1}, N_2: 15 kg ha^{-1}, N_3: 30 kg ha^{-1}, N_4: 45 kg ha^{-1}.

Result: A significantly greater plant height (cm), number of tillers m^{-2}, dry matter accumulation (q ha^{-1}), number of effective tillers $plant^{-1}$, number of grains $panicle^{-1}$, length of panicle (cm) and grain yield (q ha^{-1}) was recorded (39.7 q ha^{-1}) under the execution of *S. aculeata* and with the 100% recommended dose of nitrogen (45 kg ha^{-1}). The findings suggest that incorporating green manuring accompanied by optimal nitrogen levels enhances soil fertility, stimulating plant growth, increases basmati rice yield. These practices are fundamental for sustainable crop production and should be integrated into holistic nutrient management to ensure long-term agricultural productivity.

Key words: Grain yield, Green manure, Nitrogen management, Pusa basmati 1121.

INTRODUCTION

Rice (*Oryza sativa* L.) is the primary crop for food in Southern and Southeastern regions, feeding approximately fifty percent of the global population. It is a key dietary staple for more than 66% of people in India, holding crucial to ensuring food security playing a critical role in the national economy. Basmati rice, dubbed as the “Queen of Rice”. During the 2022-23 fiscal year, India produced a total of 135.7 million tons of rice, with a substantial portion coming from basmati rice (DGCIS, 2023). Efficient nitrogen management is pivotal in basmati rice cultivation, as excessive nitrogen application increases the incidence of pests, diseases and lodging, ultimately compromising grain quality and market value (Luong and Heong, 2005; Kowsalya *et al.,* 2022). Integrating chemical fertilizers with organic inputs, particularly green manure, is widely recognized as an effective approach for enhancing nutrient use efficiency, improving soil fertility, reducing production costs and sustaining crop productivity. Green manuring, the incorporation of fresh plant biomass into the soil, contributes significantly to soil structure and fertility. However, rice growing regions often face high temperatures and fluctuating moisture, which accelerate organic matter decomposition and deplete soil organic carbon (Mohammad *et al.,* 2005).

Green manure species include both leguminous and non-leguminous plants. Legumes, through symbiosis with Rhizobium bacteria, fix atmospheric nitrogen, offering a natural and sustainable source of nitrogen to rice ecosystems. Consequently, leguminous green manures contribute more substantially to soil nitrogen pools than non-leguminous species (Zhang *et al.,* 2023). These crops have gained considerable attention for their role in improving soil microbial activity, enhancing nutrient cycling and supporting long-term agricultural sustainability (Meena *et al.,* 2018).

Empirical evidence supports these benefits. Selvi and Kalpana (2009) reported that green manures can replace 30-100 kg N/ha while improving soil physical and biological properties. Garg *et al.* (2007) demonstrated that Sesbania green manuring improved Basmati rice yield by 7.5% and significantly reduced synthetic nitrogen and phosphorus input requirements. Premi (2003) found that integrating

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green manure with reduced nitrogen application maintained yield levels. In rainfed systems, combining farmyard manure with inorganic nitrogen substantially enhanced productivity (Sarangthem *et al.,* 2008). Furthermore, in-situ incorporation of green manure improves soil physical and chemical characteristics, increases grain yield and reduces greenhouse gas emissions by lowering urea dependency. Hence, the approach of integrated soil fertility managing along with improving production, quality and fertility status of soil (Zhang *et al.,* 2023).

In spite of the fact that several studies have investigated the individual impacts of nitrogen application and green manuring on crop performance, particularly for major crops like wheat and rice, there is an evident literature gap regarding their collective effects on basmati rice. This research endeavors to address this gap, exploring integrated nutrient management (INM) practices in enhancing growth, yield in basmati rice, which is critical for sustainable agricultural practices. While individual agronomic practices such as nitrogen applications and green manuring have demonstrated substantial benefits in enhancing crop yield and soil health, the synergistic effects of combining these strategies, particularly for Basmati rice. The current study focuses on evaluating the impact of different nitrogen levels along with green manuring on the development, grain production of Basmati rice, accompanied by the objective of establishing sustainable nutrient management approaches to optimize rice yield.

MATERIALS AND METHODS

The field experiment was conducted during the *kharif* season of 2023 at the Agricultural Research Farm of Lovely Professional University, Phagwara, Punjab, India, which was situated at 31°13′N and 75°46′E. The study was performed using the basmati rice cultivar Pusa Basmati 1121, to evaluate the feasibility of various doses of nitrogen in combination with different green manuring crops under Punjab conditions. A split-plot experimental design was used, with three replications for each treatment. The experimental treatments include four main plots: M_0: Control (no green manuring), M_1: *Sesbania aculeata*, M_2: *Crotalaria juncea*, M_3: *Vigna. unguiculata* and four sub plots: N_1: 0 kg ha^{-1}, N_2: 15 kg ha^{-1}, N_3: 30 kg ha^{-1}, N_4: 45 kg ha^{-1}. where Forty-five-day-old green manuring crops were incorporated into the soil with a disc plough before transplanting basmati rice seedlings. Sowing was carried out during June, with seed rate of 20 kg/ha. Seedlings, upon reaching the 5 to 6 leaf stage, were transplanted from the nursery to the field in the first fortnight of July. Urea (46% N), di-ammonium phosphate (DAP) (18% N and 46% P_2O_5) and muriate of potash (MOP) (60% K_2O) were used as the source of nitrogen, phosphorus and potassium. Nitrogen was applied in three equal portions, as a basal dose, at the CRI stage and at the active tillering stage, following irrigation. In contrast, the complete doses of phosphorous and potassium were applied at sowing. The soil of the experimental site was sandy loam in nature with good tilth having good drainage with an initial average of 296 kg ha^{-1} of available nitrogen (N) (Alkaline permanganate method), 28.11 kg ha^{-1} available phosphorus (P) (Olsen's method), 248.1 kg ha^{-1} available potassium (K) (Flame photometer method), respectively. The weekly average maximum and minimum temperature ranged 23.5-38°C and 6.45-29°C during the crop season. However, the total rainfall received during the crop season was 434.8 mm.

Statistical analysis

The collected data were evaluated using ANOVA (analysis of variance) in a split-plot design, as described by Gomez and Gomez (1984), to investigate the outcomes of various treatments and their interaction on growth, yield and graphical representations using R software.

RESULTS AND DISCUSSION

Plant height (cm)

Based on the statistically analyzed results, integration of green manuring and nitrogen levels was found to be significant (Table 1). The highest plant height (110 cm) was recorded when *S. aculeata* (M_1) was incorporated into the soil, followed by *C. juncea* and *V. unguiculata*, the lowest plant height (102.5 cm), was observed in control treatments. Among the different nitrogen doses applied, the plant height increased to (110.5 cm) with 45 kg N ha^{-1} (N_4), whereas the lowest height of (104.5 cm) was evident in the experimental plots with no nitrogen application (N1). A notable increase in plant height was observed with the combined application of *S. aculeata* with 45 kg N ha^{-1} (M_1N_4), as depicted in Fig 1(a). These results highlighted the potential of integrating *S. aculeata* with optimized nitrogen application to improve plant height. Moreover, the increased chlorophyll concentration at all growth stages likely enhanced photosynthesis, contributing to greater plant height (Rusdiansyah and Saleh, 2017). Similarly, Kamboj *et al*., (2024) observed that the combined application of green manuring and a 10% increase in the recommended nitrogen dose resulted in the highest plant height compared to no green manuring. Likewise, Nawaz *et al*., (2017) noted that incorporating green manuring enhanced nutrient uptake, which likely promote the growth in plant height. the benefits related to integrated nutrient management practices in promoting plant height. In a related context, Deshpande and Devasenapathy (2011) supported that combined application of Sesbania and nitrogen fertilizer influenced the growth characteristics of rice.

Tillers m^{-2}

The scrutiny of the data exhibited that the count of tillers per square meter was profoundly influenced by both green manuring and nitrogen levels (Table 1). The highest count (370.8) was recorded with the incorporation of *S. aculeata* (M_1), followed by *C. juncea* (M_3) and *V. unguiculata* (M_2),

while the lowest count (314.2) was observed in the no green manuring treatment (M_0). These results suggest that S. *aculeata* effectively enhances tiller production, aligning with findings by Mandi and Shivay (2021), who reported that green manuring with S. aculeata resulted in the highest yield attributes, including 47 more effective tillers per m^2. Regarding nitrogen applications, the highest number of tillers (372.2) was detected in 45 kg N ha^{-1} (N_4) succeeded by 30 kg N ha^{-1} (N_3), meanwhile the lowest (327.3) was observed when nitrogen was not applied (N_1). As shown in Fig 1(b) illustrates a significant increment in the tillers count per meter square was noted alongside the combined incorporation of S. aculeata and 45 kg N ha^{-1} (M_1N_4) relative to control treatments. Similarly, findings were recorded by Shah *et al*. (2017), who stated that the incorporation of Sesbania and the application of appropriate fertilizers were crucial factors in increasing tiller. Kamboj *et al*., (2024) found that the greatest number of tillers per plant was achieved with green manuring and 10% higher than recommended nitrogen dose. Moreover Kumar *et al*. (2018) reported a positive correlation between green manure and nitrogen levels in enhancing the number of tillers for each square meter, while Sarkar *et al*. (2004) accentuated the necessity of these practices in optimizing rice growth and yield.

Dry matter accumulation (q ha^{-1})

The results of analysis on dry matter accumulation (Table 1) demonstrated a significant impact of green manuring, rated of nitrogen and their interaction Fig 1(c). The highest dry matter (197.7 q ha^{-1}) was observed with the incorporation of *S. aculeata* (M_1), which was on par with *C. juncea* (M_3) and *V. unguiculata* (M_2). The lowest dry matter (121.7 q ha^{-1}) was noted when no green manuring was applied (M_0). These findings are aligned in comparison to Mandi and Shivay (2021), who stated increased dry matter accumulation and enhanced soil fertility with the use of green manure species like *S. aculeata*. Regarding nitrogen application, the maximum dry weight accumulation (212.8 q ha^{-1}) was revealed with 45 kg N ha^{-1} (N_4). The lowest dry matter (139.6 q ha^{-1}) was recorded without the application of nitrogen (N_1). A considerable increase in dry matter accumulation through the co-application of *S. aculeata* and 45 kg N ha^{-1} (M_1N_4), as highlighted in Fig 1(c) exhibiting a statistically substantial compared to the control treatments. This evidence is consistent as observed in the research of Ma *et al*. (2023), demonstrated that optimal nitrogen application significantly enhances dry matter accumulation. Furthermore, as evidenced by Islam *et al*. (2019), the absence of green manuring led to significantly reduced growth and dry matter accumulation. Additionally, a study by Li *et al*. (2020) corroborates these findings, indicating that green manuring increased dry weight content in rice. Correspondingly, Zhang *et al*. (2023) found that the combination of green manure along with nitrogen fertilizers contributed to marked improvement in rice yield. Aligned with the previous findings, Efthimiadou *et al*. (2010) reported that combining green manuring with nitrogen markedly improved dry matter accumulation *via* enhanced photosynthesis.

Effective tillers $plant^{-1}$

The count of effective tillers showed significant variation due to the different green manure sources, nitrogen doses and their interaction (Table 2), Fig 2(a). The lowest number of effective tillers per plant (14.5) was recorded when no green manuring (M_0) was utilized. In contrast, the maximum count of effective tillers (17.3) was observed with *S. aculeata* (M_1), which was statistically similar to *C. juncea* (M_3) and *V. unguiculata* (M_2). Within the nitrogen application, the maximum effective tiller count of (17.87) was achieved with the application of 45 kg N ha^{-1} (N_4), which was considerably

Table 1: Influence of green manuring with different levels of nitrogen on growth attributes of basmati rice 1121.

Treatment	Plant height (cm)	Tillers m^{-2}	Dry matter accumulation (q h^{a-1})
		Green manures (GM's)	
No green manure (M_0)	102.5^b	314.2^b	121.7^b
S. aculeata (M_1)	110.0^a	370.8^a	197.7^a
V. unguiculata (M_2)	108.6^a	358.8^a	180.0^a
C. juncea (M_3)	109.4^a	366.3^a	187.8^a
LSD ($p \leq 0.05$)	1.6	34.9	19.3
		Nitrogen level (kg ha^{-1})	
0 kg N ha^{-1} (N_1)	104.5^d	327.3^c	139.6^d
15 kg N ha^{-1} (N_2)	107.1^c	348.1^{bc}	156.5^c
30 kg N ha^{-1} (N_2)	108.4^b	362.4^{ab}	178.3^b
45 kg N ha^{-1} (N_4)	110.5^a	372.2^a	212.8^a
LSD ($p \leq 0.05$)	0.9	21.7	9.9
Interaction (GM's × Nitrogen levels) LSD ($p \leq 0.05$)	1.9	43.3	19.8

*Distinct letters show significant at ($p \leq 0.05$) on the basis of the comparison of means using the LSD.

greater than the other nitrogen doses, whereas the treatment with no application nitrogen (N_1) 0 kg/ha recorded the least, with (15.08). The interaction due to both the aspects showed a significant increment in the count of productive tillers per plant was observed in M_2N_4, as indicated in Fig 2(a). For instance, a study by Irin *et al*. (2020) investigated those interactive effects of green manuring and nitrogen levels on effective tillers. Similarly, Singh *et al*. (2025) found that the number of effective tillers per plant was significantly influenced by green manure

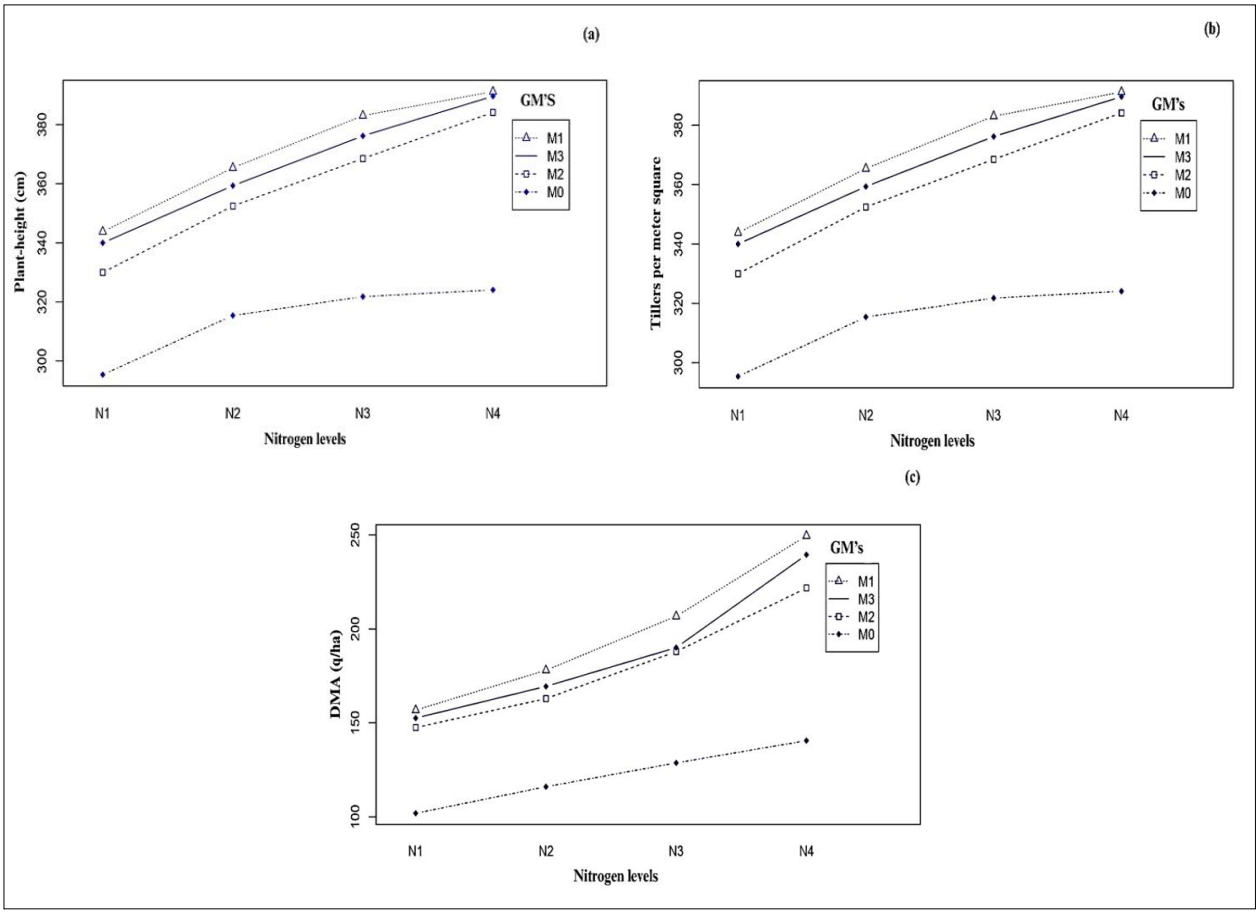


Fig 1: Interaction effect of between sources of green manuring (GM's) and nitrogen levels on plant height (a), tillers m^{-2} (b), dry matter accumulation (DMA)(q/h) (c) of basmati rice.

Table 2: Influence of green manuring with different levels of nitrogen on growth attributes of basmati rice 1121.

Treatment	Effective tillers m^{-2}	Number of grains $panicle^{-1}$	Grain yield (q ha^{-1})
		Green manures (GM's)	
No green manure (M_0)	14.5^b	94.9^d	31^b
S. aculeata (M_1)	17.3^a	105.1^a	38.1^a
V. unguiculata (M_2)	16.4^a	103.2^c	35.9^a
C. juncea (M_3)	16.4^a	104.4^b	37.2^a
LSD ($p \leq 0.05$)	1.7	10.8	4.7
		Nitrogen level (kg ha^{-1})	
0 kg N ha^{-1} (N_1)	15^b	97.8^d	32.4^b
15 kg N ha^{-1} (N_2)	15.6^b	100.4^c	34.3^b
30 kg N ha^{-1} (N_2)	16^a	103^b	35.8^b
45 kg N ha^{-1} (N_4)	17.8^a	106.3^a	39.7^a
LSD ($p \leq 0.05$)	1.4	9.7	4
Interaction (GM's × Nitrogen levels) LSD ($p \leq 0.05$)	2.53	2.06	8.79

*Distinct letters show significant at ($p \leq 0.05$) on the basis of the comparison of means using the LSD.

and nitrogen addition. Furthermore, Chen *et al*. (2017) discovered that the application of leguminous green manures significantly increased the number of effective tillers by nitrogen fixation. Moreover, as reported by Ramesh and Rathika (2017) reported that the application of *S. aculeata* with nitrogen fertilizers, with a substantial improvement in the count of tillers per plant.

Number of grains panicle^{-1}

Based on the statistically analyzed data the grain count per panicle was strongly influenced by green manuring sources, nitrogen doses and their interaction (Table 2), Fig 2(b). The incorporation of S. aculeata (M_1) resulted in the maximum count of grains per panicle (105.1), whereas the minimum count (94.9) was observed when no green manure was applied. The highest number of grains per panicle (106.3) among all nitrogen doses was recorded with 45 kg N ha^{-1} (N_4), whereas the minimum grains (97.8) were recorded at 0 kg N/ha. The effect of green manure and nitrogen dose interaction significantly impacted the number of grains per panicle, with the highest count achieved when M1 was combined with N_4, as represented in Fig 2(b). Metwally *et al*. (2010) reported that plants receiving nitrogen had more spikelet's per panicle compared to those without nitrogen. This suggests that with a greater sink capacity and limited source, the filling of grains was enhanced. The additional nitrogen from green manuring may have contributed to the increase in grains per panicle. Zheng *et al*. (2023) investigated that combining green manuring with nitrogen application significantly improved the grain count per panicle. An analysis undertaken by Singh *et al*. (2025) highlighted how the combination of reduced nitrogen application and green manure increased the rice grain number per panicle. Notable discussed by Ramesh and Rathika (2017) exploration revealed that nitrogen management along with green manuring resulted in a significant increment of 60% in total grains per panicle in rice.

Grain yield (q ha^{-1})

Grain production varied significantly influenced by the incorporation of green manuring crops, various nitrogen doses and their interaction (Table 2), Fig 2(c). The most substantial grain yield (38.1 q ha^{-1}) was observed from the incorporation of *S. aculeata* (M_1) as a green manuring crop, while statistically at par with *C. juncea* (M_3) and *V. unguiculata* (M_2). The least amount of grain yield (31 q ha^{-1}) was achieved in no green manuring treatments. The data clearly

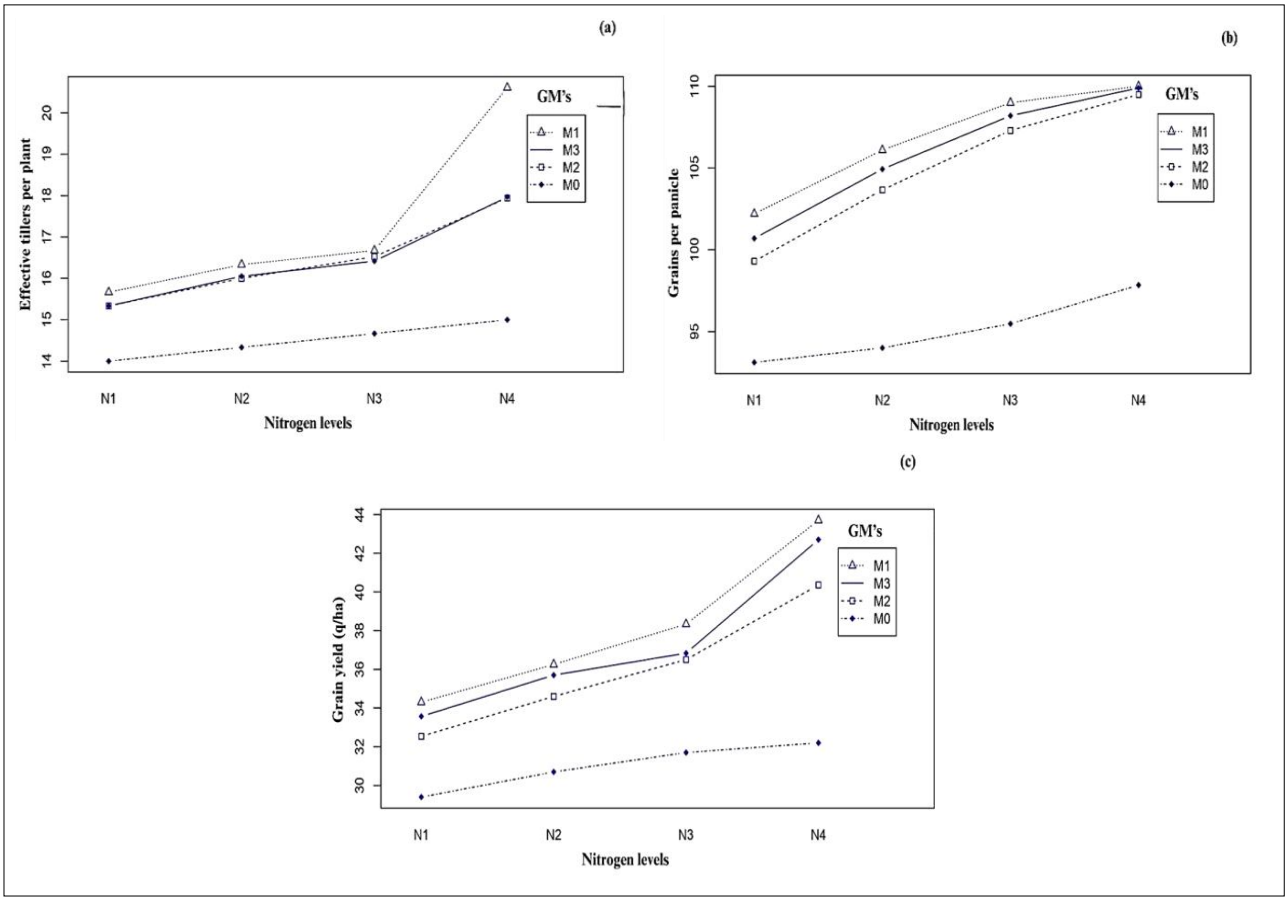


Fig 2: Interaction effect of between sources of green manuring (GM's) and nitrogen levels on effective tillers per plant (a), number of grains per panicle (b), grain yield (q ha^{-1}) (c) of basmati rice.

illustrates that the application of 45 kg N ha^{-1} (N_4) recorded highest yield (39.7 q ha^{-1}), while the lowest yield of (32.4 q/ha) occurred without N application (N_1) treatment. The interaction between the green manuring and various nitrogen doses (M_1N_4) markedly resulted in a statistically significant enhancement in grain yield, as demonstrated in Fig 2(c). The higher yield observed with green manuring combined with a higher nitrogen dose might be credited to the continuous nutrient furnish throughout the crop growth period, as suggested by Gill and Aulakh (2018). The combination of green manures like S. aculeata and *C. juncea* with optimal nitrogen levels significantly enhanced the grain yield. Moreover, Singh *et al*. (2025) observed that nitrogen combined with *S. aculeata* green manure generated significantly greater grain yield in comparison with untreated control fields. Consistent with this, Yue *et al*. (2022) reported that the application of green manures improved grain yield by enhancing soil health and rice plant vigor. A research project carried out by Qaswar *et al*. (2019) revealed this combination of green manure with various nitrogen levels, significantly improved yield with optimized nutrient management. In a comprehensive analysis, Gao *et al*. (2020) highlighted integrated nutrient management significantly improved rice production.

CONCLUSION

The findings of the present study demonstrate the significant impact of different green manuring sources, along with various nitrogen doses on the growth, yield and yield contributing factors of basmati rice. The combined application of *S. aculeata* and 45 kg N ha^{-1} observed the maximum growth and yield attributes compared to other green manuring crops such as *V. unguiculata* and *C. juncea* with 0, 15, 30 and 45 kg N ha^{-1}. Based on these findings, it can be concluded that the incorporation of summer *Sesbania* green manuring is beneficial for enhancing basmati rice yield. Additionally, the application of 45 kg N ha^{-1} is advised for improving growth, yield attributes and overall productivity of basmati rice.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect loss resulting from the use of this content.

Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the University of Animal Care Committee.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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