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Synergistic Effects of Green Manuring and Nitrogen Fertilization on Soil Fertility and Grain Quality of Basmati Rice

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ABSTRACT

Background: The integration of green manuring and nitrogen fertilization is a sustainable approach to enhance soil fertility and improve crop quality. Specifically, in crops like Basmati rice, these practices are known to influence critical parameters such as protein content and the availability of essential nutrients like nitrogen, phosphorus and potassium. This study aims to evaluate the effects of various green manuring crops and nitrogen application levels on both soil nutrient status and grain quality of Basmati rice.

Methods: The experiment was conducted during the 2023 *kharif* season at the Agricultural Research Farm of Lovely Professional University, Phagwara, Punjab, using a split-plot design. Four main plots were used: M_0 (Control, no green manuring), M_1 (*Sesbania aculeata*), M_2 (*Crotalaria juncea*) and M_3 (*Vigna unguiculata*), along with four nitrogen levels as sub-plots: N_1 (0 kg ha^{-1}), N_2 (15 kg ha^{-1}), N_3 (30 kg ha^{-1}) and N_4 (45 kg ha^{-1}). Key parameters such as nitrogen, phosphorus and potassium availability in the soil, alongside protein, nitrogen content in the rice grains, were assessed to figure out the impact of these treatments.

Result: The application of green manures, particularly in *Sesbania aculeata* (M_1), resulted in significant improvements in both the protein content of Basmati rice grains and the availability of essential nutrients in the soil. The treatments involving *Vigna unguiculata* (M_3) and *Crotalaria juncea* (M_2) also had positive effects, through to a lesser degree. Among the nitrogen levels, the highest protein content and nutrient availability were observed at 45 kg ha^{-1} nitrogen application followed by 30 kg ha^{-1} (N_3), 15 kg ha^{-1} (N_2), whereas the control treatment with 0 kg ha^{-1} (N_1), with no nutrient input, exhibited the lowest values. These findings underline the critical role of integrating green manuring and nitrogen fertilization to enhance both soil fertility and basmati rice quality.

Key words: Basmati rice quality, Green manuring, Nitrogen fertilization soil nutrient status, Sustainability.

INTRODUCTION

Rice, known scientifically as *Oryza sativa* L. is cultivated in over 95 countries around the world and is a key food staple for more than half of the global population, contributing approximately 35-80% of daily caloric intake. Among major cereals, rice is distinguished by its high digestible energy and protein efficiency, as noted by Xie *et al.* (2022). In India, the state of Punjab plays a significant role in rice production. During the 2022-23 season, this state cultivated over approximately 3.10 million hectares, producing around 12.99 million tonnes of rice, with an average yield of about 4.19 tonnes per hectare (Ministry of Agriculture and Farmers Welfare, 2023). However, rice is a nitrogen intensive crop and its production heavily relies on nitrogen fertilization to maintain high yields. Despite these impressive figures, rice cultivation in Punjab is facing numerous challenges. Rising fertilizer costs, partially driven by global disruptions such as the Russia-Ukraine conflict, have prompted farmers to reconsider traditional input heavy practices. Additionally, water scarcity and erratic weather patterns threaten the sustainability of rice farming in the region. As a result, there is growing interest in adopting resources efficient and environmentally sustainable practices, including organic amendments and green manuring. Optimizing nitrogen use efficiency has therefore become critical to reduce production costs while minimizing environmental impact. Organic practices, particularly green manuring have shown significant promise in improving soil structure, water holding capacity, microbial activity and nutrient cycling. Green manuring involves the incorporation of fast-growing leguminous crops into the soil to enrich it with organic matter and biologically available nitrogen. Vaiyapuri *et al.* (2025) observed that these practices are well established for their role in enhancing soil fertility and promoting ecological farming systems. Green manure crops serve as a protective cover, reducing soil erosion, supressing weed growth and limiting the incidence of soil borne pests and diseases, thereby contributing to improved crop performance Kumar *et al.* (2025). By increasing nutrient availability and stimulating microbial dynamics, they reduce dependence on chemical fertilizers and pesticides and support long term soil was stated by Minh *et al.* (2023). In

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addition, studies have shown that combining green manuring with nitrogen fertilizer application maintains high yields while enhancing quality in basmati rice was reported by Baral *et al.* (2023). Additionally, split nitrogen applications with green manures improve nitrogen use efficiency by aligning supply with crop demand and reducing losses through volatilization and leaching by Bana *et al.* (2022). Punjab was a major beneficiary of the green revolution, marked by the widespread adoption of high yielding crop varieties, irrigation infrastructure and agrochemical inputs. While this led to substantial gains in food production, it also contributed to the degradation of soil health, water pollution and ecological imbalances. Smallholder farmers have increasingly struggled with input costs and sustainability, highlighting the need for more balanced approaches. In the context, green manuring offers a vile alternative by increasing organic matter content enhancing nitrogen availability and improving soil moisture retention there by laying the foundation for resilient and sustainable farming systems Saini *et al.* (2019). For instance, Wang *et al.* (2022) reported that green manuring significantly enhanced soil microbial activity, enzymatic function and chlorophyll content, ultimately improving grain yield. Ahmed *et al.* (2020) observed improvements in soil texture, while Gao *et al.* (2018) noted increased levels of dissolved organic matter and reduced methane emissions. According to Nolla *et al.* (2019) maintaining soil cover through green manures or mulch is effective in conserving soil quality and ensuring crop continuity. Leguminous green manures particularly contribute atmospheric nitrogen to the soil through biological nitrogen fixation, improving nutrient availability and supporting crop growth was highlighted by Meirelles *et al.* (2022). Furthermore, the integrated use of green manure and chemical fertilizers has been shown to enhance each other's effectiveness, leading to better rice crop performance while also improving the soil chemical properties was reported by Selvi and Kalpana (2025).

Despite global recognition of the benefits of green manuring, there remains a significant gap in the adoption of these practices among rice farmers in Punjab. Disseminating knowledge and demonstrating the practical benefits of green manures can enhance both productivity and sustainability. This approach can lower production expenses, reduce reliance on nitrogen fertilizers and shorten cultivation time without compromising yields. By integrating green manures, crop profitability rises and agribusiness benefits from the cost-effective utilization of organic resources. This study proposes that employing diverse green manuring crops alongside varying nitrogen applications could enhance soil chemical characteristics and quality attributes, thereby improving the growth, yield and quality of basmati rice. The main objective of this study is to evaluate the effects of various green manures and different nitrogen application rates on soil fertility and the quality of basmati rice in the Punjab region, with the intent to provide fresh insights into optimizing agricultural practices.

MATERIALS AND METHODS

Experimental details

The field experiment was conducted in 2023 during *kharif* season (June-November) at the Agricultural Research Farm of Lovely Professional University, Phagwara, Punjab, India. The experimental field used to evaluate the effect of green manuring and different levels of nitrogen for basmati rice crop was located at a latitude of 31°24′N and longitude of 75°69′W and an altitude of 234 m above mean sea level. The soil of the experimental site was sandy loam in nature with good tilth having good drainage with an initial average of 200 kg ha^{-1} of available nitrogen (N) (Alkaline permanganate method), 20.93 kg ha^{-1} of available phosphorus (P) (Olsen's method), 239.3 kg ha^{-1} of available potassium (K) (Flame photometer method) and grain protein content (%) (kjeldahl method), with nitrogen content multiplied by a factor of 5.75, respectively. A split-plot design with three replications was employed for the experiment. The experimental treatments include four main plot treatments comprised four green manuring crops: M_0: Control (no green manuring), M_1: *Sesbania aculeata*, M_2: *Crotalaria juncea*, M_3: *Vigna unguiculata*, along with four sub plots treatments included four nitrogen levels: N_1: 0 kg ha^{-1}, N_2: 15 kg ha^{-1}, N_3: 30 kg ha^{-1}, N_4: 45 kg ha^{-1}. Green manuring crops were sown manually in early June at a seed rate of 20 kg/ha. The biomass was then incorporated after 45 days into the soil using rotavator before transplanting rice seedlings. The rice variety *Pusa Basmati 1121* was sourced from Punjab Agricultural University and sown manually using 25 days old seedlings. Fertilizers used in the study included di-ammonium phosphate (DAP) (18% N and 46% P_2O_5) and muriate of potash (MOP) (60% K_2O) was applied as RDF. Nitrogen was applied as per treatment, using urea (46% N), in three equal splits at basal, tillering and basal, tillering and panicle initiation stages. Manual weeding was performed at 20 and 40 days after transplanting. All climatic and weather data during the growing period were obtained from a meteorological station close to the study area. The experimental region is characterized by a subtropical climate, featuring hot, humid summers and dry, cool winters. The weekly average maximum and minimum temperature ranges from (23.5°C) to (38°C) and (6.45°C) to (29°C) in 2023.

Statistical analysis

The data was analyzed using a split-plot method established by Gomez and Gomez (1984) to assess the impact of different treatments and their interaction on soil physio-chemical characteristics and quality parameters, utilizing R software.

RESULTS AND DISCUSSION

Available N (kg ha^{-1})

Statistical evaluation revealed that the available nitrogen status in the soil was notably influenced by both green

manuring and varying nitrogen levels, the soil was initially found to contain 200 kg ha^{-1} of available nitrogen, as summarized in Table 1. Among the green manure treatments evaluated, *S. aculeata* (M_1) proved to be the most effective in increasing nitrogen availability, reaching 271.5 kg ha^{-1} at harvest, while the control treatment (M_0), with no nutrient input, recorded the lowest nitrogen availability at 219.7 kg ha^{-1}. From the set of nitrogen levels applied, the 45 N kg ha^{-1} (N_4), treatment resulted in a nitrogen availability of 275.5 kg ha^{-1}, showing an improvement over the control treatment (N_1), which received no nutrient input and recorded the lowest value of 231.6 kg ha^{-1}. A notable improvement in available N was recorded with the simultaneous application of *S. aculeata* with 45 kg N ha^{-1} (M_1N_4). The decomposition of organic residuals following crop harvest may contribute to an increase in soil total nitrogen levels Abera *et al.* (2012).

The present findings align with those of Gautam *et al.* (2021), who reported a 0.87% increment in soil nitrogen content following the incorporation of green manure prior to the rice crop. This enhancement in nitrogen levels is particularly notable in the legume based cropping system, where biological nitrogen fixation and residue decomposition contribute to soil fertility. The improvement in soil nitrogen can be attributed to nitrogen inputs from legume roots, stubbles and leaves, as well as improved nitrogen recycling through organic residues. Especially, the *S. aculeata* treatment showed a significant increase in soil nitrogen content, likely due to rapid decomposition of its residues and abundant nodulation, which enhances nitrogen fixation. Furthermore, green manure has been shown to inhibit nitrogen loss from urea fertilizers by stabilizing soil pH and restoring nitrogen fertilizer equilibrium

Table 1: Impact of green manuring with various levels of nitrogen on post harvest soil nutrient status and protein content of basmati rice 1121.

Treatments		Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Organic carbon (%)	Protein content (%)
			Main plot (Green manuring crop)			
No green manure (M_0)		219.75	23.3	254.38	0.55	5.84
S. *aculeata* (M_1)		271.54	26.8	266.54	0.69	8.27
C. *juncea* (M_2)		260.95	25.9	263.84	0.66	7.73
V. unguiculata (M_3)		266.24	26.2	265.19	0.68	8.01
LSD (p≤0.05)		3	6.38	8.52	2.68	0.75
			Sub plot (Levels of Nitrogen) (Kg ha^{-1})			
0 kg N ha^{-1} (N_1)		231.66	24.2	257.42	0.58	6.45
15 kg N ha^{-1} (N_2)		249.03	25.3	260.8	0.61	7.14
30 kg N ha^{-1} (N_3)		262.27	26	264.18	0.67	7.78
45 kg N ha^{-1} (N_4)		275.51	26.6	267.56	0.72	8.47
LSD (p≤0.05)		10.45	4.95	12.86	1.84	0.42
Green manuring crops	**Levels of nitrogen (kg ha^{-1})**		**Interaction (GM's × Nitrogen levels)**			
No green manure	0 (M_0N_1)	199.43	22.9	252.36	0.53	5.42
	15 (M_0N_2)	221.23	23	253.71	0.55	5.71
	30 (M_0N_3)	226.52	23.4	255.06	0.57	5.98
	45 (M_0N_4)	231.82	23.8	256.41	0.58	6.25
S. *aculeata*	0 (M_1N_1)	247.71	25.6	260.46	0.61	7.06
	15 (M_1N_2)	263.6	26.4	264.52	0.65	7.93
	30 (M_1N_3)	279.49	27.1	268.58	0.73	8.6
	45 (M_1N_4)	295.38	28.1	272.63	0.79	9.49
C. *juncea*	0 (M_2N_1)	237.12	24	257.76	0.59	6.54
	15 (M_2N_2)	253.01	25.7	261.82	0.62	7.34
	30 (M_2N_3)	268.9	26.7	265.87	0.69	8.13
	45 (M_2N_4)	284.79	27.1	269.93	0.75	8.94
V. unguiculata	0 (M_3N_1)	242.41	24.1	259.11	0.6	6.8
	15 (M_3N_2)	258.31	26.3	263.17	0.64	7.6
	30 (M_3N_3)	274.19	27	267.22	0.71	8.43
	45 (M_3N_4)	290.08	27.3	271.28	0.77	9.23
LSD (p≤0.05)		20.9	9.9	25.72	3.68	0.85
Initial status of soil (kg ha^{-1})		200	20.9	239.3	0.5	-

*Distinct letters show significant at (p≤0.05) based on the comparison of means using the LSD.

in the soil, as documented by Regmi *et al.* (2004). This practice of incorporating green manuring crops not only results in increased total available nitrogen content but also improves the quantity and quality of soil organic carbon was reported by Xie *et al.* (2017). The integration of green manure with a reduced chemical fertilizer rate noticeably enhanced the total nitrogen content in the soil compared to plots treated with the recommended dose of chemical fertilizers, according to the findings of Yang *et al.* (2018). One potential explanation for this phenomenon is that the incorporation of green manure provides as a substantial source of nitrogen, thereby enhancing the total nitrogen content within the soil. This effect may be attributed to the improved nitrogen associated with the green manure, in contrast to plots treated exclusively with chemical fertilizers, the findings were observed by (Adekiya *et al.,* 2019).

Available P (kg ha^{-1})

Analysis showed that the available phosphorus in the soil was significantly influenced by the combined influence of green manuring and nitrogen variations, with the result being statistically validated and displayed (Table 1). In terms of green manure treatments, *S. aculeata* (M_1) yielded the highest phosphorus availability, with a measure of 26.8 kg ha^{-1}, while the control treatment (M_0), lacking nutrient input, exhibited the lowest phosphorus availability at 23.3 kg ha^{-1}. Regarding phosphorus levels, the 45 N kg ha^{-1} (N_4), treatment resulted in the highest phosphorus availability, recording 26.6 kg ha^{-1}, whereas the control (N_1), with 24.2 kg ha^{-1}, displayed the lowest availability. A substantial rise in available P was observed with the simultaneous application of *S. aculeata* and 45 kg of nitrogen per hectare (M_1N_4).

The enhanced phosphorous availability observed in the soil can be attributed to the secretion of organic acids and the mineralization of organophosphate compounds during the decomposition of green manure residues. These processes convert organic phosphorous into plant available inorganic forms. Rapid decomposition of biomass releases organic acids that not only aid in phosphorous solubilization but also contribute directly to crop nutrient uptake and yield improvement.

Green manure contains nutrients, including phosphorus, which are released into the soil during the decomposition process, potentially contributing to increased phosphorus availability in soil. Gautam *et al.* (2021) explained that there was an increase in soil available phosphorus by 37.39% in *S. aculeata* treated plots with recommended dose of chemical fertilizers as compared to the traditional rice wheat cropping system. Similarly, Adekiya *et al.* (2019) noticed a 37.39% increase in soil available phosphorous in plots that incorporated green manuring compared to those that received only chemical fertilizer. The initial available phosphorus concentration in the soil before crop was 20.93 kg ha^{-1} which was exhibited in Table 1.

Available K (kg ha^{-1})

Prior to crop planting, the soil had an available potassium level of 150 kg ha^{-1}. Available potassium status in the soil was significantly influenced by the interaction between green manuring and different levels of nitrogen found to be significant (Table 1). When assessing the green manure treatments, *S. aculeata* (M1) resulted in the highest potassium availability, reaching 266.5 kg ha^{-1}, while the control treatment (M_0), showed the lowest potassium availability at 254.3 kg ha^{-1}. In terms of nitrogen levels, the 45 N kg ha^{-1} (N_4), treatment provided the highest potassium availability at 267.5 kg ha^{-1}, compared to the control (N_1), which exhibited the lowest level at 257.4 kg ha^{-1}. The interaction of both factors resulted in a significant enhancement in the availability of potassium (K) was detected in (M_2N_4).

Green manuring contributes not only to the accumulation of organic matter in the soil but also enhances the availability of essential minerals such as potassium, which are vital for plant growth. During the decomposition process, green manure facilitates potassium release through nutrient recycling, as noted by Singh *et al.* (2007). When combined with chemical fertilizers, green manure further increases the availability of potassium in the soil was reported by Kumar and Prasad (2008). A study conducted by Gautam *et al.* (2021) reported that there were 45.78% increases in the soil available potassium in *S. aculeata* treated plots with recommended dose of fertilizers as compared to plots treated solely with chemical fertilizers. Similar findings were documented by Adekiya *et al.* (2019), reinforcing the role of green manuring in improving soil potassium levels and supporting sustainable crop production.

Organic carbon (%)

The data revealed that there was significant difference in the soil total organic carbon% with the application of different types of green manuring and different levels of nitrogen (Table 1). The initial organic carbon content in the soil, measured before crop planting, was 0.5%. In the evaluation of green manure treatments, *S. aculeata* (M_1) was the most effective in boosting organic carbon content, reaching 0.6%, while the control treatment (M_0), which lacked nutrient input, recorded the lowest organic carbon percentage at 0.5%. With regard to nitrogen application levels, 45 N kg ha^{-1} (N_4), resulted in the highest organic carbon content of 0.7%, whereas the control treatment (N_1), had the lowest content at 0.58%. A considerable enhancement in percentage of organic carbon was observed with the concurrent application of *S. aculeata* and 45 kg of nitrogen per hectare (M_1N_4). The composition of green manure enriches soil microorganisms with organic acids, amino acids, carbohydrates, vitamins, organic carbon and promoting decomposition and adding organic matter after incorporation. These factors could contribute to an increase in organic matter content in the soil.

Gautam *et al.* (2021) examined that the incorporation of *S. aculeata* significantly enhanced the organic matter content of the soil, achieving an increase in 62.93% in comparison to plots subjected with chemical fertilizers. The finding highlights the potential of *S. aculeata* with recommended dose of nitrogen as a valuable practice for improving soil health and fertility. The corresponding results were identified by Zhou *et al.* (2016) reported that the incorporation of legume crop residues lead to significant increases in soil microbial biomass, nitrogen and carbon, which can directly enhance the organic matter content. An analogous conclusion was reached by Demir and Gulser (2015) also confirmed that soil organic matter content was notably higher in crop residue treated plots compared to untreated plots.

Protein content (%)

Analysis revealed that the protein content in the grains was significantly affected by the interaction between green manuring practices and nitrogen variations, with the result being statistically validated (Table 1). The green manure treatments demonstrated that *S. aculeata* (M_1) significantly increased protein content, reaching 8.2% statistically at par with *V. unguiculata* (M_2) and *C. juncea* (M_3) while the control treatment (M_0), recorded the lowest protein content at 5.8%. With respect to nitrogen application levels, the 45 N kg ha^{-1} (N_4), treatment resulted in the highest protein content of 8.4%, while the control (N_1), with no nitrogen addition, exhibited the lowest protein content at 6.4%. The synergy between green manuring and nitrogen treatments (M_1N_4) produced a marked and statistically significant enhancement in protein levels in grains.

Similar to the findings of Wang *et al.* (2022), the application of green manures in rice cultivation was found to alter microbial community abundance and enzyme activity, ultimately contributing to enhanced protein content in grains. Islam (2001) observed that nitrogen application, combined with green manuring, led to a marked increase in protein content in wheat, under optimal conditions. Similarly, these findings are consistent with Salam *et al.* (2005), who reported comparable protein increases with *S. aculeata* under similar conditions. Moreover, Sun *et al.* (2022) reported that nitrogen levels were crucial in enhancing protein content across both pulses and cereals, with recommended dosage of fertilizer resulting in substantial improvements, particularly in cereal grains. Consistent with the observations of Islam *et al.* (2019), it was found that green manures improve microbial enzyme activity, with higher nitrogen doses leading to increased protein content in grains. Additionally, An *et al.* (2024) reported comparable results, with protein content ranging from 8.69 to 40.1% in wheat under optimal nitrogen and green manuring conditions.

CONCLUSION

As agricultural practices worldwide evolve to tackle the challenges posed by increasing food demand, especially for staple crops like basmati rice, these sustainable approaches such as green manuring and integrated nutrient management hold great promise for enhancing productivity while maintaining soil health. The findings from this study demonstrated that the integration of green manuring with nitrogen fertilization on soil nutrient dynamics and crop quality in basmati rice cultivation. Among the green manures, *S. aculeata* (M_1) in combination with 45 kg ha^{-1} (N_4) consistently improved soil chemical properties specifically enhancing the availability of nitrogen, phosphorous and potassium. This treatment also led to a notable improvement in grain protein content, suggesting a positive influence on crop nutritional quality. The findings emphasize the potential of sustainable agricultural practices for maintaining long-term soil health and enhancing the nutritional values of rice, aligning with current goals for environmentally responsible and high quality production.

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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**.**

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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