



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
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NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(7): 498-505
Received: 02-05-2026
Accepted: 08-06-2026

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Effect of brown manuring and nitrogen levels on growth, productivity and economic performance of Transplanted Rice (*Oryza sativa* L.) under subtropical conditions of the Indo-Gangetic plains

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i7g.5973>

Abstract

Sustainable nutrient management is essential for improving rice productivity while maintaining soil health and economic viability under intensive cropping systems. Brown manuring has emerged as an environmentally sound practice that enhances nutrient availability, suppresses weeds and improves soil fertility. Therefore, the present investigation was conducted during the Kharif season of 2025 at the Instructional Farm, Faculty of Agricultural Sciences and Allied Industries, Rama University, Kanpur, Uttar Pradesh, India, to evaluate the effect of brown manuring and nitrogen levels on the growth, productivity and economics of transplanted rice (*Oryza sativa* L.). The experiment was laid out in a Factorial Randomized Block Design with three replications, comprising three brown manuring treatments [*Sesbania aculeata* (B₁), *Crotalaria juncea* (B₂) and no brown manuring (B₃)] in combination with four nitrogen levels (0, 40, 80 and 120 kg N ha⁻¹). Growth parameters, yield attributes, yield and economic returns were recorded and analyzed using analysis of variance.

Brown manuring significantly improved crop growth and productivity over the control. Among the brown manuring treatments, *Sesbania aculeata* produced the highest plant height at harvest (108.48 cm), dry matter accumulation (1148.62 g m⁻²), productive panicles (348.62 m⁻²), grains panicle⁻¹ (146.84) and test weight (24.86 g). Consequently, it recorded the highest grain yield (6248 kg ha⁻¹), straw yield (8126 kg ha⁻¹), biological yield (14,374 kg ha⁻¹) and harvest index (43.46%). Increasing nitrogen application significantly enhanced all growth and yield parameters. Application of 120 kg N ha⁻¹ produced the maximum plant height (111.58 cm), dry matter accumulation (1198.84 g m⁻²), grain yield (6658 kg ha⁻¹), straw yield (8524 kg ha⁻¹) and biological yield (15,182 kg ha⁻¹), although several parameters remained statistically at par with 80 kg N ha⁻¹. Economic analysis revealed that the treatment combination B₁N₄ (*Sesbania aculeata* + 120 kg N ha⁻¹) recorded the highest gross return (₹1,76,403 ha⁻¹), net return (₹1,23,524 ha⁻¹) and benefit–cost ratio (3.34), followed closely by B₁N₃ (*Sesbania aculeata* + 80 kg N ha⁻¹), indicating superior economic efficiency.

The study demonstrates that integrating *Sesbania aculeata* brown manuring with 80–120 kg N ha⁻¹ markedly enhances crop growth, biomass production, yield attributes, grain yield and farm profitability. Therefore, this integrated nutrient management practice can be recommended as a sustainable and economically viable strategy for transplanted rice cultivation under the subtropical conditions of the Indo-Gangetic Plains.

Keywords: Brown manuring, *Sesbania aculeata*, *Crotalaria juncea*, nitrogen management, transplanted rice, grain yield, integrated nutrient management, economics

1. Introduction

Rice (*Oryza sativa* L.) is one of the world's most important cereal crops and serves as the principal staple food for more than half of the global population. It contributes nearly one-fifth of the total dietary energy consumed worldwide and plays a crucial role in ensuring food and nutritional security, particularly in Asia, where approximately 90% of global rice production and consumption occur. With the continuous increase in population, urbanization and changing food preferences, global rice demand is projected to rise substantially over the coming decades. Consequently, increasing rice productivity while conserving natural resources has become a major challenge for agricultural scientists and policymakers worldwide (FAO, 2023; Peng *et al.*, 1999;

Cassman *et al.*, 2003) [8, 20, 5].

India is the second-largest producer and the largest exporter of rice in the world, cultivating the crop over nearly 47 million hectares with an annual production exceeding 135 million tonnes. Rice contributes significantly to the national economy, rural employment and livelihood security. In the Indo-Gangetic Plains (IGP), transplanted rice constitutes the backbone of the cereal-based production system owing to favourable agro-climatic conditions and extensive irrigation facilities. However, intensive cultivation of rice under conventional management practices has resulted in declining soil fertility, reduced nutrient use efficiency, deterioration of soil physical properties and increasing production costs. Furthermore, continuous dependence on inorganic fertilizers has accelerated nutrient imbalance, reduced soil organic carbon and adversely affected soil biological activity, thereby threatening the long-term sustainability of rice production systems (Prasad, 2005; Ladha *et al.*, 2016) [21, 16].

Nitrogen is the most yield-limiting nutrient in rice cultivation because it directly regulates chlorophyll synthesis, photosynthetic efficiency, leaf area development, tillering, biomass production and grain formation. Although rice exhibits a high response to nitrogen fertilization, recovery efficiency of applied nitrogen under flooded conditions generally remains low because substantial quantities are lost through volatilization, denitrification, leaching and runoff. These losses not only reduce fertilizer-use efficiency but also increase production costs and contribute to environmental pollution through greenhouse gas emissions and groundwater contamination. Therefore, strategies that improve nitrogen-use efficiency without compromising crop productivity have become increasingly important for sustainable rice cultivation (Fageria, 2014; Dobermann & Fairhurst, 2000) [9, 7]. Integrated nutrient management has emerged as an effective approach for sustaining crop productivity by combining inorganic fertilizers with biologically derived nutrient sources. Among these approaches, brown manuring has attracted considerable attention because of its ability to supply nutrients, suppress weeds and improve soil quality without disturbing the standing rice crop. In brown manuring, fast-growing leguminous species are sown simultaneously with rice and subsequently terminated chemically at an early growth stage. The dead biomass remains on the soil surface where it gradually decomposes, releasing nutrients and forming an organic mulch that suppresses weeds, conserves soil moisture and improves soil biological activity. Unlike conventional green manuring, brown manuring does not require additional time or land preparation before transplanting, making it particularly suitable for intensive rice production systems (Sharma *et al.*, 2010; Chauhan *et al.*, 2021) [25, 6].

Among the available leguminous species, *Sesbania aculeata* and *Crotalaria juncea* are widely recognized for their rapid biomass production, efficient biological nitrogen fixation and favourable decomposition characteristics. Their residues contribute appreciable quantities of nitrogen, phosphorus and potassium to the soil while simultaneously improving soil aggregation, microbial biomass and nutrient cycling. Previous investigations have demonstrated that decomposition of leguminous brown manure can contribute approximately 60–90 kg N ha⁻¹ depending upon species, biomass production and environmental conditions, thereby reducing dependence on external nitrogen fertilizers (Roy *et al.*, 2006; Balasubramanian *et al.*, 2007; Yadavinder Singh *et al.*, 2019) [23, 2, 31].

Apart from nutrient addition, brown manuring provides an efficient biological method of weed suppression. Following chemical knockdown, the decomposing biomass forms a protective mulch layer that restricts light penetration, suppresses

weed germination and reduces crop–weed competition during the critical growth period. The gradual release of nutrients from decomposing residues synchronizes nutrient availability with crop demand, leading to improved nutrient uptake, greater dry matter accumulation and enhanced yield formation. Consequently, brown manuring has been recognized as an environmentally sound practice capable of improving productivity while reducing dependence on herbicides and excessive fertilizer inputs (Singh *et al.*, 2017; Naresh *et al.*, 2020) [28, 18]. Although numerous studies have independently examined the influence of brown manuring or nitrogen fertilization on rice productivity, comparatively fewer investigations have evaluated their combined effects under the subtropical agro-climatic conditions of the central Indo-Gangetic Plains. Furthermore, comparative information regarding the performance of *Sesbania aculeata* and *Crotalaria juncea* under graded nitrogen levels remains limited, particularly with respect to crop growth, yield formation and economic returns. Identification of an optimum combination of brown manuring species and nitrogen fertilization is therefore essential for improving nutrient-use efficiency, sustaining soil productivity and enhancing farm profitability under intensive rice cultivation.

Based on these considerations, the present investigation was undertaken during the Kharif season of 2025 at Rama University, Kanpur, Uttar Pradesh, India, to evaluate the combined influence of brown manuring and nitrogen management on transplanted rice under subtropical conditions.

2. Materials and Methods

The experiment was conducted during Kharif 2025 at Rama University, Kanpur, Uttar Pradesh, India. The site lies in the Indo-Gangetic Plains with a subtropical climate. During the crop period, temperatures ranged from 18–40°C with adequate monsoonal rainfall and humidity, favouring rice growth and decomposition of brown manuring biomass. Soil samples (0–15 cm) were analyzed before transplanting. The soil was sandy loam, slightly alkaline (pH 7.62) with low EC (0.28 dS m⁻¹). It contained 0.41% organic carbon, low nitrogen (176.48 kg ha⁻¹), and medium phosphorus (18.62 kg ha⁻¹) and potassium (224.84 kg ha⁻¹). The experiment was laid out in a Factorial Randomized Block Design with three replications. Treatments included three brown manuring options: *Sesbania aculeata* (B₁), *Crotalaria juncea* (B₂) and no brown manuring (B₃), combined with four nitrogen levels: 0, 40, 80 and 120 kg N ha⁻¹. A total of 12 treatment combinations were tested. Rice variety PR-114 was transplanted at 25 days after sowing with 20 × 15 cm spacing. Brown manuring crops were sown simultaneously and knocked down at 30–35 days using 2,4-D. Nitrogen was applied through urea in split doses, while phosphorus and potassium were applied basally. Standard agronomic practices were followed. Data on growth, yield attributes and yield were recorded from selected plants. Biomass of brown manuring crops was measured before knockdown. Grain and straw yields were calculated on a hectare basis. Economic parameters were also evaluated. Data were analyzed using ANOVA for FRBD. Treatment means were compared using LSD at 5% significance level.

3. Results and Discussion

3.1 Plant Population

Initial plant population was not significantly affected by brown manuring or nitrogen levels, indicating uniform crop establishment across treatments. This uniformity suggests that the experimental conditions, including transplanting method and seedling vigor, were consistent across all plots, thereby

minimizing variability at the initial stage.

At harvest, plant population was significantly influenced by both brown manuring and nitrogen application (Table 1). Among brown manuring treatments, *Sesbania aculeata* recorded the highest plant population, followed by *Crotalaria juncea*, while the control showed the lowest values. The improved plant survival under *Sesbania* may be attributed to its rapid decomposition and higher nutrient release, which enhances soil fertility and microbial activity. According to Sharma *et al.* (2010) [25], incorporation of leguminous brown manure improves soil physical properties and nutrient availability, thereby supporting better crop establishment and survival. Similarly, Singh *et al.* (2017) [28] reported that *Sesbania* incorporation enhances soil organic matter and promotes favorable conditions for plant growth.

Plant population also increased with higher nitrogen levels. Application of 120 kg N ha⁻¹ recorded the highest plant population, which was at par with 80 kg N ha⁻¹ but significantly

higher than 0 and 40 kg N ha⁻¹. Adequate nitrogen supply plays a crucial role in promoting vegetative growth, root development and chlorophyll synthesis, which ultimately enhances plant survival. Fageria *et al.* (2011) [10] emphasized that nitrogen is a key nutrient influencing crop growth and productivity, and its adequate supply ensures better plant vigor and stand establishment. Similarly, Dobermann and Fairhurst (2000) [7] reported that sufficient nitrogen availability improves plant health and reduces mortality under field conditions.

The interaction effect between brown manuring and nitrogen levels was non-significant, indicating that both factors independently contributed to plant population. However, the combination of *Sesbania aculeata* with 120 kg N ha⁻¹ recorded the highest plant population, while the control with no nitrogen recorded the lowest. This suggests that integrated nutrient management practices can synergistically improve crop performance, even though statistical interaction may not always be significant.

Table 1: Effect of brown manuring and nitrogen levels on plant population (plants m⁻²)

Treatment	Initial plant population (m ⁻²)	Plant population at harvest (m ⁻²)
Factor A: Brown Manuring		
B ₁ : <i>Sesbania aculeata</i>	32.84	30.96
B ₂ : <i>Crotalaria juncea</i>	32.12	29.84
B ₃ : Control (No brown manuring)	31.48	28.72
SEm±	0.62	0.58
CD (P=0.05)	NS	1.68
Factor B: Nitrogen Levels		
N ₁ : 0 kg N ha ⁻¹	31.12	27.84
N ₂ : 40 kg N ha ⁻¹	31.86	29.24
N ₃ : 80 kg N ha ⁻¹	32.28	30.36
N ₄ : 120 kg N ha ⁻¹	33.12	31.64
SEm±	0.71	0.67
CD (P=0.05)	NS	1.95
Interaction (B × N)	NS	NS

These results indicate that brown manuring with *Sesbania aculeata* combined with higher nitrogen levels improves plant survival and maintains optimum plant population. The findings are in agreement with Chauhan *et al.* (2021) [6] and Naresh *et al.* (2020) [18], who reported enhanced crop establishment and plant stand under integrated use of green manures and nitrogen fertilizers.

3.2 Plant Height

Plant height is an important indicator of crop growth and vigour, reflecting the combined effects of nutrient availability, photosynthetic efficiency and environmental conditions during the crop growth period. The data presented in Table 2 indicated that plant height increased progressively with advancement in crop age and was significantly influenced by both brown manuring and nitrogen levels at all stages of observation. However, their interaction effect was found to be non-significant. Among the brown manuring treatments, *Sesbania aculeata* recorded the highest plant height at all growth stages, followed by *Crotalaria juncea*, while the control treatment showed the lowest values. At 30 DAT, plant height under *Sesbania aculeata* and *Crotalaria juncea* remained statistically at par, but as the crop advanced, *Sesbania aculeata* showed a clear superiority and produced significantly taller plants at 60 DAT, 90 DAT and at harvest. The enhanced plant height under *Sesbania aculeata* may be attributed to its higher biomass production and rapid decomposition, which ensured a continuous supply of nutrients,

particularly nitrogen. This improved nutrient availability enhanced chlorophyll synthesis, photosynthetic activity and cell elongation, resulting in better vegetative growth. Additionally, decomposition of leguminous biomass improved soil microbial activity and nutrient mineralization, thereby creating favourable conditions for plant growth. Similar results were reported by Sharma *et al.* (2010) [25], Singh *et al.* (2017) [28] and Chauhan *et al.* (2021) [6].

Nitrogen levels also had a significant effect on plant height at all growth stages. Plant height increased progressively with increasing nitrogen levels from 0 to 120 kg N ha⁻¹. The highest plant height was recorded with 120 kg N ha⁻¹, which remained statistically at par with 80 kg N ha⁻¹ but was significantly superior to 40 kg N ha⁻¹ and the control. The increase in plant height with higher nitrogen application can be attributed to improved nitrogen availability, which enhances chlorophyll formation, photosynthetic efficiency and synthesis of structural proteins, thereby promoting stem elongation and leaf development. These findings are in agreement with those reported by Fageria *et al.* (2011) [10] and Dobermann and Fairhurst (2000) [7].

Although the interaction between brown manuring and nitrogen levels was non-significant, the combination of *Sesbania aculeata* with 120 kg N ha⁻¹ consistently produced the tallest plants at all growth stages, whereas the control without brown manuring and nitrogen recorded the lowest plant height. This indicates that both brown manuring and nitrogen fertilization had complementary effects on crop growth.

Table 2: Effect of brown manuring and nitrogen levels on plant height (cm) of rice at different growth stages

Treatment	30 DAT	60 DAT	90 DAT	At harvest
Factor A: Brown Manuring				
B ₁ : <i>Sesbania aculeata</i>	42.64	78.42	102.84	108.48
B ₂ : <i>Crotalaria juncea</i>	39.82	74.18	98.62	104.16
B ₃ : Control	36.48	69.24	92.16	96.84
SEm $\pm$	1.02	1.84	2.12	2.28
CD (P=0.05)	2.96	5.34	6.14	6.62
Factor B: Nitrogen Levels				
N ₁ : 0 kg N ha ⁻¹	34.28	65.84	88.12	92.46
N ₂ : 40 kg N ha ⁻¹	38.72	72.18	96.44	101.82
N ₃ : 80 kg N ha ⁻¹	41.96	76.84	101.28	107.16
N ₄ : 120 kg N ha ⁻¹	44.18	81.64	105.92	111.58
SEm $\pm$	1.18	2.12	2.44	2.58
CD (P=0.05)	3.42	6.16	7.08	7.48
Interaction (B $\times$ N)	NS	NS	NS	NS

The results clearly indicate that integrated nutrient management through brown manuring and appropriate nitrogen application significantly improved plant height and overall vegetative growth of transplanted rice. Among the treatments, *Sesbania aculeata* combined with 120 kg N ha⁻¹ proved to be the most effective in enhancing plant growth, suggesting better synchronization between nutrient release from organic sources and inorganic nitrogen supply. These findings are in line with those reported by Fageria *et al.* (2011) [10], Ladha *et al.* (2016) [16] and Shekhawat *et al.* (2021) [26], who emphasized the importance of integrating organic and inorganic nutrient sources for improving crop growth and productivity.

3.3 Dry Matter Accumulation

Dry matter accumulation increased progressively with crop age and was significantly influenced by brown manuring and nitrogen levels, whereas their interaction effect was found to be non-significant (Table 3).

Among the brown manuring treatments, *Sesbania aculeata* recorded the highest dry matter accumulation at all growth stages, followed by *Crotalaria juncea* and the control. At harvest, *Sesbania aculeata* produced 1148.62 g m⁻², which was significantly higher than *Crotalaria juncea* (1086.48 g m⁻²) and control (982.84 g m⁻²). This improvement may be attributed to the

rapid decomposition of *Sesbania aculeata*, leading to timely nutrient release and enhanced crop growth.

Nitrogen application significantly increased dry matter accumulation at all stages. The highest dry matter was recorded with 120 kg N ha⁻¹ (1198.84 g m⁻² at harvest), followed by 80, 40, and 0 kg N ha⁻¹. Increased nitrogen availability enhances chlorophyll synthesis, leaf area development, and photosynthetic efficiency, resulting in greater biomass production.

Although the interaction between brown manuring and nitrogen levels was non-significant, the combination of *Sesbania aculeata* with higher nitrogen levels consistently resulted in higher dry matter accumulation.

The higher dry matter accumulation observed under *Sesbania aculeata* may be due to its rapid decomposition and continuous nutrient supply, which promotes better plant growth and biomass production. Similar results were reported by Sharma *et al.* (2010) [25], who observed improved crop growth under brown manuring practices. The increase in dry matter with higher nitrogen levels can be attributed to enhanced photosynthetic activity and nutrient uptake, as reported by Fageria (2014) [9] and Dobermann and Fairhurst (2000) [7]. Furthermore, the combined use of organic and inorganic nutrient sources improves nutrient availability and crop productivity (Singh *et al.*, 2005) [27].

Table 3: Effect of brown manuring and nitrogen levels on dry matter accumulation (g m⁻²) of rice at different growth stages

Treatment	30 DAT	60 DAT	90 DAT	At harvest
Factor A: Brown Manuring				
B ₁ : <i>Sesbania aculeata</i>	112.48	428.16	862.84	1148.62
B ₂ : <i>Crotalaria juncea</i>	104.24	396.82	814.42	1086.48
B ₃ : Control	92.16	348.24	742.18	982.84
SEm ($\pm$)	3.84	11.28	18.62	24.42
CD (P=0.05)	11.14	32.74	54.02	70.84
Factor B: Nitrogen Levels				
N ₁ : 0 kg N ha ⁻¹	84.12	312.18	706.44	942.84
N ₂ : 40 kg N ha ⁻¹	98.26	368.42	792.18	1048.24
N ₃ : 80 kg N ha ⁻¹	110.48	418.86	852.64	1134.42
N ₄ : 120 kg N ha ⁻¹	120.82	462.16	896.48	1198.84
SEm ($\pm$)	4.42	12.84	20.16	26.82
CD (P=0.05)	12.84	37.28	58.52	77.82
Interaction (B $\times$ N)	NS	NS	NS	NS

Overall, the integration of brown manuring and nitrogen fertilization significantly improved dry matter accumulation, with *Sesbania aculeata* and higher nitrogen levels proving most effective.

3.4 Yield Attributes

Yield attributes represent the cumulative outcome of various physiological and biochemical processes occurring during crop growth and development. These parameters directly determine

the productivity potential of rice under different nutrient management practices. The data presented in Table 4 revealed that brown manuring treatments and nitrogen levels significantly influenced panicle formation, grain development and yield attributes of rice. However, the interaction effect between brown manuring and nitrogen levels remained non-significant for all yield parameters.

Among the brown manuring treatments, *Sesbania aculeata* recorded significantly superior yield attributes compared to *Crotalaria juncea* and the control. It produced the highest number of panicles (348.62 m⁻²), longest panicles (27.84 cm), maximum grains panicle⁻¹ (146.84) and highest test weight (24.86 g). *Crotalaria juncea* remained intermediate, while the control treatment recorded the lowest values for all parameters. The superiority of *Sesbania aculeata* may be attributed to its rapid decomposition, higher biomass production and continuous nutrient release, which enhanced soil microbial activity, nutrient availability and moisture conservation. These factors collectively

improved reproductive growth, assimilate translocation and grain formation.

Nitrogen application also significantly influenced all yield attributes. Progressive increase in nitrogen levels from 0 to 120 kg N ha⁻¹ resulted in a corresponding increase in panicle number, panicle length, grains panicle⁻¹ and test weight. The highest values were recorded under 120 kg N ha⁻¹, which remained statistically at par with 80 kg N ha⁻¹ but significantly superior to lower nitrogen levels. Enhanced nitrogen availability improved photosynthetic efficiency, vegetative growth and assimilate partitioning towards reproductive organs, thereby increasing sink capacity and grain filling.

Although the interaction effect between brown manuring and nitrogen levels was non-significant, the combination of *Sesbania aculeata* with 120 kg N ha⁻¹ consistently produced the highest values for all yield attributes, indicating better synchronization of nutrient supply and improved crop performance.

Table 4: Effect of brown manuring and nitrogen levels on yield attributes of rice

Treatment	Panicles (m ⁻²)	Panicle length (cm)	Grains panicle ⁻¹	Test weight (g)
Factor A: Brown Manuring				
B ₁ : <i>Sesbania aculeata</i>	348.62	27.84	146.84	24.86
B ₂ : <i>Crotalaria juncea</i>	326.84	26.18	138.26	23.94
B ₃ : Control	286.48	23.96	121.48	22.48
SEm (±)	8.24	0.62	3.42	0.42
CD (P=0.05)	23.92	1.80	9.92	1.22
Factor B: Nitrogen Levels				
N ₁ : 0 kg N ha ⁻¹	272.46	22.84	116.24	21.86
N ₂ : 40 kg N ha ⁻¹	308.18	25.18	132.48	23.18
N ₃ : 80 kg N ha ⁻¹	342.62	27.12	145.82	24.52
N ₄ : 120 kg N ha ⁻¹	366.84	28.64	152.64	25.48
SEm (±)	9.48	0.72	3.94	0.48
CD (P=0.05)	27.54	2.10	11.46	1.40
Interaction (B × N)	NS	NS	NS	NS

Overall, the results demonstrate that integrated nutrient management through brown manuring and balanced nitrogen fertilization substantially improved reproductive development and yield attributes of transplanted rice. Among all treatments, *Sesbania aculeata* integrated with 120 kg N ha⁻¹ proved to be the most effective combination, indicating superior nutrient synchronization and enhanced assimilate partitioning during grain development. These findings are in close agreement with those of Cassman *et al.* (2003)^[5], Fageria *et al.* (2011)^[10], Ladha *et al.* (2016)^[16] and Shekhawat *et al.* (2021)^[26], who reported that

integration of organic residues with optimum nitrogen fertilization significantly improves reproductive efficiency and yield formation in rice.

3.5. Grain Yield (kg ha⁻¹)

Grain yield is the ultimate expression of cumulative effects of growth and yield contributing characters influenced by nutrient management practices. The data pertaining to grain yield of rice as influenced by brown manuring and nitrogen levels are presented in Table 5.

Table 5: Effect of Brown Manuring and Nitrogen Levels on Grain Yield, Straw Yield, Biological Yield and Harvest Index of Rice

Treatment	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)	Harvest index (%)
Factor A: Brown Manuring				
B ₁ : <i>Sesbania aculeata</i>	6248	8126	14374	43.46
B ₂ : <i>Crotalaria juncea</i>	5864	7742	13606	43.10
B ₃ : Control (No brown manuring)	5128	7064	12192	42.05
SEm±	124	162	248	0.62
CD (P=0.05)	360	470	720	NS
Factor B: Nitrogen Levels				
N ₁ : 0 kg N ha ⁻¹	4682	6584	11266	41.56
N ₂ : 40 kg N ha ⁻¹	5486	7422	12908	42.48
N ₃ : 80 kg N ha ⁻¹	6224	8146	14370	43.31
N ₄ : 120 kg N ha ⁻¹	6658	8524	15182	43.84
SEm±	142	186	284	0.71
CD (P=0.05)	412	540	824	2.06
Interaction (B × N)	NS	NS	NS	NS

The data presented in Table 5 revealed that grain yield of rice was significantly influenced by different brown manuring treatments and nitrogen levels. Among the brown manuring treatments, *Sesbania aculeata* (B₁) recorded significantly highest grain yield (6248 kg ha⁻¹), which proved superior over *Crotalaria juncea* (B₂) and control treatment (B₃). Treatment B₂ recorded grain yield of 5864 kg ha⁻¹ and remained statistically at par with B₁ but significantly superior over control. The lowest grain yield (5128 kg ha⁻¹) was recorded under no brown manuring treatment.

The increase in grain yield under *Sesbania aculeata* might be attributed to higher biomass decomposition, greater nutrient recycling, improved soil microbial activity and enhanced nutrient availability throughout the crop growth period. Brown manuring also suppressed weed growth and reduced crop-weed competition, thereby improving source-sink relationship and grain formation. Similar findings were reported by Sharma *et al.* (2010) [25] and Chauhan *et al.* (2021) [6], who observed that brown manuring with *Sesbania* significantly enhanced rice productivity through improved nutrient availability and weed suppression.

Among nitrogen levels, application of 120 kg N ha⁻¹ (N₄) recorded significantly maximum grain yield (6658 kg ha⁻¹), which remained statistically at par with 80 kg N ha⁻¹ (N₃) recording 6224 kg ha⁻¹. However, both these treatments proved significantly superior over lower nitrogen levels. The lowest grain yield (4682 kg ha⁻¹) was recorded under no nitrogen application (N₁).

The increase in grain yield with increasing nitrogen levels may be attributed to enhanced vegetative growth, increased tillering, improved photosynthetic efficiency and better assimilate translocation towards developing grains. Adequate nitrogen supply improved panicle development, spikelet fertility and grain filling percentage, ultimately resulting in higher grain productivity. These results are in conformity with the findings of Fageria (2014) [9] and Peng *et al.* (1999) [20], who reported that optimum nitrogen application significantly enhances rice yield by improving growth and yield attributes. The interaction effect between brown manuring and nitrogen levels remained non-significant, indicating similar response pattern of rice crop under different treatment combinations.

3.6 Straw Yield (kg ha⁻¹)

Straw yield reflects vegetative biomass production and overall growth performance of rice crop under different nutrient management practices.

The data presented in Table 5 indicated that straw yield was significantly influenced by brown manuring practices and nitrogen levels. Among the brown manuring treatments, *Sesbania aculeata* (B₁) recorded significantly highest straw yield (8126 kg ha⁻¹), which remained statistically superior over control treatment and at par with *Crotalaria juncea* (7742 kg ha⁻¹). The lowest straw yield (7064 kg ha⁻¹) was observed under no brown manuring treatment. The higher straw yield under brown manuring treatments might be due to improved nutrient availability, enhanced root development and increased photosynthetic activity which promoted vegetative biomass production. Brown manuring also improved soil physical conditions and microbial activity, thereby supporting vigorous crop growth. Similar observations were reported by Singh *et al.* (2005) [27], who emphasized the role of organic inputs in enhancing biomass production and soil fertility.

Among nitrogen levels, application of 120 kg N ha⁻¹ recorded significantly highest straw yield (8524 kg ha⁻¹), which remained statistically at par with 80 kg N ha⁻¹ but significantly superior over lower nitrogen levels. The lowest straw yield was observed under

control treatment receiving no nitrogen. Higher nitrogen application enhanced vegetative growth, leaf area development and dry matter accumulation, which ultimately increased straw production. Nitrogen stimulates chlorophyll formation and photosynthetic efficiency, resulting in greater biomass synthesis. These findings are supported by Marschner (2012) [17] and Dobermann and Fairhurst (2000) [7], who reported that nitrogen plays a crucial role in biomass accumulation and vegetative growth in rice. The interaction effect between brown manuring and nitrogen levels remained non-significant.

3.7 Biological Yield (kg ha⁻¹)

Biological yield represents the total biomass produced by the crop and reflects overall crop productivity under different treatments.

The data presented in Table 5 revealed that biological yield was significantly influenced by brown manuring treatments and nitrogen levels. Among brown manuring treatments, *Sesbania aculeata* recorded significantly highest biological yield (14374 kg ha⁻¹), followed by *Crotalaria juncea* (13606 kg ha⁻¹), whereas the control treatment recorded minimum biological yield (12192 kg ha⁻¹). Treatment B₂ remained statistically at par with B₁ but significantly superior over control. The increased biological yield under brown manuring treatments might be due to improved nutrient cycling, greater nutrient uptake, enhanced microbial activity and favourable soil conditions which collectively promoted crop growth and biomass production. Similar results were reported by Giller (2001) [12], who highlighted the importance of green manuring in improving soil fertility and crop productivity.

Among nitrogen levels, application of 120 kg N ha⁻¹ recorded significantly highest biological yield (15182 kg ha⁻¹), which remained statistically at par with 80 kg N ha⁻¹ but significantly superior over lower nitrogen levels. The minimum biological yield (11266 kg ha⁻¹) was observed under no nitrogen application. The increase in biological yield under higher nitrogen levels may be attributed to enhanced vegetative growth, higher photosynthetic efficiency and greater accumulation of dry matter throughout the crop growth period. Nitrogen application improved leaf area index, tillering and nutrient assimilation, resulting in increased total biomass production. These findings are in agreement with the reports of Cassman *et al.* (2003) [5] and Ladha *et al.* (2016) [16], who emphasized the role of nitrogen in improving crop productivity and biomass accumulation in rice-based systems.

3.8 Economics

Economic analysis provides a practical basis for evaluating the feasibility and profitability of agronomic practices under field conditions. The economic performance of rice cultivation, expressed in terms of cost of cultivation, gross return, net return and benefit-cost (B:C) ratio, was significantly influenced by brown manuring and nitrogen fertilization. The treatment-wise economic analysis is presented in Table 7.

The cost of cultivation varied among treatment combinations due to differences in the expenditure incurred on brown manuring seed and nitrogen fertilizer application. The lowest cost of cultivation (₹49,325 ha⁻¹) was recorded under the control treatment without brown manuring and nitrogen application (B₃N₁), whereas the highest cultivation cost (₹53,129 ha⁻¹) was recorded under *Crotalaria juncea* integrated with 120 kg N ha⁻¹ (B₂N₄). Although the brown manuring treatments slightly increased production costs, the additional investment was compensated by substantial improvements in grain and straw yields, resulting in greater economic returns. Among all treatment

combinations, B_1N_4 (*Sesbania aculeata* + 120 kg N ha⁻¹) recorded the highest gross return (₹1,76,403 ha⁻¹), net return (₹1,23,524 ha⁻¹) and benefit–cost ratio (3.34), and was found to be significantly superior to all other treatments. The superior profitability of this treatment was primarily attributed to its higher grain yield (70.92 q ha⁻¹) and straw yield (88.50 q ha⁻¹), which generated greater monetary returns despite the comparatively higher cultivation cost. Treatment B_1N_3 (*Sesbania aculeata* + 80 kg N ha⁻¹) was statistically at par with B_1N_4 for economic returns and recorded gross return of ₹1,68,985 ha⁻¹, net return of ₹1,16,624 ha⁻¹ and a B:C ratio of 3.23. These results indicate that application of 80–120 kg N ha⁻¹ in combination with *Sesbania aculeata* provides an economically efficient nutrient management strategy for transplanted rice.

Among the brown manuring treatments, *Sesbania aculeata* proved economically superior to *Crotalaria juncea*. Although cultivation with *Crotalaria juncea* also improved profitability compared with the control, its gross return, net return and B:C ratio remained comparatively lower. The better economic performance of *Sesbania aculeata* may be attributed to its rapid decomposition, greater nutrient contribution and comparatively lower seed cost, which collectively enhanced crop growth, yield attributes and final productivity. Increasing nitrogen application from 0 to 120 kg ha⁻¹ progressively improved economic returns. Higher nitrogen availability enhanced vegetative growth, dry matter accumulation and reproductive development, resulting in increased grain and straw yields and consequently higher gross and net returns. Although the expenditure on fertilizer increased

with higher nitrogen levels, the additional investment was effectively offset by the corresponding increase in crop productivity. These findings are consistent with those reported by Fageria *et al.* (2011)^[10], Cassman *et al.* (2003)^[5], Ladha *et al.* (2016)^[16] and Sapkota *et al.* (2022)^[24], who reported that balanced nitrogen management significantly improves productivity, profitability and nutrient-use efficiency in rice-based production systems. The lowest economic performance was recorded under B_3N_1 (control without brown manuring and nitrogen), which produced the minimum grain yield (42.40 q ha⁻¹), gross return (₹1,07,508 ha⁻¹), net return (₹58,183 ha⁻¹) and benefit–cost ratio (2.18). The poor profitability of this treatment clearly indicates that omission of both brown manuring and nitrogen fertilization considerably limits crop productivity and economic returns.

Overall, the results clearly demonstrated that integration of brown manuring with optimum nitrogen fertilization substantially enhanced the profitability of transplanted rice. Among all treatment combinations, *Sesbania aculeata* integrated with 120 kg N ha⁻¹ (B_1N_4) emerged as the most remunerative treatment, while *Sesbania aculeata* combined with 80 kg N ha⁻¹ (B_1N_3) also proved highly profitable and remained statistically comparable for most economic parameters. Therefore, integration of *Sesbania aculeata* brown manuring with 80–120 kg N ha⁻¹ can be recommended as an economically viable and sustainable nutrient management strategy for maximizing rice productivity and profitability under the subtropical conditions of the Indo-Gangetic Plains.

Table 6: Effect of Brown Manuring and Nitrogen Levels on Economics of Rice

Treatment	Treatment details	Cost of cultivation (₹ ha ⁻¹)	Grain yield (q ha ⁻¹)	Straw yield (q ha ⁻¹)	Gross return (₹ ha ⁻¹)	Net return (₹ ha ⁻¹)	B:C ratio
B_1N_1	Sesbania + 0 kg N	51,325	54.80	73.60	1,37,080	85,755	2.67
B_1N_2	Sesbania + 40 kg N	51,843	61.45	80.40	1,53,398	1,01,555	2.96
B_1N_3	Sesbania + 80 kg N	52,361	67.85	86.20	1,68,985	1,16,624	3.23
B_1N_4	Sesbania + 120 kg N	52,879	70.92	88.50	1,76,403	1,23,524	3.34
B_2N_1	Crotalaria + 0 kg N	51,575	51.26	71.20	1,28,578	77,003	2.49
B_2N_2	Crotalaria + 40 kg N	52,093	58.64	77.42	1,46,553	94,460	2.81
B_2N_3	Crotalaria + 80 kg N	52,611	63.82	82.64	1,59,281	1,06,670	3.03
B_2N_4	Crotalaria + 120 kg N	53,129	66.84	86.42	1,66,696	1,13,567	3.14
B_3N_1	Control + 0 kg N	49,325	42.40	62.72	1,07,508	58,183	2.18
B_3N_2	Control + 40 kg N	49,843	48.96	68.44	1,22,878	73,035	2.47
B_3N_3	Control + 80 kg N	50,361	55.05	75.60	1,37,855	87,494	2.74
B_3N_4	Control + 120 kg N	50,879	59.98	78.80	1,49,746	98,867	2.94

4. Conclusion

This study showed that combining brown manuring with suitable nitrogen levels improved the growth, yield and economic returns of transplanted rice under subtropical conditions of the Indo-Gangetic Plains. Among the treatments, brown manuring with *Sesbania aculeata* performed better than *Crotalaria juncea* and the control. It enhanced plant growth, dry matter production and yield components, leading to higher grain, straw and biological yields. This improvement may be due to faster decomposition and better nutrient release from *Sesbania aculeata*.

Nitrogen application also had a strong effect on crop performance. Increasing nitrogen from 0 to 120 kg ha⁻¹ improved plant growth and yield. The highest yields were recorded at 120 kg N ha⁻¹, although results were similar to 80 kg N ha⁻¹ for several parameters. This suggests that proper nitrogen management plays an important role in improving crop productivity and nutrient use. Economic results showed that although brown manuring and higher nitrogen levels slightly increased the cost of cultivation, they resulted in higher returns and better benefit–cost ratio. The

combination of *Sesbania aculeata* with 120 kg N ha⁻¹ gave the best economic outcome. In conclusion, integrating brown manuring, especially with *Sesbania aculeata*, along with appropriate nitrogen fertilization can improve rice yield and profitability. This approach can help farmers achieve better production while supporting more sustainable nutrient management practices in the Indo-Gangetic Plains.

Practical Recommendation

Based on the findings of the present investigation, brown manuring with *Sesbania aculeata* integrated with 120 kg N ha⁻¹ is recommended as an effective nutrient management strategy for transplanted rice under the subtropical conditions of the Indo-Gangetic Plains. This integrated practice enhances crop growth, improves grain and straw yield, maximizes economic returns and contributes to sustainable nutrient management through improved nutrient-use efficiency and reduced dependence on sole inorganic fertilization.

Acknowledgements

The authors gratefully acknowledge the Faculty of Agricultural Sciences and Allied Industries, Rama University, Kanpur, Uttar Pradesh, India, for providing the necessary research facilities, experimental field and laboratory support to conduct the present investigation. The authors also express their sincere gratitude to the faculty members, technical staff and field assistants for their valuable cooperation during the execution of the experiment and collection of experimental data.

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