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Research Paper

Influence of different legumes on nutrient content and soil biological health in basmati rice-based cropping systems

SANJEEV KUMAR[1], UDAY PRATAP SHAHI[2], SATENDRA KUMAR[3], YOGESH KUMAR[4], VIVEK[5] KAMAL KHILARI[6] AND VAISHALI SINGH[7]

Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh 250 110

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ABSTRACT

To evaluate the long-term effects of legume integration in basmati rice–based systems, five production systems—fallow, basmati rice–wheat–*dhaincha* (*Sesbania aculeata*), basmati rice–kabuli chickpea–mung bean, basmati rice–chickpea–mung bean, and basmati rice–berseem–mung bean were assessed in a randomized block design with four replications during 2016–2023. The results showed that legume inclusion significantly improved yield-attributing traits, including tillers/m^2, panicle/m^2, and grains/panicle. Among the systems evaluated, basmati rice–berseem–mung bean consistently performed best, registering 4.5% higher tiller density and 6.3% more grains/panicle compared with the basmati rice–chickpea–mung bean system. Grain and straw concentrations of N, P, and K were the highest under the basmati rice–berseem–mung bean and basmati rice–wheat–*dhaincha* systems. Soil biological properties followed similar trends, with the highest microbial biomass carbon (205.75 μg/g) and microbial biomass nitrogen (19.48 μg/g) recorded under the basmati rice–berseem–mung bean system in the 0–15 cm soil layer. Although microbial activity declined with soil depth, it remained consistently higher under legume-based systems than under fallow. The findings indicate that inclusion of berseem or *dhaincha* in basmati rice–based cropping systems enhances yield attributes, nutrient contents, and soil biological health. Therefore, integration of berseem (winter season)/ dhaincha (summer season) is recommended as a sustainable intensification strategy for efficient basmati rice production in the Indo-Gangetic Plains.

Key words: Basmati rice, Berseem, Nutrient content, Soil microbial biomass carbon

Basmati rice is a premium aromatic rice grown extensively in the Indo-Gangetic Plains, occupying a unique position in global trade due to its grain quality, and aroma (Prodhan *et al.,* 2024). Hence, sustaining its productivity is imperative for ensuring farmer profitability as well as maintaining India's competitiveness in the global rice market. Basmati rice, demands balanced nutrient supply and improved soil quality for sustaining productivity (Nayak *et al.,* 2017). Sustainability of the long-term rice-wheat system is questioned due to declining factor productivity, poor nutrient and energy use efficiency, and soil health deterioration (Kumar *et al.,* 2022). Declining soil organic carbon (SOC) and biological activity are of particular concern, as they reduce the resilience of basmati rice to climatic and environmental stresses. Therefore, innovative and sustainable approaches are required to restore soil fertility and biological functions while maintaining high productivity. Inclusion of legumes in rice-based systems has emerged as a sustainable intensification strategy due to their ability to fix atmospheric nitrogen, solubilize phosphorus, mobilize micronutrients, and enhance soil organic matter (Vanlauwe *et al.,* 2019). Legume roots and rhizodeposition also stimulate microbial activity, thereby improving soil biological indicators such as microbial biomass carbon, and enzymatic activities (Babu *et al.,* 2020).

Nutrient density in rice grain and straw is strongly influenced by the preceding crops in a production system. The residual effects of legumes enhance rice quality by improving nutrient availability and promoting beneficial root–microbe interactions. However, legumes differ in their ability to enrich soil fertility and regulate microbial dynamics owing to variations in root architecture, nodulation capacity, and residue quality. Consequently, different legumes

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[2]**Corresponding author's Email:** upshahi@svpuat.edu.in
[1]Ph.D. Scholar, [2]Professor & Head Soil Science, [3]Professor Soil Science, [4]Professor Agronomy, [5]Professor Plant Pathology, College of Agriculture, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh 250 110

may confer varying benefits to crop productivity, nutrient accumulation, and soil biological functioning. Despite these advantages, systematic evaluation of the effects of diverse legumes on grain nutrient density and soil biological indicators in basmati rice–based systems remain limited. Considering the premium value of basmati rice and the pressing need to reduce fertilizer dependency while improving soil biological health, a comparative assessment of different legumes is critically important. Therefore, the present investigation was undertaken to evaluate the effects of selected legumes on yield-contributing traits, grain and straw nutrient density, and soil biological indicators of basmati rice. The outcomes are expected to support the development of sustainable and resilient basmati rice production strategies in the Indo-Gangetic Plains.

MATERIAL AND METHODS

The study was conducted at Modipuram, Meerut, situated in the Indo-Gangetic plains of Western Uttar Pradesh (29.08°N latitude, 77.70°E longitude, 230 m above mean sea level). Five production systems, viz. Fallow, Basmati rice–wheat–*Dhaincha* (*Sesbania aculeata)*, Basmati rice–kabuli chickpea–mung bean, Basmati rice–chickpea–mung bean, Basmati rice–berseem–mung bean were evaluated during 2016–23 in four times replicated RBD in a fixed plot manner. The basmati rice was transplanted during June-July by using 25–30-day-old seedlings and grown as per the recommended agronomic practices of the region. After harvest of basmati rice, rabi season crops namely wheat, kabuli chickpea, chickpea and berseem was sown in October–November, under basmati rice–wheat–*dhaincha*, basmati rice–kabuli chickpea–mungbean, basmati rice–chickpea–mungbean, basmati rice–berseem–mungbean systems, respectively. All the rabi crops were harvested during April-May except berseem. The first cutting of berseem was taken 55–60 days after sowing, followed by multiple cuttings at 25–30 days intervals until March. After harvest of rabi crops, summer mungbean was sown April-May in all basmati rice-based production systems except under basmati rice-wheat-*dhaincha*, where *dhaincha* seed was broadcast with the seed rate of 20–25 kg/ha. Mature pods of mungbean were picked in the month of June in the mungbean embedded systems, while dhaincha was trampled in June under basmati rice–wheat–*dhaincha* system. All the crops under basmati–rice–based production systems were grown as per the recommended agronomic practices. Yield attributing parameters and nutrient content in basmati rice grain and straw was recorded at harvest stage with standard procedure. After harvest, composite soil samples from 0–15 cm, 15–30 cm, and 30–45 cm depth were collected from four sampling points in each plot in June 2023. After sample processing the soil microbial biomass carbon (SMBC) was estimated by the chloroform fumigation-extraction method (Jenkinson and Ladd, 1981). Likewise, the soil microbial biomass nitrogen (SMBN) was estimated by the chloroform fumigation-extraction method (Brookes *et al.,* 1985).

All the data were statistically analyzed using the Analysis of Variance (ANOVA) method, and the significance of treatment effects was evaluated using the "F" test as described by Gomez and Gomez (1984). To determine differences between treatment means, the standard error of the mean (SEm±) and the least significant difference (LSD) at a 5% probability level ($p<0.05$) were calculated.

RESULTS AND DISCUSSION

Effect of legume integration on yield contributing parameters of basmati rice

The yield-attributing characters of basmati rice were significantly influenced by the inclusion of different legumes in the production system (Table 1). The number of tillers/m² varied between 228.0 (basmati rice–chickpea–mung bean) and 238.3 (basmati rice–berseem–mung bean), with the latter recording the highest value, which was ~4.5% greater than basmati rice–chickpea–mung bean. A similar trend was observed for panicles/m², where basmati rice–berseem–mung bean (228.3) and rice–wheat–dhaincha (226.3) produced significantly more panicles compared to basmati rice–chickpea–mung bean (217.0). Grains/panicle ranged from 103.3 in basmati rice–

Table 1. Seven-year impact of legume integration on yield attributes of basmati rice

Production system	Tillers/m^2	Panicle/m^2	Grains/panicle	Test wt. (g)
Fallow	…	…	…	…
Basmati rice–wheat–*dhaincha*	236	227	108	23.19
Basmati rice–kabuli chickpea–mung bean	230	219	106	23.25
Basmati rice–chickpea–mung bean	231	217	103	23.20
Basmati rice–berseem–mung bean	238	228	110	23.35
SEm±	1.07	1.26	1.49	0.30
CD (P=0.05)	3.18	3.73	4.44	NS

SEm±, Standard error of mean; CD, Critical difference chickpea–mung bean to 109.8 in basmati rice–berseem–mung bean, representing an improvement of about 6.3% due to berseem integration. The test weight remained statistically at par across the systems. The integration of legumes, particularly berseem and dhaincha, improved yield attributing parameters of basmati rice might be due to their positive role in soil fertility restoration and biological nitrogen fixation. Yield enhancement in cereals after legume inclusion and optimized nutrient management were reported by many workers (Babu *et al.,* 2020; Jat *et al.,* 2019).

Effect of legume integration on grain nutrient contents in basmati rice

Nutrient concentration in basmati rice grain and straw was significantly affected by the inclusion of legumes in the production system (Table 2). Among legume integration, inclusion of berseem followed by mung bean recorded the highest N content in basmati grain (1.45%) this indicates 7.4% improvement over chickpea- mungbean systems. A similar trend was observed in straw N. Likewise, phosphorus content in grain was maximum under basmati rice–berseem–mung bean (0.46%), followed by basmati rice–wheat–dhaincha (0.44%). Straw P also followed the same pattern, with berseem (0.19%), although effect was statistically non-significant. Grain K content remained comparable across systems (0.43–0.46%), but basmati rice–dhaincha (0.46%) and berseem (0.45%) showed a slight edge over chickpea inclusion. Straw K was the highest under dhaincha (1.49%) and the lowest under basmati rice-chickpea–mung bean (1.47%), though differences were marginal. The higher NPK content in basmati rice under berseem and dhaincha systems may be attributed to their strong nitrogen-fixing ability, higher biomass contribution, and efficient nutrient recycling, which improved soil fertility and nutrient uptake. Similar results were also reported by Aulakh *et al.,* (2016) and Poddar *et al.,* (2025).

Effect of legume integration on soil biological indicators

The MBC and MBN represent the living component of soil organic matter, which play a vital role in nutrient cycling and soil functioning. MBC serves as an indicator of the active microbial population and available carbon for microbial metabolism, while MBN reflects the microbial nitrogen pool vital for nutrient mineralization and plant uptake. These biomass components fluctuate with soil depth, management practices, and seasonal conditions (Jiang *et al.,* 2021). Microbial activity in soil, as measured by MBC and MBN, varied significantly across basmati rice–based production systems and depths (Fig. 1 and Fig. 2). Irrespective of production systems, both MBC and MBN decrease with an increase in soil depth. The basmati rice-berseem-mung bean system recorded the highest MBC (205.75 μg/g) in the surface layer (0–15 cm), followed by basmati rice–wheat–*dhaincha* (199.50 μg/g), basmati rice–chickpea–mung bean (191.00 μg/g), and basmati rice–kabuli chickpea–mung bean (186.75 μg/g). This trend

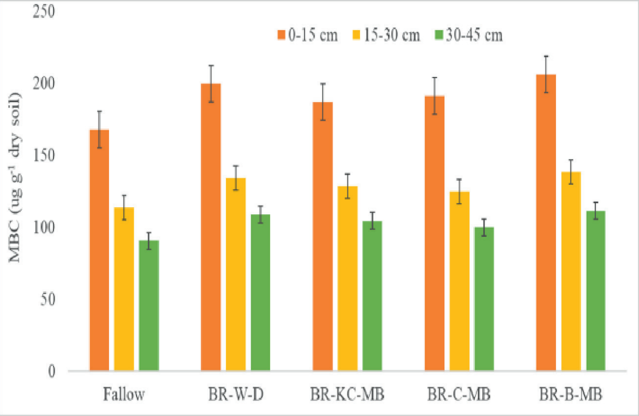

Fig. 1. Effect of basmati rice–based production systems on soil MBC. Fallow, BR-W-D: Basmati rice–wheat–*dhaincha*, BR-KC-MB: Basmati rice–kabuli chickpea–mung bean, BR-C-MB: Basmati rice–chickpea–mung bean, BR-B-MB: Basmati rice–berseem–mung bean. Error bar indicates critical difference (CD) at P=0.05

Table 2. Seven-year impact of legume integration on nutrient density of basmati rice grain and straw

Production system	N content (%)		P content (%)		K content (%)	
	Grain	straw	Grain	straw	Grain	straw
Fallow	…	…	…	…	…	…
Basmati rice–wheat–*dhaincha*	1.41	0.49	0.44	0.18	0.46	1.49
Basmati rice–kabuli chickpea–mung bean	1.36	0.43	0.43	0.17	0.44	1.48
Basmati rice–chickpea–mung bean	1.35	0.44	0.44	0.16	0.43	1.47
Basmati rice–berseem–mung bean	1.45	0.50	0.45	0.19	0.45	1.48
SEm±	0.02	0.01	0.004	0.06	0.03	0.08
CD (P=0.05)	0.07	0.03	0.012	NS	NS	NS

SEm±, Standard error of mean; CD, Critical difference

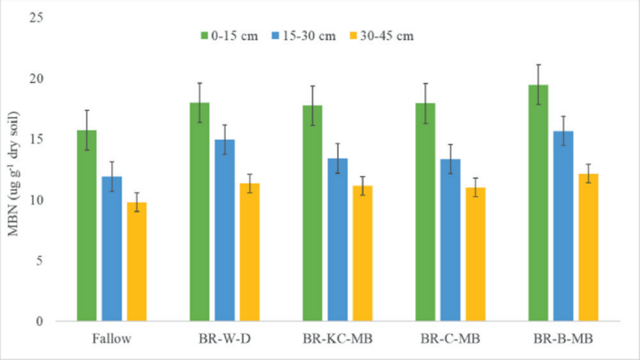

Fig. 2. Effect of basmati rice-based production systems on soil MBN Fallow, BR-W-D: Basmati rice–wheat–*dhaincha*, BR-KC-MB: Basmati rice–kabuli chickpea–mung bean, BR-C-MB: Basmati rice–chickpea–mung bean, BR-B-MB: Basmati rice–berseem–mung bean. Error bar indicates critical difference (CD) at P=0.05

highlights the benefits of legumes. Legumes contribute higher biomass and organic matter, which support robust microbial growth at the surface (Choudhary and Gill, 2013). At 15–30 cm and 30–45 cm depths, the basmati rice–berseem–mung bean system consistently promoted microbial biomass effectively, likely due to its high-quality organic residue, extensive root system, and nitrogen-fixing capability. Soil under fallow land had the lowest MBC (167.50 µg/g). Similarly, at the 15–30 cm layer, basmati rice–berseem–mung bean had the highest MBC (138.45 µg/g), followed by basmati rice–wheat–*dhaincha* (133.90 µg/g), basmati rice–kabuli chickpea–mungbean (128.63 µg/g), and basmati rice–chickpea–mungbean system (124.66 µg/g). Concerning the 30–45 cm layer, soil under the basmati rice–berseem–mung bean system recorded significantly higher MBC (111.33 µg/g), followed by the basmati rice–wheat–*dhaincha* system (108.71 µg/g).

Soil under fallow land had the least MBC (90.46 µg/g MBC at 30–45 cm depth). MBN followed a similar pattern to MBC. In the 0–15 cm layer, soil under basmati rice-berseem-mung bean system recorded the highest MBN (19.48 µg/g), followed by basmati rice–wheat–*dhaincha* (18.00 µg/g), basmati rice–chickpea–mung bean (17.95 µg/g), and basmati rice–kabuli chickpea–mung bean (17.75 µg/g). Soil under fallow land had the lowest MBN (15.75 µg/g) in the surface layer–15 cm depth). At the 15–30 cm depth, soil under basmati rice–berseem–mung bean had the highest MBN (15.67 µg/g), followed by basmati rice–wheat–*dhaincha* system. Similarly, at 30–45 cm depth, cultivation of basmati rice–berseem–mung bean recorded the highest (12.18 µg/g), and soil under fallow land has the lowest MBN (9.82 µg/g). Legume-embedded basmati rice-based production systems had ~ 12.43–24.03% higher MBC over fallow land at 30–45 cm soil depth. Diversified rice-based production systems improve soil microbial health, especially when integrating legumes and green manures (Jones *et al.,* 2018). Similar findings were reported by Padbhushan *et al.* (2015).

Thus, long-term integration of legumes in basmati rice–based cropping systems markedly enhanced yield-attributing traits, grain nutrient density, and soil biological health. Among the evaluated systems, basmati rice–berseem–mung bean and basmati rice–wheat–*dhaincha* consistently produced the greatest improvements in basmati rice performance. Therefore, inclusion of berseem (rabi season) or *dhaincha* (summer season) in rice-based systems is strongly recommended as a sustainable intensification strategy to enhance rice productivity while ensuring long-term soil resilience.

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