International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2025; SP-9(10): 957-960
www.biochemjournal.com
Received: 23-07-2025
Accepted: 26-08-2025

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Studies on the yield, quality, and nutrient uptake of pigeon pea (*Cajanus cajan* L. Millsp.) through integrated nutrient management

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DOI: https://www.doi.org/10.33545/26174693.2025.v9.i10Sl.5952

Abstract
A field experiment was executed during the kharif season of 2024 at the Agronomy Farm, College of Agriculture, Dhule, Maharashtra, to evaluate integrated nutrient management (INM) practices in pigeon pea. The study employed a Randomized Block Design (RBD) with thirteen treatment combinations and three replications. Treatments included recommended fertilizer doses, combinations with farmyard manure (FYM), vermicompost, neem cake, and micronutrient applications. Among them, the treatment comprising GRDF (25 N: 50 P_2O_5: 0 K_2O kg ha^{-1}) along with FYM at 5 t ha^{-1} recorded the highest seed and straw yields, which were on par with most integrated treatments except the control and RDF alone. Protein content and protein yield also peaked under this treatment, while control plots consistently produced the lowest values. Nutrient uptake of N, P, and K was also maximum in the FYM-based GRDF treatment, with results being statistically similar to several integrated approaches. These findings suggest that combining inorganic fertilizers with organic amendments and micronutrients significantly improves pigeon pea yield, quality, and nutrient uptake.

Keywords: Integrated nutrient management, pigeon pea, micronutrients, organic manures, yield, quality, nutrient uptake

Introduction
Pigeon pea (Cajanus cajan L. Millsp.) is an important pulse crop valued for its high protein content and adaptability to semi-arid, rainfed regions. Known as red gram, arhar, or tur in India, its productivity is frequently constrained by moisture deficits during critical stages such as flowering and pod development (Sharma *et al*., 2012) [9]. One of the strategies to mitigate yield losses is the use of integrated nutrient management (INM), which emphasizes the balanced application of chemical fertilizers alongside organic and biological sources. As highlighted by Reddy *et al*. (2011) [8], this approach sustains soil fertility, enhances productivity, and reduces the cost of cultivation.

Continuous and excessive use of inorganic fertilizers has caused soil nutrient imbalances and declining crop yields in intensive systems. Pulses, although capable of fixing atmospheric nitrogen through symbiosis, often face limited growth due to macro-and micronutrient deficiencies. Micronutrients such as zinc, iron, and boron play a pivotal role in improving productivity, with foliar application shown to be particularly effective (Bhuiyan *et al*., 1999; Anitha *et al*., 2004) [3, 1]. Therefore, INM practices combining mineral fertilizers, organic manures, and crop residues are essential for achieving sustainable pigeon pea production.

Materials and Methods
The field trial was conducted at the Agronomy Farm, College of Agriculture, Dhule, Maharashtra, on clay-textured soil characterized as medium in nitrogen and phosphorus but rich in potassium. The pigeon pea variety 'Phule Trupti' was selected. The experiment was laid out in a Randomized Block Design with thirteen treatments replicated thrice. The treatment structure included absolute control, recommended doses of fertilizer (RDF), generalized RDF supplemented with FYM, vermicompost, neem cake, and combinations of these with multi-micronutrient formulations (both soil-applied and foliar).

Sowing was completed on June 25, 2024, and harvesting occurred on December 28, 2024. Standard agronomic practices were followed for crop management.

Results and Discussion

Yield

Grain yield (qt ha^{-1})

Application of INM treatments markedly influenced grain yield. The maximum yield (22.09 q ha^{-1}) was observed in GRDF combined with FYM (5 t ha^{-1}). This performance was statistically similar to several integrated nutrient combinations but significantly higher than RDF alone and the control. The lowest yield (10.26 q ha^{-1}) was noted in untreated control plots. Previous studies (Pandey *et al*., 2015) [7] have also demonstrated yield advantages of incorporating FYM and vermicompost, supporting the present findings.

Straw yield (qt ha^{-1})

Similar to grain yield, straw yield was highest in the GRDF + FYM treatment (71.22 q ha^{-1}), significantly outperforming the control (34.56 q ha^{-1}). The enhanced straw production can be linked to better growth attributes and higher biomass accumulation, consistent with the observations of Verma *et al*. (2022) [12] and Gupta *et al*. (2022) [5].

Quality studies

Protein content (%) and protein yield (kg ha^{-1})

Protein content and protein yield improved substantially under integrated nutrient applications. The GRDF + FYM treatment registered the highest values (20.06% protein content and 443.12 kg ha^{-1} protein yield), which were statistically similar to the micronutrient-supplemented GRDF treatment. In contrast, control plots produced the lowest protein levels. These results corroborate earlier reports by Gurjar *et al*. (2018) [6] and Pandey *et al*. (2015) [7].

Table 1: Effect of integrated nutrient management on grain yield and straw yield of pigeon pea.

Tr. No.	Treatment details	Grain yield (qt ha^{-1})	Straw yield (qt ha^{-1})
T_1	Absolute control (No fertilizer)	10.26	34.56
T_2	RDF (25 N: 50 P_2O_5: 0 K_2O) kg ha^{-1}	18.09	64.00
T_3	GRDF (25 N: 50 P_2O_5: 0 K_2O kg ha^{-1} + FYM 5t ha^{-1})	22.09	71.22
T_4	75% GRDF + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1}	17.00	62.38
T_5	75% GRDF + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	17.48	63.65
T_6	75% GRDF + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	21.84	70.46
T_7	100% RDN through Vermicompost	19.52	67.82
T_8	100% RDN through FYM	19.45	67.45
T_9	100% RDN through Neem cake	19.30	67.35
T_{10}	75% of N through Vermicompost + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	20.32	69.86
T_{11}	75% of N through FYM + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	19.94	69.04
T_{12}	75% of N through Neem cake + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	19.70	68.46
T_{13}	75% of RDF + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	19.57	68.00
	S. Em $\pm$	1.23	1.47
	C.D. at 5%	3.60	4.30

Table 2: Protein content (%) and Protein yield (kg ha^{-1}) of pigeon pea as influenced by different treatments

	Treatment details	Protein Content (%)	Protein yield (kg ha^{-1})
T_1	Absolute control (No fertilizer)	19.56	200.68
T_2	RDF (25 N: 50 P_2O_5: 0 K_2O) kg ha^{-1}	19.68	356.01
T_3	GRDF (25 N: 50 P_2O_5: 0 K_2O kg ha^{-1} + FYM 5t ha^{-1})	20.06	443.12
T_4	75% GRDF + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1}	19.68	334.56
T_5	75% GRDF + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	19.75	345.23
T_6	75% GRDF + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	20.06	438.11
T_7	100% RDN through Vermicompost	19.81	386.69
T_8	100% RDN through FYM	19.81	385.30
T_9	100% RDN through Neem cake	19.75	381.17
T_{10}	75% of N through Vermicompost + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	20.00	406.40
T_{11}	75% of N through FYM + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	19.93	397.40
T_{12}	75% of N through Neem cake + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	19.93	392.62
T_{13}	75% of RDF + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	19.87	388.85
	S. Em $\pm$	0.232	7.18
	C.D. at 5%	NS	21.44

Table 3: Nutrient content (%) of pigeon pea grain and stover as influenced by different treatments.

	Treatment details	Nutrient content in grain (%)			Nutrient content in stover (%)		
		N	P	K	N	P	K
T_1	Absolute control (No fertilizer)	3.13	0.33	1.49	1.15	0.20	2.28
T_2	RDF (25 N: 50 P_2O_5: 0 K_2O) kg ha^{-1}	3.15	0.34	1.51	1.17	0.22	2.29
T_3	GRDF (25 N: 50 P_2O_5: 0 K_2O kg ha^{-1} + FYM 5t ha^{-1})	3.21	0.38	1.56	1.22	0.26	2.36
T_4	75% GRDF + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1}	3.15	0.34	1.51	1.18	0.22	2.30
T_5	75% GRDF + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	3.16	0.35	1.52	1.19	0.23	2.31
T_6	75% GRDF + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	3.21	0.38	1.56	1.22	0.26	2.35
T_7	100% RDN through Vermicompost	3.17	0.36	1.54	1.20	0.24	2.33
T_8	100% RDN through FYM	3.17	0.35	1.53	1.20	0.24	2.32
T_9	100% RDN through Neem cake	3.16	0.35	1.53	1.20	0.23	2.32
T_{10}	75% of N through Vermicompost + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	3.20	0.37	1.55	1.22	0.25	2.34
T_{11}	75% of N through FYM + Soil application of Multi-micronutrient Grade I @ 25 kg ha^1 + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	3.19	0.37	1.55	1.21	0.25	2.34
T_{12}	75% of N through Neem cake + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	3.19	0.37	1.54	1.21	0.24	2.33
T_{13}	75% of RDF + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	3.18	0.36	1.54	1.20	0.23	2.33
	S. Em $\pm$	0.11	0.05	0.07	0.13	0.02	0.08
	C.D. at 5%	NS	NS	NS	NS	NS	NS

Table 4: Nitrogen, Phosphorous and Potassium Uptake (kg ha^{-1}) of pigeon pea as influenced by different treatments

	Treatment details	Nitrogen Uptake (kg ha^{-1})	Phosphorous Uptake (kg ha^{-1})	Potassium Uptake (kg ha^{-1})
T_1	Absolute control (No fertilizer)	71.85	10.29	94.08
T_2	RDF (25 N: 50 P_2O_5: 0 K_2O) kg ha^{-1}	131.15	20.23	173.87
T_3	GRDF (25 N: 50 P_2O_5: 0 K_2O kg ha^{-1} + FYM 5t ha^{-1})	157.79	26.91	202.53
T_4	75% GRDF + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1}	127.15	19.50	169.14
T_5	75% GRDF + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	130.98	20.75	173.60
T_6	75% GRDF + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	156.38	26.68	200.26
T_7	100% RDN through Vermicompost	143.26	23.30	188.08
T_8	100% RDN through FYM	142.59	22.99	186.24
T_9	100% RDN through Neem cake	141.80	22.24	185.78
T_{10}	75% of N through Vermicompost + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	150.25	24.98	194.96
T_{11}	75% of N through FYM + Soil application of Multi-micronutrient Grade I @ 25 kg ha^1 + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	147.14	24.63	192.46
T_{12}	75% of N through Neem cake + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	145.67	23.71	189.84
T_{13}	75% of RDF + Soil application of Multi-micronutrient Grade I @ 25 kg ha^{-1} + Two foliar sprays of Phule Liquid Micro Grade II @ 1% at flowering and pod filling stage	143.83	22.68	188.57
	S. Em $\pm$	8.42	1.98	7.85
	C.D. at 5%	24.61	5.83	23.03

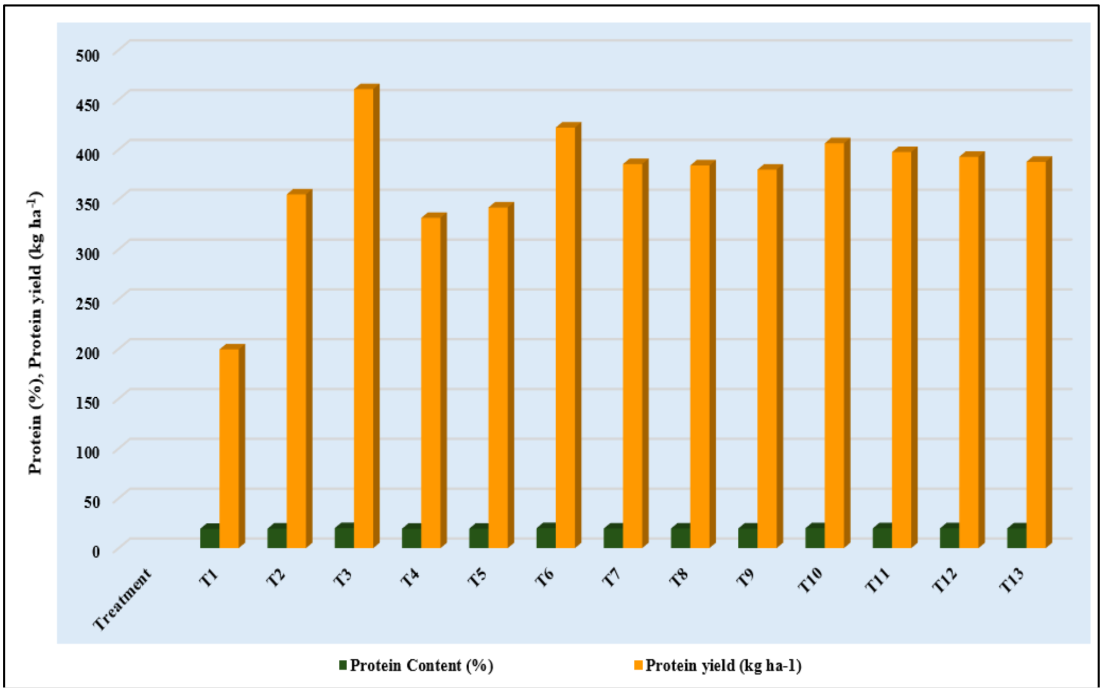

Fig 1: Protein (%) and protein yield (kg ha^{-1}) of pigeon pea as influenced by different treatment

Nutrient content and nutrient uptake

Nutrient concentrations of N, P, and K in both grain and straw were enhanced with GRDF + FYM. This treatment recorded the highest uptake values, though several integrated treatments yielded comparable results. Nutrient uptake was significantly lower under control conditions. The findings align with earlier reports (Devi *et al*., 2013; Bathula *et al*., 2019; Tiwari *et al*., 2012) [4, 2, 11], emphasizing the positive role of INM in nutrient assimilation.

Conclusion

Integrated nutrient management strategies considerably improved yield, quality, and nutrient uptake in pigeon pea. The treatment combining GRDF with FYM (5 t ha^{-1}) consistently outperformed others, delivering maximum grain and straw yields, protein yield, and nutrient uptake. These results highlight the importance of supplementing chemical fertilizers with organic amendments and micronutrients for enhancing crop productivity and maintaining soil health under rainfed conditions.

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