Madras Agric.J.,2025; https://doi.org/10.29321/MAJ.10.SE1231

RESEARCH ARTICLE

Enhancing Nutrient Use Efficiency in Cowpea through Soil Test Crop Response and Decision-Support Tools in Karnataka

Krishna Murthy, R*[1], Bhavya, N[2], Govinda, K[1], Shivakumara, M.N[1], Mohammed Saqeebulla, H[1], Basavaraja, P.K[1], Gangamrutha, G.V[1], Sanjay Srivastava[3],Immanuel Chongboi Haokip[3], Pradip Dey[4]

[1]All India Coordinated Research Project on Soil Test Crop Response, University of Agricultural Sciences, Bangalore
[2] Department of Soil Science and Agricultural Chemistry, College of Agriculture, University of Agricultural Sciences, Bangalore
[3]All India Coordinated Research Project on Soil Test Crop Response, ICAR-Indian Institute of Soil Science, Bhopal
[4] Indian Council of Agricultural Research-Agricultural Technology Application Research Institute, Kolkata

ABSTRACT

Nutrient imbalance and imprecise fertiliser use are significant constraints to crop productivity in India, often resulting from blanket recommendations that fail to consider the site-specific soil fertility status. Soil testing and modern nutrient management approaches, such as the Soil Test Crop Response (STCR) methodology and decision-support tools like Dhartimitra software, provide a scientific basis for balanced fertilisation and sustainable yield targets. To evaluate their effectiveness, a field experiment was conducted during the Kharif 2024 season at farmers' fields in the Bangalore Rural, Tumakuru, and Chikkaballapura districts of Karnataka. The trial compared STCR-based recommendations (using Dhartimitra software and actual soil test values) with the soil test laboratory approach, the general recommended dose, farmers' practices, and an absolute control in a randomised complete block design with three replications. Results showed that STCR-based nutrient management for a targeted yield of 15 q ha^{-1} through Dhartimitra software achieved the highest mean grain yield (15.28 q ha^{-1}), followed by STCR through actual soil test values (14.97 q ha^{-1}), both significantly superior to conventional recommendations. These treatments also recorded the highest nutrient uptake of N, P_2O_5, and K_2O. Nutrient use efficiency indices revealed that nitrogen agronomic efficiency was maximum under STCR treatments (39.6 kg kg^{-1}), while phosphorus recovery efficiency remained low due to fixation; however, relative internal utilisation efficiency was stable. This study demonstrates that soil test–based STCR recommendations, particularly when supported by Dhartimitra software, enhance yield, nutrient uptake, and efficiency compared to blanket fertiliser use, ensuring sustainable crop production and improved nutrient stewardship.

Received: 22 Jun 2025

Revised: 03 Aug 2025

Accepted: 28 Aug 2025

Keywords: *Soil Test Crop Response, Dhartimitra Software, Cowpea productivity, Nutrient use efficiency*

INTRODUCTION

Cowpea (*Vigna unguiculata* L.) is an important legume crop grown for its protein-rich seeds, tender pods, and fodder value Rukhsar *et al*., (2020). It plays a significant role in the diets of millions and serves as a crucial crop in sustainable agriculture due to its nitrogen-fixing ability and adaptability to marginal

*Corresponding author mail: srkmurthyssac@gmail.com

soils (Yururdurmaz 2022). India is one of the largest producers of cowpea, with cultivation spread across states such as Uttar Pradesh, Madhya Pradesh, Maharashtra, Karnataka, Tamil Nadu, and Andhra Pradesh. In India, cowpea is cultivated over an area of approximately 4.0 lakh hectares with an annual production of around 2.5 lakh tonnes. However, the national average productivity remains relatively low, at around 600–700 kg ha^{-1}, primarily due to suboptimal crop management and poor nutrient management practices (Agarwal and Devra, 2024). Karnataka, especially the northern dry zones, contributes significantly to the total area under cowpea cultivation in India. The state grows cowpea both as a pulse and as a vegetable crop, with considerable acreage in districts like Dharwad, Belagavi, and Raichur. Despite its regional importance, cowpea productivity in Karnataka also remains below its genetic potential, highlighting the need for improved agronomic and nutrient management strategies (Ashoka *et al*., 2025).

Among the various factors limiting cowpea productivity, improper and imbalanced fertiliser application stands out as a major concern. Blanket fertiliser recommendations often fail to address the specific nutrient needs of soils and crops, resulting in either nutrient deficiency or excess. Soil testing plays a crucial role in determining the existing nutrient status of the soil and serves as the basis for precise fertiliser recommendations (Krishna Murthy *et al*., 2021). Site-specific nutrient management through soil testing ensures better crop response, efficient fertiliser use, and environmental sustainability. Several modern approaches have emerged to improve the accuracy of fertiliser recommendations. One such method is the Soil Test Crop Response (STCR) approach, which combines soil test values, crop nutrient requirements, and fertiliser efficiency to provide balanced nutrient recommendations for targeted yields (Bhavya and Basavaraja, 2021). This approach has proven effective in enhancing productivity and maintaining soil health. In recent years, mobile and software-based platforms, such as 'Dhartimitra' developed by All India Coordinated Research Project on Soil Test Crop Response, have revolutionised nutrient management by providing real-time, location-specific fertiliser recommendations to farmers based on soil test data. These digital tools bridge the gap between scientific knowledge and on-farm decision-making, promoting efficient and need-based fertilizer use among farmers.

Another critical issue in cowpea cultivation is nutritional imbalance, which results from continuous cultivation without adequate nutrient replenishment or due to the omission of secondary and micronutrients (Omomowo and Babalola, 2021). Imbalanced fertilization leads to poor growth, low pod setting, and reduced grain quality, ultimately affecting the economic returns of the crop. Addressing these nutritional gaps through appropriate recommendation strategies is essential to harness the full yield potential of cowpea and ensure soil sustainability. Given this background, the present research aims to evaluate and compare different approaches to fertiliser recommendation — including conventional, STCR, and software-based methods—for their effectiveness in improving cowpea productivity, nutrient uptake, and nutrient use efficiency.

MATERIAL AND METHODS

A field experiment evaluating different approaches to fertiliser recommendation was conducted during the Kharif season of 2024 at the farmers' fields in various districts of Karnataka, including Bengaluru Rural, Tumakuru, and Chikkaballapura, which belong to the Eastern dry zone of Karnataka. The area experiences a dry tropical savanna climate, marked by hot summers and mild winters, with an average annual rainfall of 943.9 mm. The initial soil properties of the experimental sites are provided in Table 1.

Table 1: Initial Properties of the experimental site

Parameters	Bengaluru Rural	Tumakuru	Chikkaballapura
pH	6.01	6.12	6.25
EC (dS m^{-1})	0.30	0.31	0.40
OC (kg g^{-1})	3.21	3.05	3.47
N (kg ha^{-1})	230.56	284.15	289.67
P_2O_5 (kg ha^{-1})	58.94	85.25	56.63
K_2O (kg ha^{-1})	190.46	152.31	200.08

Fertilizer Prescription Equation Development for Cowpea

To derive fertiliser recommendations, the STCR methodology, involving two sequential field trials, was adopted. First, a fertility gradient experiment was conducted to generate spatial variability in nutrient status, followed by a test crop experiment using cowpea as the test crop (Ramamoorthy *et al.,* 1967). The data collected from the test crop experiment were used to determine the basic parameters, including nutrient requirements, soil and fertiliser contributions, and manure efficiency.

Fertilizer requirements for cowpea were calculated using the derived STCR equations:

- $FN = 11.02T - 0.43\ SN$
- $FP_2O_5 = 8.48 - 0.466SP_2O_5$
- $FK_2O = 1.775T - 0.150SK_2O$

Where:

FN, FP_2O_5, FK_2O = Fertilizer nitrogen, phosphorus, and potassium (kg ha^{-1}); T = Target yield (q ha^{-1}); SN, SP_2O_5, SK_2O = Soil-available phosphorus and potassium. FYM was added @ 7.5 t ha^{-1}

Experimental Design and Treatment Details

The experiment was structured using a Randomized Complete Block Design (RCBD) with three replications and comprised seven fertilization treatments and an absolute control: T_1: STCR TY 15 q ha^{-1} through dhartimitra software, T_2: STCR TY 15 q ha^{-1} through actual soil test values, T_3: STCR TY 12 q ha^{-1} through dhartimitra software, T_4: STCR TY 12 q ha^{-1} through actual soil test values, T_5: Soil test laboratory approach, T_6: General Recommended dose T_7: Farmers practice, T_8: Absolute control. Before sowing, soil samples were collected from a depth of 0–20 cm were collected for nutrient analysis. Farmyard manure (FYM) was added at the rate of 7.5 t ha^{-1} from treatment 1 to 7 and incorporated 15 days before planting, with nutrient contents of 0.57% N, 0.34% P, and 0.51% K. Calculated quantity of fertilisers was applied as per treatments, and for treatments 1 & 3, fertiliser dose obtained with the software was used. Half of the nitrogen, full phosphorus, and potassium were applied as a basal dose using urea, single superphosphate, and muriate of potash, respectively. Crop management followed standard agronomic practices, and harvesting was done at physiological maturity. To assess treatment efficacy, the following indices were computed using standard methods (Ramamoorthy *et al*., 1970):

$$\text{Response Yardstick (RYS)} = \frac{\text{Yield increase } (\text{kg ha}^{-1})}{\text{Total nutrient applied } (\text{kg ha}^{-1})}$$

$$\text{Percent deviation} = \frac{[\text{Actual yield obtained } (\text{kg ha}^{-1}) - \text{Targeted yield } (\text{kg ha}^{-1})]}{\text{Targeted yield } (\text{kg ha}^{-1})} \times 100$$

$$\text{Value cost ratio (VCR)} = \frac{[\text{Yield in treated plot } (\text{kg ha}^{-1}) - \text{Yield in control plot } (\text{kg ha}^{-1})]}{\text{Cost of fertilizers and FYM applied to treated plot}} \times \text{Cost kg}^{-1} \text{ of seed}$$

Soil and Plant Analysis

Soil samples were air-dried, sieved through a 2 mm mesh, and analysed for various parameters. Soil pH and electrical conductivity (EC) were determined in a 1:2.5 soil–water suspension (Jackson, 1973); organic carbon was estimated via the Walkley and Black method (1934); available nitrogen using the alkaline $KMnO_4$ method (Subbiah and Asija, 1956); available phosphorus through Bray's No. 1 extractant and colorimetry (Bray and Kurtz, 1945); and available potassium by 1N ammonium acetate extraction and flame photometry (Page *et al*., 1982). Plant samples from each plot were shade-dried, then oven-dried at 65 °C, and ground for nutrient analysis. Nitrogen content was determined using the Micro-Kjeldahl method (Piper, 1966). Phosphorus and potassium were extracted through di-acid digestion (HNO_3:$HClO_4$ in a 9:4 ratio) and measured using the vanadomolybdate yellow colour method and flame photometry, respectively (Jackson, 1973). Nutrient uptake (kg ha^{-1}) was calculated as (nutrient concentration × dry matter yield in kg ha^{-1}) / 100.

Nutrient Use Efficiency Calculations

Nutrient (N/P/K) use efficiency parameters, *viz.,* Agronomic nutrient use efficiency (AE), Recovery efficiency (RE), and Reciprocal internal utilisation efficacy (RIUE), were calculated using the following formulae, as per Krishna Murthy *et al*., (2023a):

$$AE(kg\ kg^{-1}) = \frac{[\text{Grain yield in treated plot } (\text{kg ha}^{-1}) - \text{Grain yield in control plot } (\text{kg ha}^{-1})]}{\text{Fertilizer nutrient applied } (\text{kg ha}^{-1})}$$

$$RE(kg\ kg^{-1}) = \frac{[\text{Nutrient uptake in treated plot } (\text{kg ha}^{-1}) - \text{Nutrient uptake in control plot } (\text{kg ha}^{-1})]}{\text{Fertilizer nutrient applied } (\text{kg ha}^{-1})}$$

$$RIUE(kg\ kg^{-1}) = \frac{\text{Nutrient uptake by grain } (\text{kg ha}^{-1})}{\text{Grain yield } (\text{kg ha}^{-1})}$$

Statistical Analysis

Statistics were used for the information gathered on yield, nutrient uptake, and nutrient availability. A

P-value of 0.05 was selected as the level of significance for the "F" and "t" tests. When the 'F' test revealed a significant result, critical difference (CD) values were determined for P = 0.05 following the procedures outlined by Gomez and Gomez (1984).

RESULTS AND DISCUSSIONS

Yield

The grain yield of the crop was significantly influenced by different nutrient management approaches (Table 2). Among the treatments, the STCR approach for a targeted yield of 15 q ha^{-1} through the Dhartimitra software recorded the highest mean yield (15.28 q ha^{-1}) across the three locations, which was statistically superior to all other treatments. This was followed by the STCR approach, targeting a yield of 15 q ha^{-1} based on actual soil test values, with an actual yield of 14.97 q ha^{-1}. Moderate yield levels were observed in T_3 (12.38 q ha^{-1}) and T_4 (12.35 q ha^{-1}), which corresponded to STCR-based fertiliser application with a lower yield target of 12 q ha^{-1}. The soil test laboratory approach and the general recommended dose recorded yields of 11.43 q ha^{-1} and 11.07 q ha^{-1}, respectively, which were significantly lower than those of the STCR-based treatments. The farmers' practice resulted in a still lower yield of 9.67 q ha^{-1}, whereas the absolute control produced only 5.29 q ha^{-1}, highlighting the importance of nutrient application in realising higher productivity. The critical difference (CD) values indicated that the yield advantage of the STCR approach, as determined by Dhartimitra software and actual soil test values, over the conventional approaches was statistically significant. The consistency of performance across locations also confirmed the robustness of STCR-based nutrient management.

The higher yields obtained in the STCR approach at a higher target through the Dhartimitra software and actual soil test values may be attributed to the balanced and site-specific application of N, P_2O_5, and K_2O, coupled with the inclusion of FYM, which not only supplied essential nutrients but also improved soil organic matter and nutrient-use efficiency (Rangaiah *et al*., 2025). The use of Dhartimitra software for fertiliser prescription was found to be as effective as direct soil test-based calculations, indicating its practical utility for farmers as a digital decision-making tool. The slight but consistent yield advantage of T_1 over T_2 suggests that software-guided recommendations can serve as a reliable extension tool for broader adoption. The lower yield targets (T_3 and T_4) also responded positively, though their yields remained below those of T_1 and T_2, reflecting the importance of setting appropriate yield targets in STCR technology. In contrast, the soil test laboratory approach and general recommended dose did not perform as well, likely due to their inability to

Table 2: Quantity of fertilisers added through different nutrient management approaches and yield of cowpea at Bangalore Rural, Tumakuru, and Chikkaballapura Districts of Karnataka

Trt	Nutrient applied (kg ha^{-1}) Mean of 3 locations			Yield (q ha^{-1})		
	N	P_2O_5	K_2O	Location 1	Location 2	Location 3
T_1	25.21	65.63	23.64	15.10	14.95	15.78
T_2	37.07	52.99	25.29	14.80	14.65	15.47
T_3	22.58	60.47	15.12	11.52	11.14	12.48
T_4	30.56	42.89	16.47	12.09	11.96	12.99
T_5	25.00	50.00	23.48	11.30	11.18	11.81
T_6	25.00	50.00	25.00	10.94	10.83	11.44
T_7	28.00	30.00	10.00	9.55	9.46	9.99
T_8	0.00	0.00	0.00	5.23	5.17	5.46
			SEm±	0.79	0.78	0.84
			CD@5%	2.40	2.37	2.55

Note: T_1: STCR TY 15 q ha^{-1} through dhartimitra software, T_2: STCR TY 15 q ha^{-1} through actual soil test values, T_3: STCR TY 12 q ha^{-1} through dhartimitra software, T_4: STCR TY 12 q ha^{-1} through actual soil test values, T_5: Soil test laboratory approach, T_6: General Recommended dose T_7: Farmers practice, T_8: Absolute control.

account for site-specific nutrient dynamics and target yields (Krishna Murthy *et al*., 2024a; Annappa *et al*., 2025). Farmers' practices resulted in suboptimal yields due to imbalanced nutrient application, particularly the low use of phosphorus and potassium. The absolute control confirmed the inherent low productivity of the soil when no external nutrients were applied, with yields less than half of the STCR-based approaches (Sing *et a*l., 2021; Krishna Murthy *et al*., 2024b).

Response Yardstick (RYS), Per cent Deviation and Value Cost Ratio (VCR)

The response yardstick (RYS), per cent deviation, and value cost ratio (VCR) of cowpea varied significantly across different fertiliser recommendation approaches and locations (Table 3). The STCR-based 15 q ha⁻¹ targets recorded the highest efficiency with RYS values of 8.3–9.0, minimal deviation from the target (–2.33 to +5.20%), and consistently high VCR (>2.5), indicating both yield stability and economic viability. The STCR 12 q ha⁻¹ targets also showed favourable responses (RYS 6.1–8.4, VCR 1.6–2.2), though deviations were slightly larger (–7.17 to +8.25%). In contrast, the soil test laboratory approach and general recommended dose were less efficient (RYS <6.5, VCR ~1.6–1.7) with negative deviations (–5.83 to –9.75%), while the farmer's practice was least effective (RYS ~6.3, VCR ~1.4, deviation –16.75 to –21.17%). The absolute control had the most significant yield gap (>–54% deviation), underscoring the importance of nutrient application. Overall, the results clearly establish the superiority of STCR-based recommendations, especially with FYM integration, in enhancing nutrient use efficiency, achieving targeted yields, and ensuring higher profitability compared to conventional or blanket recommendations.

The findings of the present study are in close agreement with earlier reports, where STCR-based nutrient management has proven superior to blanket or conventional recommendations. Studies have highlighted that STCR approaches, especially when integrated with FYM, not only improve yield realisation but also enhance nutrient use efficiency and profitability compared to farmers' practices or recommended doses. Similar results were obtained, where STCR-IPNS treatments recorded higher nutrient uptake and better benefit–cost ratios, confirming the consistency of this approach across legumes and agro-ecological zones (Krishna Murthy *et al*., 2024c). Evidence from aerobic rice also showed that STCR with FYM was economically superior and contributed to sustaining soil fertility (Bhavya *et al.,* 2022). The present results, showing higher response yardstick, lower deviation from targets, and favourable VCR in STCR treatments (T1 and T2), reinforce these observations and establish that precision-based fertiliser prescription models, particularly STCR coupled with organics, are more effective in achieving

Table 3: Effect of different nutrient management approaches and Response Yardstick (RYS), Per cent deviation and Value Cost Ratio (VCR) of cowpea at Bangalore Rural, Tumakuru, and Chikkaballapura Districts of Karnataka

Trt	Location 1			Location 2			Location 3		
	RYS	% deviation	VCR	RYS	% deviation	VCR	RYS	% deviation	VCR
T_1	8.62	0.67	2.54	8.54	-0.33	2.51	9.01	5.2	2.65
T_2	8.3	-1.33	2.58	8.22	-2.33	2.56	8.68	3.13	2.7
T_3	6.41	-4	1.72	6.08	-7.17	1.63	7.15	4	1.92
T_4	7.63	0.75	2.03	7.55	-0.33	2.01	8.37	8.25	2.23
T_5	6.16	-5.83	1.69	6.1	-6.83	1.67	6.45	-1.58	1.77
T_6	5.71	-8.83	1.58	5.66	-9.75	1.57	5.98	-4.67	1.65
T_7	6.35	-20.42	1.42	6.31	-21.17	1.41	6.66	-16.75	1.49
T_8	–	-56.42	–	–	-56.92	–	–	-54.5	–

Note: T_1: STCR TY 15 q ha⁻¹ through dhartimitra software, T_2: STCR TY 15 q ha⁻¹ through actual soil test values, T_3: STCR TY 12 q ha⁻¹ through dhartimitra software, T_4: STCR TY 12 q ha⁻¹ through actual soil test values, T_5: Soil test laboratory approach, T_6: General Recommended dose T_7: Farmers practice, T_8: Absolute control.

targeted yields, improving efficiency, and ensuring sustainable cowpea production than conventional recommendations or farmers' practice

Nutrient Uptake

The nutrient uptake of cowpea differed significantly among the nutrient management treatments across the three locations (Bangalore Rural, Tumakuru, and Chikkaballapura districts of Karnataka) (Table 4). Among the treatments, STCR approach at 15 q ha^{-1} through Dhartimitra software recorded the highest N, P_2O_5 and K_2O uptake at all three locations, with values of 68.71, 11.54, and 35.48 kg ha^{-1}, respectively, in Bangalore Rural; 68.02, 10.84, and 35.13 kg ha^{-1} in Tumakuru; and 71.80, 12.01, and 37.08 kg ha^{-1} in Chikkaballapura. This was followed by the STCR approach at 15 q ha^{-1}, based on actual soil test values, which also showed consistently higher nutrient uptake, although slightly lower than T_1. Intermediate uptake values were observed under the STCR approach at 12 q ha^{-1}, as determined by Dhartimitra software, and at 12 q ha^{-1} through actual soil test values. In contrast, the Soil Test Laboratory approach and the General Recommended Dose showed comparatively lower uptakes. The lowest nutrient uptake among fertilised treatments was recorded under the Farmers' practice. In contrast, absolute control recorded the minimum uptake of N (23.8–24.8 kg ha^{-1}), P_2O_5 (3.75–4.25 kg ha^{-1}), and K_2O (12.15–12.83 kg ha^{-1}) across locations. The statistical analysis indicated that differences among treatments were statistically significant.

The superior performance of STCR-based nutrient management, integrated with FYM, can be attributed to a balanced and site-specific supply of nutrients that more efficiently matched the crop requirements (Krishna Murthy *et al.,* 2023b; Tiwari *et al*., 2020). The use of the Dhartimitra software further optimised nutrient allocation based on soil fertility status, enhancing nutrient uptake efficiency. These findings align with earlier reports that STCR-based fertilisation, when integrated with organics, enhances nutrient availability, root growth, and microbial activity, resulting in higher uptake of N, P, and K (Mahajan *et al*., 2019; Krishna Murthy *et al*., 2023c).

The slightly higher uptake in Dhartimitra-guided treatments compared to soil test-based STCR suggests the advantage of decision-support tools in improving precision nutrient management at the field level. Treatments receiving lower target yields (12 q ha^{-1}) recorded lower uptake than their corresponding 15 q ha^{-1} counterparts, reflecting the direct relationship between nutrient supply, crop demand, and nutrient

Table 4: Effect of different nutrient management approaches on total uptake of major nutrients in cowpea at Bangalore Rural, Tumakuru, and Chikkaballapura Districts of Karnataka

Trt	Location 1			Location 2			Location 3		
	N uptake	P_2O_5 Uptake	K_2O uptake	N uptake	P_2O_5 Uptake	K_2O uptake	N uptake	P_2O_5 Uptake	K_2O uptake
T_1	68.71	11.54	35.48	68.02	10.84	35.13	71.8	12.01	37.08
T_2	67.34	10.73	34.78	66.66	10.62	34.43	70.39	11.22	36.35
T_3	52.42	8.35	27.07	50.69	8.08	26.18	56.78	9.05	29.33
T_4	55.01	8.77	28.41	54.42	8.67	28.11	59.1	9.42	30.53
T_5	51.42	8.19	26.56	50.87	8.11	26.27	53.74	8.56	27.75
T_6	49.78	7.93	25.71	49.28	7.85	25.45	52.05	8.29	26.88
T_7	43.45	6.92	22.44	43.04	6.86	22.23	45.45	7.24	23.48
T_8	23.8	4.01	12.29	23.52	3.75	12.15	24.84	4.25	12.83
SEm±	0.49	0.11	0.26	0.40	0.08	0.22	0.47	0.09	0.24
CD@5%	1.50	0.35	0.80	1.22	0.24	0.68	1.44	0.27	0.74

Note: T_1: STCR TY 15 q ha^{-1} through dhartimitra software, T_2: STCR TY 15 q ha^{-1} through actual soil test values, T_3: STCR TY 12 q ha^{-1} through dhartimitra software, T_4: STCR TY 12 q ha^{-1} through actual soil test values, T_5: Soil test laboratory approach, T_6: General Recommended dose T_7: Farmers practice, T_8: Absolute control.

absorption. In contrast, the soil test laboratory approach and general recommended dose did not consider site-specific variability or yield targets, resulting in sub-optimal uptake (Bhavya *et al*., 2021; Spoorthishankar *et al*., 2025).

Nutrient use efficiency

The nutrient use efficiency indices in cowpea varied considerably across the nutrient management treatments at Bangalore Rural, Tumakuru, and Chikkaballapura districts. For nitrogen, agronomic efficiency (AE) was highest in T_1 (39.6 kg kg^{-1}) and declined progressively to the lowest in T_7 (4.36 kg kg^{-1}). The apparent recovery efficiency (RE) of nitrogen ranged from 1.8 kg kg^{-1} in T_1 to 0.19 kg kg^{-1} in T_7, showing that higher fertiliser inputs did not proportionally increase nitrogen uptake. Relative internal utilisation efficiency (RIUE) of nitrogen remained relatively constant across treatments (4.48–4.60 kg kg^{-1}), indicating that the crop efficiently used the absorbed nitrogen regardless of application levels. Phosphorus use efficiency showed a different trend. AE ranged from 9.2 kg kg^{-1} in T_4 to 31.5 kg kg^{-1} in T_7, while RE remained low across all treatments (0.11–0.21 kg kg^{-1}), reflecting strong soil fixation and limited phosphorus uptake. Despite low recovery, RIUE values were relatively stable (0.69–0.75 kg kg^{-1}), indicating that phosphorus absorbed by the plant was effectively utilised. Potassium efficiency was comparatively stable. AE varied from 23.3 kg kg^{-1} in T_7 to 42.15 kg kg^{-1} in T_1, while RE remained low (0.73–0.99 kg kg^{-1}), suggesting that only a small fraction of applied potassium was recovered by the crop. RIUE values were consistent across treatments (2.12–2.38 kg kg^{-1}), indicating efficient internal utilisation of absorbed potassium.

These results highlight that nitrogen use efficiency declines with increasing fertiliser inputs (Moharana et al., 2017; Nagendrachari et al., 2025), phosphorus efficiency is limited by soil fixation despite effective internal utilisation, and potassium efficiency remains relatively stable (Banerjee et al., 2018). These patterns are consistent with previous studies on nutrient use efficiency as reported by Krishna Murthy et al., (2023d) and emphasise the need for optimised fertiliser management to maximise nutrient recovery while maintaining sustainable crop productivity

Post-Harvest Soil Available NPK Status

Post-harvest soil test values of N, P_2O_5, and K_2O varied significantly across locations and treatments, reflecting the influence of nutrient management strategies (Figures 1, 2, and 3). In Bangalore Rural, residual N among fertilised treatments ranged from 187.06 kg ha^{-1} in T_1 to 215.11 kg ha^{-1} in T_7. At the same time, P_2O_5 was highest in T_3 (81.06 kg ha^{-1}) and lowest in T_7 (52.02 kg ha^{-1}), with K_2O values remaining comparatively stable but higher under balanced treatments (T_5 and T_6). In Tumakuru, residual N was lowest in T_1 (241.34 kg ha^{-1}) and highest in

Table 5: Effect of different nutrient management approaches on nutrient use efficiency in cowpea at Bangalore Rural, Tumakuru, and Chikkaballapura Districts of Karnataka

Treatment	Nitrogen (kg kg^{-1})			Phosphorus (kg kg^{-1})			Potassium (kg kg^{-1})		
	AE	RE	RIUE	AE	RE	RIUE	AE	RE	RIUE
T_1	39.6	1.80	4.55	15.20	0.11	0.75	42.15	0.99	2.38
T_2	26.30	1.19	4.54	18.20	0.16	0.73	38.40	0.90	2.36
T_3	13.42	0.60	4.53	18.00	0.11	0.72	25.00	0.74	2.35
T_4	11.65	0.52	4.50	9.20	0.11	0.72	29.20	0.73	2.32
T_5	8.27	0.38	4.60	11.00	0.15	0.73	25.70	0.73	2.25
T_6	6.63	0.31	4.58	13.20	0.15	0.69	25.60	0.78	2.12
T_7	4.36	0.19	4.48	31.50	0.21	0.70	23.30	0.73	2.15
T_8	—	—	—	—	—	—	—	—	—

Note: T_1: STCR TY 15 q ha^{-1} through dhartimitra software, T_2: STCR TY 15 q ha^{-1} through actual soil test values, T_3: STCR TY 12 q ha^{-1} through dhartimitra software, T_4: STCR TY 12 q ha^{-1} through actual soil test values, T_5: Soil test laboratory approach, T_6: General Recommended dose T_7: Farmers practice, T_8: Absolute control.

T_7 (269.11 kg ha⁻¹), P_2O_5 was better maintained in STCR treatments (T_1 and T_3: 105.04–102.64 kg ha⁻¹) compared to T_7 and T_8 (73.39–69.56 kg ha⁻¹), while residual K_2O was highest in T_5 and T_6 (149.52–151.86 kg ha⁻¹). Similarly, in Chikkaballapura, residual N varied from 243.08 kg ha⁻¹ in T_1 to 272.22 kg ha⁻¹ in T_7, P_2O_5 was higher in T_1 and T_3 (80.25 and 78.05 kg ha⁻¹) but lowest in T_8 (50.45 kg ha⁻¹), and K_2O was best sustained under T_5 and T_6 (195.81–198.20 kg ha⁻¹). Across all districts, STCR-based targeted yield approaches (T_1 and T_2) maintained relatively higher and balanced nutrient levels, notably P and K, compared to conventional recommendations, while farmers' practice (T_7) and absolute control (T_8) consistently depleted soil P and K due to imbalanced or no fertiliser application (Sinchana *et al.*, 2025). These results highlight that precision nutrient management through STCR and Dhartimitra software not only improves yields and nutrient uptake but also conserves post-harvest soil fertility, ensuring the sustainability of cowpea production systems. These results conform with the findings of (Rangaiah *et al.*, 2025; Spoorthishankar *et al.*, 2024)

CONCLUSION

The study clearly demonstrated that the Soil Test Crop Response (STCR) approach significantly improved cowpea productivity, nutrient uptake, and nutrient use efficiency compared to conventional fertiliser recommendations and farmers' practices. Among the treatments, STCR-based recommendations for a targeted yield of 15 q ha⁻¹, as determined by Dhartimitra software and actual soil test values, recorded the highest yields and nutrient uptake, highlighting the superiority of precision-based prescriptions over blanket applications. Nitrogen agronomic efficiency was maximised under STCR treatments,

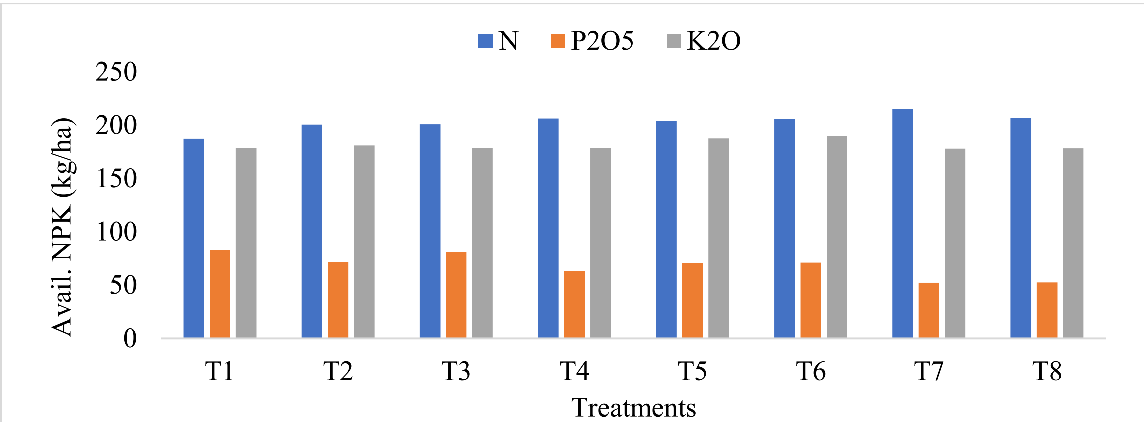

Fig. 1 Influence of different approaches of nutrient recommendations on post-harvest soil available N, P_2O_5 and K_2O at Bangalore Rural district of Karnataka

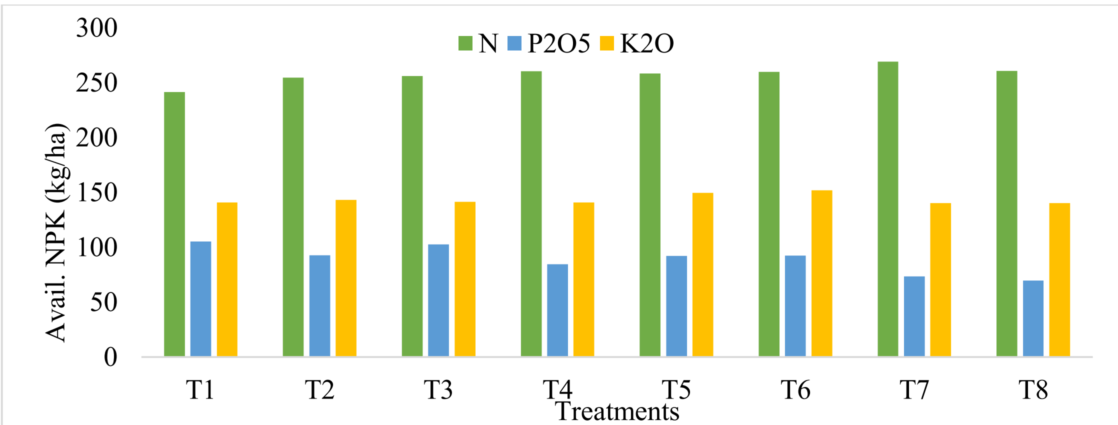

Fig. 2 Influence of different approaches of nutrient recommendations on post-harvest soil available N, P_2O_5 and K_2O at Tumakuru district of Karnataka

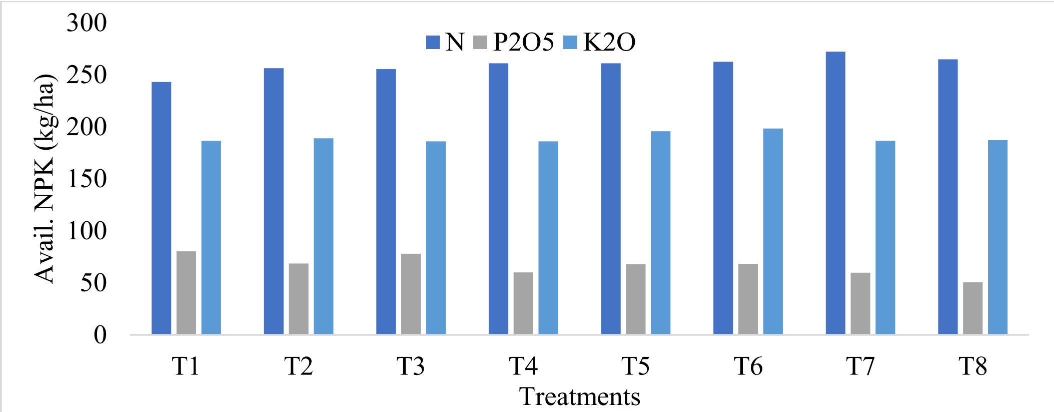

Fig. 3 Influence of different approaches of nutrient recommendations on post-harvest soil available N, P_2O_5 and K_2O at Chikkaballapura district of Karnataka

while phosphorus recovery was constrained by soil fixation, although its internal utilisation was efficient. Potassium efficiency was comparatively stable across treatments. The findings highlight the importance of soil testing and decision-support tools in correcting nutrient imbalances, optimising fertiliser use, and ensuring both economic viability and environmental sustainability. Thus, the integration of STCR technology with digital platforms, such as Dhartimitra, offers a practical, scalable, and farmer-friendly approach for enhancing cowpea production and promoting sustainable nutrient management in diverse agro-ecological zones.

Acknowledgements:

We greatly acknowledge the Indian Council of Agricultural Research, Indian Institute of Soil Science, Bhopal (ICAR_IISS), and the University of Agricultural Sciences, Bangalore, for funding the research.

Originality and Plagiarism:

We hereby declare that the work presented in this manuscript is original and has not been published elsewhere, nor is it currently under consideration for publication by any other journal. All sources used or quoted are correctly cited and acknowledged. We affirm that the manuscript is free from plagiarism, including self-plagiarism, and complies with the ethical standards for academic publishing.

Data availability statement:

The data that support this study will be shared upon reasonable request to the corresponding author.

Conflict of interest:

The author reported no potential conflicts of interest.

REFERENCES

Agarwal, D., and Devra, S.J. 2024. Pulses in India: Comprehensive analysis of production, challenges, and strategic vision for 2030. *Journal of Experimental Agriculture International* 46(11): 293–304. https://doi.org/10.9734/jeai/2024/v46i113053

Annappa, N.N., Krishna Murthy, R., Saralakumari, J., Thimmegowda, M.N., and Veeranagappa, P. 2025. A comprehensive analysis of the effects of balanced NPK fertilization on maize quality, nutrient uptake and soil sustainability using hierarchical cluster dendrogram techniques. *Plant Science Today* 12(2): 1–19. https://doi.org/10.14719/pst.7282

Ashoka, N., Ravi, Y., Vishwanatha, S., and Venkatesha, M.M. 2025. Optimizing cowpea (*Vigna unguiculata* (L.) Walp) for economic prosperity: A strategic approach to amplify agricultural revenue in Karnataka. *Range Management and Agroforestry* 46(1): 145–150. https://doi.org/10.59515/rma.2025.v46.i1.20

Banerjee, H., Ray, K., Dutta, S.K., Majumdar, K., Satyanarayana, T., and Timsina, J. 2018. Optimizing potassium application for hybrid rice (*Oryza sativa* L.) in coastal saline soils of West Bengal, *India. Agronomy* 8(12): 292. https://doi.org/10.3390/agronomy8120292

Bhavya, N., and Basavaraja, P.K. 2021. Influence of different approaches of nutrient recommendations on growth and yield of aerobic rice. *Mysore Journal of Agricultural Sciences* 55: 61–69.

Bhavya, N., Basavaraja, P.K., and Krishna Murthy, R. 2021. Assessment of soil test crop response based fertilization on nutrient requirement, nutrient uptake and nutrient use efficiency of aerobic rice. *Chemical Science Review and Letters* 9: 1–5. https://doi.org/10.37273/chesci.CS2820501002

Bhavya, N., Basavaraja, P.K., Krishna Murthy, R., Saqeebulla, M.H, and Gangamrutha, G.V. 2022. Impact of different approaches of nutrient recommendations for aerobic rice on soil fertility of *Alfisols* of Eastern Dry Zone of Karnataka. *International Journal of Plant & Soil Science* 34: 37–46. https://doi.org/10.9734/ijpss/2022/v34i1030921

Bray, R.H., and Kurtz, L.T. 1945. Determination of total, organic, and available phosphorus in soil. *Soil Science* 9: 39–46.

Gomez, K.A., and Gomez, A.A. 1984. Statistical Procedures for Agricultural Research. John Wiley & Sons, New York, p. 680.

Jackson, M.L. 1973. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi, p. 498.

Krishna Murthy, R., Basavaraja, P.K., Bhavya, N., Dey, P., Mohamed Saqueebulla, H., Gangamurtha, G.V., and Venkata Shiva Reddy, J.S. 2023. Development and validation of soil test based fertilizer prescription equations for enhancing yield, uptake and nutrient use efficiency of foxtail millet (*Setaria italica*) under dryland condition. *Journal of Plant Nutrition* 46(13): 3082–3100. https://doi.org/10.1080/01904167.2023.2188065

Krishna Murthy, R., Bhavya, N., Govinda, K., Uday Kumar, S.N., Basavaraja, P.K., Mohamed Saqueebulla, H.S., Srivastava, S., and Dey, P. 2023. Modelling soil, plant and fertilizer relationship to optimize nutrient management for chilli (*Capsicum annuum* L) under *Alfisols* of Southern India. *Archives of Agronomy and Soil Science* 69(15): 3570–3586. https://doi.org/10.1080/03650340.2023.2264210

Krishna Murthy, R., Bhavya, N., Govinda, K., Uday Kumar, S.N., Basavaraja, P.K., and Mohamed Saqueebulla, H. 2023. Influence of different approaches and forms of fertilizer application on yield and nutrient uptake of hybrid maize. *Theoretical Biology Forum* 12: 252–259. https://doi.org/10.61739/TBF.2023.12.2.252

Krishna Murthy, R., Nagaraju, B., Govinda, K., Uday Kumar, S.N., Basavaraja, P.K., Saqeebulla, H. M., Gangamrutha, G.V., Srivastava, S., and Dey, P. 2024. Soil test crop response nutrient prescription equations for improving soil health and yield sustainability—A long-term study under *Alfisols* of Southern India. *Frontiers in Plant Science* 15: 1439523. https://doi.org/10.3389/fpls.2024.1439523

Krishna Murthy, R., Nagaraju, B., Kasturappa, G., Kadappa, B.P., Narayanaswamy, U.K. S., Sab, M.S.H., Veerabadraiah, G.G., Srivastava, S., and Dey, P. 2024. Optimizing nutrient management for Kodo millet (*Paspalum scrobiculatum* L.) in the *Alfisols* of Southern India through modeling soil, plant, and fertilizer interactions. *Scientific Reports* 14(1): 31852. https://doi.org/10.1038/s41598-024-83265-y

Krishna Murthy, R., Nagaraju, B., Kasturappa, G., Nagendrachari, A.N., Kadappa, B.P., Narayanaswamy, U.K.S., Sab, M.S.H., Veerabadraiah, G.G., Srivastava, S., and Dey, P. 2024. Inductive cum targeted yield model-based integrated fertilizer prescription for sweet corn (*Zea mays* L. Saccharata) on *Alfisols* of Southern India. *PLoS One* 19(8): e0307168. https://doi.org/10.1371/journal.pone.0307168

Krishna Murthy, R., Nagaraju, B., Shankaraiah, S.K., Kasturappa, G., Kadappa, B.P., Sugatur Narayanaswamy, U.K., Saqeebulla, M., and Dey, P. 2024. Enhancing yield, uptake and nutrient use efficiency of brinjal through soil test crop response approach. *Communications in Soil Science and Plant Analysis* 55(7): 998–1014. https://doi.org/10.1080/00103624.2023.2289988

Mahajan, G.R., Pandey, R.N., Datta, S.C., Kumar, D., Sahoo, R.N., Patel, K.P., Murgaonkar, D., and Das, B. 2019. Predicting post-harvest soil test values in hybrid rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) cropping sequence using a multivariate analysis technique. *Communications in Soil Science and Plant Analysis* 50(13): 1624–1639. https://doi.org/10.1080/00103624.2019.1631328

Moharana, P.C., Sharma, B.M., and Biswas, D.R. 2017. Changes in the soil properties and availability of micronutrients after six-year application of organic and chemical fertilizers using STCR-based targeted yield equations under pearl millet-wheat cropping system. *Journal of Plant Nutrition* 40: 165–176. https://doi.org/10.1080/01904167.2016.1201504

Nagendrachari, A.N., Rangaiah, K.M., Jayaramreddy, S., Nanjundegowda, T.M., and

Parameshwarappa, V. 2025. Hierarchical cluster analysis approach for evaluating variability in nutrient uptake and composition of maize. *Communications in Soil Science and Plant Analysis* 56(11): 1685–1708. https://doi.org/10.1080/00103624.2025.2472894

Omomowo, O.I. and Babalola, O.O. 2021. Constraints and prospects of improving cowpea productivity to ensure food, nutritional security and environmental sustainability. *Frontiers in Plant Science* 12: 751731. https://doi.org/10.3389/fpls.2021.751731

Page, A.L., Miller, R.H., and Keeny, D.R. 1982. Methods of Soil and Plant Analysis. American Society of Agronomy, Madison, WI, USA, p. 498.

Piper, C. 1966. Soil and Plant Analysis. Hans Publications, Bombay, pp. 137–153.

Ramamoorthy, B., Narasimham, R.L., and Dinesh, R. S. 1967. Fertilizer application for specific yield targets on Sonora 64 (wheat). *Indian Farming* 17: 43–45.

Rangaiah, K.M., Nagaraju, B., Kasturappa, G., Nanjundappa, M.S., Narayanaswamy, U. K.S., Srivastava, S., and Dey, P. 2025. Assessment of fertilizer prescription equations, crop and soil performance with different nutrient management practices for green gram (*Vigna radiata*) in Southern India's *Alfisols*. *Scientific Reports* 15(1): 31954. https://doi.org/10.1038/s41598-025-04738-2

Rukhsar, C.B., Pithia, M.S., and Raval, L.J. 2020. Discriminate function analysis in cowpea (*Vigna unguiculata* (L.) Walp.). *Electronic Journal of Plant Breeding* 12(1): 54-57. https://doi.org/10.37992/2021.1201.008

Sinchana, M.A., Krishna Murthy, R., Bhavya, N., Govinda, K., and Shivakumara, M.N. 2025. Evaluation of different approaches of fertilizer recommendations on yield, nutrient uptake, and use efficiency of finger millet (*Eleusine coracana* L. Garten). *Madras Agricultural Journal* 112: 94–102. https://doi.org/10.29321/MAJ.10.701201

Singh, V.K., Gautam, P., Nanda, G., Dhaliwal, S.S., Pramanick, B., Meena, S.V., Alsanie, W.F., Ahmed, G., Sayed, S., and Hossain, A. 2021. Soil test-based fertilizer application improves productivity, profitability and nutrient use efficiency of rice (*Oryza sativa* L.) under direct seeded condition. *Agronomy* 11: 1756. https://doi.org/10.3390/agronomy11091756

Spoorthishankar, K.S., Krishna Murthy, R., Kadalli, G.G., Vasanthi, B.G., Pushpa, K., and Muthuraju, R. 2025. Comparative study on nutrient recommendation approaches for optimizing green gram productivity in *Alfisols*. *Mysore Journal of Agricultural Sciences* 59(1): 386–397.

Spoorthishankar, K.S., Krishna Murthy, R., Kadalli, G.G., Vasanthi, B.G., Pushpa, K., and Muthuraju, R. 2024. Comparison of STCR and conventional fertilizer approaches for improved yield, uptake and nutrient use efficiency in green gram. *Journal of Advances in Biology and Biotechnology* 27(11): 312–323. https://doi.org/10.9734/jabb/2024/v27i111614

Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for the determination of available nitrogen in soils. *Current Science* 37: 259–260.

Tiwari, R., Upadhyay, A.K., Rai, H.K., and Dey, P. 2020. Impact of fertilizers and manure on growth, yield, nutrient uptake by rice and soil properties in a *Vertisol* under STCR approach. *International Archives of Applied Sciences and Technology* 11: 57–65. https://doi.org/10.15515/iaast.0976-4828.11.2.5765

Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 37: 29–38.

Yururdurmaz, C. 2022. Impact of different fertilizer forms on yield components and macro–micronutrient contents of cowpea (*Vigna unguiculata* L.). *Sustainability* 14(19): 12753. https://doi.org/10.3390/su141912753