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

**Krishna Murthy, R**\*1, **Bhavya, N2, Govinda, K1, Shivakumara, M.N1, Mohammed Saqeebulla, H1, Basavaraja, P.K1, Gangamrutha, G.V1, Sanjay Srivastava3, Pradip Dey4**

1 All India Coordinated Research Project on Soil Test Crop Response, University of Agricultural Sciences, Bangalore

2 Assistant Professor, Department of Soil Science and Agricultural Chemistry, College of Agriculture, University of Agricultural Sciences, Bangalore

3 Project Coordinator, All India Coordinated Research Project on Soil Test Crop Response, ICAR-Indian Institute of Soil Science, Bhopal

4Director, Indian Council of Agricultural Research-Agricultural Technology Application Research Institute, Kolkata

**\*Corresponding address:** srkmurthyssac@gmail.com**,** Contact no: 9632202521

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| S.no | Other Author(s) | \*Mail ID | \*Orchid ID | \*Linkedin ID |
| 1. | **Krishna Murthy R1** | srkmurthyssac@gmail.com | 0000-0001-9922-7683 | <https://www.linkedin.com/in/dr-r-krishna-murthy-a6904817/> |
| 2. | **Bhavya N2** | bhavyanagraj.6@gmail.com | 0000-0001-7954-2985 | <https://www.linkedin.com/in/bhavya-n-96b299143/> |
| 3. | **Govinda, K1** | kgovind958@gmail.com | 0009-0002-2172-8554 | <https://www.linkedin.com/in/govind-k-777334259/> |
| 4. | **Shivakumara,M. N1** | mnshivakumara@gmail.com | 0000-0001-9915-4509 | <https://www.linkedin.com/in/dr-shivakumara-mn-n-002137133/> |
| 5. | **Mohammed Saqeebulla, H1** | Saqeeb323@gmail.com | 0000-0001-6714-5050 | <https://www.linkedin.com/in/dr-mohamed-saqeebulla-h-42709041/>  |
| 6. | **Basavaraja, P.K1** | pujarikbraj@gmail.com | 0009-0009-0285-883X | <https://www.linkedin.com/in/basavaraj-pk-889958286/>  |
| 7. | **Gangamrutha, G.V1** | gangamrutha@gmail.com | 0009-0007-7925-495X | - |
| 8. | **Sanjay Srivastava3** | pcstcr@gmail.com | 0009-0001-2935-4852 | <https://www.linkedin.com/in/sanjay-srivastava-85611620/>  |
| 9. | **Pradip Dey4** | pradipdey@yahoo.com | 0000-0002-9161-4707 | <https://www.linkedin.com/in/dey-pradip/>  |

**ABSTRACT**

Nutrient imbalance and imprecise fertilizer use are major constraints to crop productivity in India, often resulting from blanket recommendations that fail to consider 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 fertilization and sustainable yield targets. To evaluate their effectiveness, a field experiment was conducted during Kharif 2024 at farmers’ fields in Bangalore Rural, Tumakuru, and Chikkaballapura districts of Karnataka. The trial compared STCR-based recommendations (using Dhartimitra software and actual soil test values), soil test laboratory approach, general recommended dose, farmers’ practice, and an absolute control in a randomized 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, P₂O₅, and K₂O. 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, though relative internal utilization 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 fertilizer use, ensuring sustainable crop production and improved nutrient stewardship.

**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. 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 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 fertilizer application stands out as a major concern. Blanket fertilizer recommendations often fail to address the specific nutrient needs of soils and crops, leading to either deficiency or excess of nutrients. Soil testing plays a critical role in diagnosing the existing nutrient status of the soil and serves as the foundation for precise fertilizer recommendations (Krishna Murthy *et al*., 2021). Site-specific nutrient management through soil testing ensures better crop response, efficient fertilizer use, and environmental sustainability. Several modern approaches have emerged to improve the accuracy of fertilizer recommendations. One such method is the Soil Test Crop Response (STCR) approach, which combines soil test values, crop nutrient requirements, and fertilizer 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 revolutionized nutrient management by providing real-time, location-specific fertilizer 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 of fertilizer 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 based on the evaluation of different approaches of fertilizer recommendation was conducted during the Kharif season of 2024 at the farmers’ field of various districts of Karnataka *viz*., 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 |
| P2O5 (kg ha-1) | 58.94 | 85.25 | 56.63 |
| K2O (kg ha-1) | 190.46 | 152.31 | 200.08 |

**Fertilizer Prescription Equation Development for Cowpea**

To derive fertilizer recommendations, the STCR methodology involving two sequential field trials was adopted - first, a fertility gradient experiment 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 requirement, soil and fertilizer contribution, and manure efficiency.

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

* FN = 11.02T – 0.43 SN
* FP₂O₅ = 8.48 – 0.466SP₂O₅
* FK₂O = 1.775T − 0.150SK₂O

Where:

FN, FP₂O₅, FK₂O = Fertilizer nitrogen, phosphorus, and potassium (kg ha⁻¹); T = Target yield (q ha⁻¹); SN, SP₂O₅, SK₂O = 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: T1: STCR TY 15 q ha⁻¹ through dhartimitra software, T2: STCR TY 15 q ha⁻¹ through actual soil test values, T3: STCR TY 12 q ha⁻¹ through dhartimitra software, T4: STCR TY 12 q ha⁻¹ through actual soil test values, T5: Soil test laboratory approach, T6: General Recommended dose T7: Farmers practice, T8: Absolute control. Before sowing, soil samples from 0–20 cm depth were collected for nutrient analysis. Farmyard manure (FYM) was added at the rate of 7.5 t ha-1 from treatment 1 to 7and incorporated 15 days before planting, with nutrient contents of 0.57% N, 0.34% P, and 0.51% K. Calculated quantity of fertilizers was applied as per treatments, and for treatments 1 &3, fertilizer dose obtained with the software was used. Half of nitrogen and full phosphorus and potassium were applied as a basal dose using urea, single super phosphate, 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):

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

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

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

**Soil and Plant Analysis**

Soil samples were air-dried, sieved through a 2 mm mesh, and analyzed 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 KMnO₄ 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), while phosphorus and potassium were extracted through di-acid digestion (HNO₃:HClO₄ in 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 utilization efficacy (RIUE) were calculated using the following formulae, as per Krishna Murthy *et al*., (2023a):

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

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

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

**Statistical Analysis**

Statistics were used for the information gathered on yield, nutrient uptake, and nutrient availability. P = 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).

**RESULT AND DISCUSSIONS**

**Yield**

The grain yield of the crop was significantly influenced by different nutrient management approaches (Table 2). Among the treatments, STCR approach for targeted yield of 15 q ha⁻¹ through 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 STCR approach for targeted yield of 15 q ha⁻¹ based on actual soil test values with the yield of 14.97 q ha⁻¹. Moderate yield levels were observed in T3 (12.38 q ha⁻¹) and T4 (12.35 q ha⁻¹), which corresponded to STCR-based fertilizer application with a lower yield target of 12 q ha⁻¹. The soil test laboratory approach and general recommended dose recorded yields of 11.43 q ha⁻¹ and 11.07 q ha⁻¹, respectively, which were significantly lower than STCR-based treatments. 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 realizing higher productivity. The critical difference (CD) values indicated that the yield advantage of STCR approach through Dhartimitra software as well as 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.

**Table 2: Quantity of fertilizers 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** | **P2O5** | **K2O** | **Location 1** | **Location 2** | **Location 3** |
| T1 | 25.21 | 65.63 | 23.64 | 15.10 | 14.95 | 15.78 |
| T2 | 37.07 | 52.99 | 25.29 | 14.80 | 14.65 | 15.47 |
| T3 | 22.58 | 60.47 | 15.12 | 11.52 | 11.14 | 12.48 |
| T4 | 30.56 | 42.89 | 16.47 | 12.09 | 11.96 | 12.99 |
| T5 | 25.00 | 50.00 | 23.48 | 11.30 | 11.18 | 11.81 |
| T6 | 25.00 | 50.00 | 25.00 | 10.94 | 10.83 | 11.44 |
| T7 | 28.00 | 30.00 | 10.00 | 9.55 | 9.46 | 9.99 |
| T8 | 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:** T1: STCR TY 15 q ha⁻¹ through dhartimitra software, T2: STCR TY 15 q ha⁻¹ through actual soil test values, T3: STCR TY 12 q ha⁻¹ through dhartimitra software, T4: STCR TY 12 q ha⁻¹ through actual soil test values, T5: Soil test laboratory approach, T6: General Recommended dose T7: Farmers practice, T8: Absolute control. |

The higher yields obtained in STCR approach at higher target through dhartimitra software and actual soil test values may be attributed to the balanced and site-specific application of N, P₂O₅, and K₂O, 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 softwarefor fertilizer prescription was found to be as effective as direct soil test-based calculations, indicating its practical utility for farmers as a digital decision support tool. The small but consistent yield advantage of T1 over T2 suggests that software-guided recommendations can serve as a reliable extension tool for wider adoption. The lower yield targets (T3 and T4) also responded positively, though their yields remained below those of T1 and T2, 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 account for site-specific nutrient dynamics and target yields (Krishna Murthy *et al*., 2024a; Annappa *et al*., 2025). Farmers’ practice resulted in suboptimal yield due to imbalanced nutrient application, particularly 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 Ration (VCR)**

The response yardstick (RYS), percent deviation, and value cost ratio (VCR) of cowpea varied significantly across fertilizer 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 largest 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 proved superior over blanket or conventional recommendations. Studies highlighted that STCR approaches, especially when integrated with FYM, not only improved yield realization but also enhanced nutrient use efficiency and profitability compared to farmers’ practice 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 fertilizer prescription models, particularly STCR coupled with organics, are more effective in achieving targeted yields, improving efficiency, and ensuring sustainable cowpea production than conventional recommendations or farmers’ practice

**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** |
| T1 | 8.62 | 0.67 | 2.54 | 8.54 | -0.33 | 2.51 | 9.01 | 5.2 | 2.65 |
| T2 | 8.3 | -1.33 | 2.58 | 8.22 | -2.33 | 2.56 | 8.68 | 3.13 | 2.7 |
| T3 | 6.41 | -4 | 1.72 | 6.08 | -7.17 | 1.63 | 7.15 | 4 | 1.92 |
| T4 | 7.63 | 0.75 | 2.03 | 7.55 | -0.33 | 2.01 | 8.37 | 8.25 | 2.23 |
| T5 | 6.16 | -5.83 | 1.69 | 6.1 | -6.83 | 1.67 | 6.45 | -1.58 | 1.77 |
| T6 | 5.71 | -8.83 | 1.58 | 5.66 | -9.75 | 1.57 | 5.98 | -4.67 | 1.65 |
| T7 | 6.35 | -20.42 | 1.42 | 6.31 | -21.17 | 1.41 | 6.66 | -16.75 | 1.49 |
| T8 | – | -56.42 | – | – | -56.92 | – | – | -54.5 | – |
| **Note:** T1: STCR TY 15 q ha⁻¹ through dhartimitra software, T2: STCR TY 15 q ha⁻¹ through actual soil test values, T3: STCR TY 12 q ha⁻¹ through dhartimitra software, T4: STCR TY 12 q ha⁻¹ through actual soil test values, T5: Soil test laboratory approach, T6: General Recommended dose T7: Farmers practice, T8: Absolute control. |

***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, P₂O₅ and K₂O 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 STCR approach at 15 q ha⁻¹ through actual soil test values, which also showed consistently higher uptake of nutrients, though slightly lower than T1. Intermediate uptake values were observed under STCR approach at 12 q ha⁻¹ through Dhartimitra software and STCR approach at 12 q ha⁻¹ through actual soil test values, while Soil Test Laboratory approach and General recommended dose showed comparatively lower uptakes. The lowest nutrient uptake among fertilized treatments was recorded underFarmers’ practice, whereas absolute controlrecorded the minimum uptake of N (23.8–24.8 kg ha⁻¹), P₂O₅ (3.75–4.25 kg ha⁻¹), and K₂O (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 matched the crop requirement more efficiently (Krishna Murthy *et al.,* 2023b; Tiwari et al., 2020). The use of Dhartimitra software further optimized nutrient allocation based on soil fertility status, thereby enhancing nutrient uptake. These findings are in line with earlier reports that STCR-based fertilization, when integrated with organics, improves nutrient availability, root growth, and microbial activity, leading to 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 absorption. In contrast, the soil test laboratory approachand general recommended dosedid not consider site-specific variability or yield targets, resulting in sub-optimal uptake (Bhavya *et al*., 2021; Spoorthishankar *et al*., 2025).

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

|  |  |  |  |
| --- | --- | --- | --- |
| **Trt** | **Location 1** | **Location 2** | **Location 3** |
| **N uptake** | **P2O5 Uptake** | **K2O uptake** | **N uptake** | **P2O5 Uptake** | **K2O uptake** | **N uptake** | **P2O5 Uptake** | **K2O uptake** |
| T1 | 68.71 | 11.54 | 35.48 | 68.02 | 10.84 | 35.13 | 71.8 | 12.01 | 37.08 |
| T2 | 67.34 | 10.73 | 34.78 | 66.66 | 10.62 | 34.43 | 70.39 | 11.22 | 36.35 |
| T3 | 52.42 | 8.35 | 27.07 | 50.69 | 8.08 | 26.18 | 56.78 | 9.05 | 29.33 |
| T4 | 55.01 | 8.77 | 28.41 | 54.42 | 8.67 | 28.11 | 59.1 | 9.42 | 30.53 |
| T5 | 51.42 | 8.19 | 26.56 | 50.87 | 8.11 | 26.27 | 53.74 | 8.56 | 27.75 |
| T6 | 49.78 | 7.93 | 25.71 | 49.28 | 7.85 | 25.45 | 52.05 | 8.29 | 26.88 |
| T7 | 43.45 | 6.92 | 22.44 | 43.04 | 6.86 | 22.23 | 45.45 | 7.24 | 23.48 |
| T8 | 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:** T1: STCR TY 15 q ha⁻¹ through dhartimitra software, T2: STCR TY 15 q ha⁻¹ through actual soil test values, T3: STCR TY 12 q ha⁻¹ through dhartimitra software, T4: STCR TY 12 q ha⁻¹ through actual soil test values, T5: Soil test laboratory approach, T6: General Recommended dose T7: Farmers practice, T8: Absolute control. |

**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 T1 (39.6 kg kg⁻¹) and declined progressively to the lowest in T7 (4.36 kg kg⁻¹). The apparent recovery efficiency (RE) of nitrogen ranged from 1.8 kg kg⁻¹ in T1 to 0.19 kg kg⁻¹ in T7, showing that higher fertilizer inputs did not proportionally increase nitrogen uptake. Relative internal utilization efficiency (RIUE) of nitrogen remained fairly 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 T4 to 31.5 kg kg⁻¹ in T7, 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 utilized. Potassium efficiency was comparatively stable. AE varied from 23.3 kg kg⁻¹ in T7 to 42.15 kg kg⁻¹ in T1, 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 utilization of absorbed potassium.

These results highlight that nitrogen use efficiency declines with increasing fertilizer inputs (Moharana et al., 2017; Nagendrachari et al., 2025), phosphorus efficiency is limited by soil fixation despite effective internal utilization, and potassium efficiency remains 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 emphasize the need for optimized fertilizer management to maximize nutrient recovery while maintaining sustainable crop productivity

**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** |
| T1 | 39.6 | 1.80 | 4.55 | 15.20 | 0.11 | 0.75 | 42.15 | 0.99 | 2.38 |
| T2 | 26.30 | 1.19 | 4.54 | 18.20 | 0.16 | 0.73 | 38.40 | 0.90 | 2.36 |
| T3 | 13.42 | 0.60 | 4.53 | 18.00 | 0.11 | 0.72 | 25.00 | 0.74 | 2.35 |
| T4 | 11.65 | 0.52 | 4.50 | 9.20 | 0.11 | 0.72 | 29.20 | 0.73 | 2.32 |
| T5 | 8.27 | 0.38 | 4.60 | 11.00 | 0.15 | 0.73 | 25.70 | 0.73 | 2.25 |
| T6 | 6.63 | 0.31 | 4.58 | 13.20 | 0.15 | 0.69 | 25.60 | 0.78 | 2.12 |
| T7 | 4.36 | 0.19 | 4.48 | 31.50 | 0.21 | 0.70 | 23.30 | 0.73 | 2.15 |
| T8 | — | — | — | — | — | — | — | — | — |
| **Note:** T1: STCR TY 15 q ha⁻¹ through dhartimitra software, T2: STCR TY 15 q ha⁻¹ through actual soil test values, T3: STCR TY 12 q ha⁻¹ through dhartimitra software, T4: STCR TY 12 q ha⁻¹ through actual soil test values, T5: Soil test laboratory approach, T6: General Recommended dose T7: Farmers practice, T8: Absolute control. |

**Post Harvest Soil Available NPK Status**

Post-harvest soil test values of N, P₂O₅, and K₂O varied significantly across locations and treatments, reflecting the influence of nutrient management strategies (Figure 1,2&3). In Bangalore Rural, residual N among fertilized treatments ranged from 187.06 kg ha⁻¹ in T1 to 215.11 kg ha⁻¹ in T7, while P₂O₅ was highest in T3 (81.06 kg ha⁻¹) and lowest in T7 (52.02 kg ha⁻¹), with K₂O values remaining comparatively stable but higher under balanced treatments (T5 and T6). In Tumakuru, residual N was lowest in T1 (241.34 kg ha⁻¹) and highest in T7 (269.11 kg ha⁻¹), P₂O₅ was better maintained in STCR treatments (T1 and T3: 105.04–102.64 kg ha⁻¹) compared to T7 and T8 (73.39–69.56 kg ha⁻¹), while residual K₂O was highest in T5 and T6 (149.52–151.86 kg ha⁻¹). Similarly, in Chikkaballapura, residual N varied from 243.08 kg ha⁻¹ in T1 to 272.22 kg ha⁻¹ in T7, P₂O₅ was higher in T1 and T3 (80.25 and 78.05 kg ha⁻¹) but lowest in T8 (50.45 kg ha⁻¹), and K₂O was best sustained under T5 and T6 (195.81–198.20 kg ha⁻¹). Across all districts, STCR-based targeted yield approaches (T1 and T2) maintained relatively higher and balanced nutrient levels, particularly P and K, compared to conventional recommendations, while farmers’ practice (T7) and absolute control (T8) consistently depleted soil P and K due to imbalanced or no fertilizer application (Sinchana *et al*., 2025). These results highlight that precision nutrient management through STCR and Dhartimitra software not only improved yields and nutrient uptake but also conserved post-harvest soil fertility, thereby ensuring sustainability of cowpea production systems. These results are in conformity with the findings of (Rangaiah *et al.,* 2025; Spoorthishankar *et al*., 2024)

**Fig. 1 Influence different approaches of nutrient recommendations on post harvest soil available N, P2O5 and K2O at Bangalore Rural district of Karnataka**

**Fig. 2 Influence different approaches of nutrient recommendations on post harvest soil available N, P2O5 and K2O at Tumakuru district of Karnataka**

**Fig. 3 Influence different approaches of nutrient recommendations on post harvest soil available N, P2O5 and K2O at Chikkaballapura district of Karnataka**

**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 fertilizer recommendations and farmers’ practice. Among the treatments, STCR-based recommendations for a targeted yield of 15 q ha⁻¹ through 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 maximized under STCR treatments, while phosphorus recovery remained constrained by soil fixation, though its internal utilization was efficient. Potassium efficiency was comparatively stable across treatments. The findings emphasize the importance of soil testing and decision-support tools in correcting nutrient imbalances, optimizing fertilizer use, and ensuring both economic viability and environmental sustainability. Thus, the integration of STCR technology with digital platforms like Dhartimitra offers a practical, scalable, and farmer-friendly approach for enhancing cowpea production and promoting sustainable nutrient management in diverse agro-ecological zones.

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**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 that have been used or quoted are properly 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.

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