

RESEARCH PAPER

Precision Nutrient Management in Maize (*Zea mays* L.) through STCR-Based Fertilizer Prescriptions and the Dhartimitra Decision-Support Tool in Alfisols of Southern Karnataka

Krishna Murthy, R.^{1*}, Shivakumara, M.N.¹, Govinda, K.¹, Bhavya, N.², Mohammed Saqeebulla, H.¹, Basavaraja, P.K.¹, Gangamrutha, G.V.¹, Sanjay Srivastava³, Immanuel Chongboi Haokip⁴ and Pradip Dey⁵

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

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

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

⁴Scientist, All India Coordinated Research Project on Soil Test Crop Response, ICAR-Indian Institute of Soil Science, Bhopal, India

⁵Director, Indian Council of Agricultural Research-Agricultural Technology Application Research Institute, Kolkata, India

*Corresponding author: srkmurthyssac@gmail.com (ORCID ID: 0000-0001-9922-7683)

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ABSTRACT

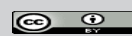
This multi-location field validation study was conducted across 13 representative farmer-managed sites in the southern districts of Karnataka to evaluate the effectiveness of the Soil Test Crop Response (STCR) approach for precision nutrient management in Maize (*Zea mays* L.). The research compared eight nutrient management strategies, including STCR-targeted yield goals of 70 and 65 qha⁻¹ delivered via the Dhartimitra digital decision-support tool and manual soil test values, against the General Recommended Dose (GRD), the Soil Test Laboratory approach, and farmers' prevailing practices. The results demonstrated that the STCR approach for a targeted yield of 70 qha⁻¹ recorded the highest mean grain yield (71.58 qha⁻¹), followed by the software-guided T1 treatment (70.46 qha⁻¹), representing a significant improvement over both GRD (62.56 qha⁻¹) and farmers' practice (55.25 qha⁻¹). Precision-based treatments also exhibited superior economic returns, with the Dhartimitra software approach achieving a high response yardstick (15.22) and a minimal percent deviation (+0.65%) from the target yield. Furthermore, STCR-guided management significantly enhanced nitrogen and potassium use efficiency while maintaining critical post-harvest soil fertility compared to the "soil mining" or imbalanced buildup observed in conventional and farmer practices. The study concludes that integrating STCR methodology with digital platforms like Dhartimitra provides a scalable and highly accurate strategy for optimizing maize productivity and soil health across diverse agro-ecological zones of Karnataka.

HIGHLIGHTS

- ① The Soil Test Crop Response (STCR) approach for a high-yield target of 70 q ha⁻¹ significantly outperformed conventional methods, recording the highest mean grain yield of 71.58 q ha⁻¹ and surpassing farmer practices by up to 29.56%.
- ② The developed STCR equations proved highly valid for the Alfisols of Southern Karnataka, with

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software-guided prescriptions through the Dhartimitra tool achieving a minimal percent deviation of only +0.65% from the targeted yield while maintaining superior nutrient use efficiency and soil fertility.

Keywords: Dhartimitra software, Maize, Nutrient use efficiency, Precision nutrient management, STCR methodology, Soil fertility

Maize (*Zea mays* L.) holds immense global economic significance as a premier cereal crop, contributing substantially to food security, livestock feed production, and industrial raw materials (Cheptoe *et al.* 2021; Annappa *et al.* 2026). Its nutritional value is noteworthy; maize kernels are an abundant source of energy through starch (70-75%), while also providing vital proteins (8-10%), dietary fiber, essential vitamins, and minerals (Saritha *et al.* 2020; Sairam *et al.* 2023). Furthermore, as a highly efficient C4 plant, maize possesses an exceptional photosynthetic rate and biomass production potential, making it the “queen of grains” with the ability to thrive in diverse agro-climatic conditions (Sairam *et al.* 2025; Maitra *et al.* 2026).

Being a notoriously exhaustive crop, maize requires a substantial and balanced supply of essential nutrients throughout its growth cycle to achieve optimal development and maximum grain yield (Krishna *et al.* 2024; Ray *et al.* 2025a). However, maize productivity is frequently constrained by several factors, prominently including imbalanced nutrient management. The inadequate or excessive application of chemical fertilizers can lead to nutrient deficiencies, physiological stress, and reduced nutrient use efficiency, as traditional blanket recommendations often fail to address the specific nutrient demands of the crop in different soil types (Singh and Sahdeo Nath, 2025; Ray *et al.* 2025b). Soil spatial variability significantly exacerbates this issue, as the inherent nutrient-supplying capacity of soils fluctuates considerably; consequently, uniform fertilizer application across a field frequently results in over-fertilization in some areas and under-fertilization in others (Rangaiah *et al.* 2025a).

To address the profound challenges of imbalanced nutrient use and to optimize fertilizer application, comprehensive soil testing serves as an indispensable diagnostic tool (Maitra *et al.* 2025). Soil testing involves the systematic analysis of soil samples to quantify available nutrient reserves, providing a reliable foundational basis for tailored fertilizer recommendations (Krishna Murthy *et al.* 2023a).

The Soil Test Crop Response (STCR) approach represents a critical advancement in soil test-based nutrient management. It is a precise and scientific methodology that mathematically integrates soil nutrient availability, the specific crop’s response to applied nutrients, and a predefined yield target. Key features of the STCR framework include targeted yield, where recommendations aim to achieve a specific production goal (e.g., 70 q ha⁻¹) by aligning nutrient application with crop demand; calibration experiments, which involve field trials to correlate soil test values with crop response to applied nutrients; and fertilizer prescription equations (FPEs), which calculate the exact quantities of N, P, and K required based on initial soil test values and specific nutrient requirements, such as the 1.65 kg N, 0.68 kg P₂O₅, and 1.41 kg K₂O required to produce one quintal of maize grain (Rangaiah *et al.* 2025b)

MATERIALS AND METHODS

The multi-location field validation trials were conducted during the Kharif season of 2023 across thirteen representative districts of Southern Karnataka, specifically Tumakuru, Chamarajanagara, Bengaluru Rural, Mandya, Ramanagara, Hassan, Chitradurga, Kolar, and Chikballapur. The details of the farmers, including their survey numbers, initial soil status, and recommended fertilizer doses, are provided in Supplementary table1. This region is characterized by a diverse agro-climatic spectrum spanning semi-arid to sub-humid zones, with an environmental matrix defined by a mean annual rainfall ranging from 700 to 1400 mm and a temperature regime fluctuating between 20°C and 35°C. These tropical to sub-tropical climates provide a conducive environment for intensive cereal-based cropping systems, within which maize has emerged as a critical component of the local cropping sequence. These sites were strategically selected to capture a wide range of variability in soil fertility, irrigation sources, and management conditions. Each field location was georeferenced using GPS technology, with corresponding survey numbers documented for reference. The selected



sites represented a fertility gradient from medium to high status and were managed under realistic field conditions to ensure the practical applicability of the research findings.

The experimental sites were situated on Alfisols, which exhibit significant spatial variability in soil fertility status and physical properties across the nine districts. While the region has a historical significance for maize cultivation supported by diverse irrigation networks including canals, borewells, and open-well systems the inherent heterogeneity in soil nutrient-supplying capacity necessitates a departure from traditional blanket fertilizer recommendations. This variability underscores the requirement for site-specific nutrient management (SSNM) strategies. Consequently, there is a clear imperative for validating Soil Test Crop Response (STCR)-based fertilizer prescriptions to ensure sustainable and optimized maize productivity in Southern Karnataka.

A Randomized Complete Block Design (RCBD) was adopted for the study, featuring eight distinct fertilizer treatments designed to evaluate various nutrient management strategies. The experimental layout within each farmer's field ensured uniform replication and randomization to minimize experimental error. The treatments included STCR-based targeted yield (TY) goals of 70 and 65 q ha⁻¹ administered via the Dhartimitra digital decision-support tool (T1 and T3) and manual soil test value prescriptions (T2 and T4). These were compared against the Soil Test Laboratory (STL) approach (T5), the General Recommended Dose (GRD) (T6), farmers' prevailing practices (T7), and an absolute control (T8). All other agronomic practices, excluding treatment-specific fertilizer applications, were maintained according to the locally recommended package of practices for irrigated maize. The treatments details are given below:

- ♦ **T1:** STCR TY 70 q ha⁻¹ through dhartimitra software
- ♦ **T2:** STCR- STCR TY 70 q ha⁻¹ through actual soil test values
- ♦ **T3:** STCR TY 65 q ha⁻¹ through dhartimitra software
- ♦ **T4:** STCR TY 65 q ha⁻¹ through actual soil test values

- ♦ **T5:** Soil test laboratory approach,
- ♦ **T6:** Blanket General Recommended Dose (GRD) as per university/state guidelines
- ♦ **T7:** Farmer's prevailing fertilizer practice
- ♦ **T8:** Absolute control (no fertilizer applied)

Prior to sowing, composite soil samples (0–15 cm depth) were collected from each experimental plot following standard protocols. Baseline soil samples with corresponding GPS coordinates were documented for all locations. The samples were analyzed for physico-chemical properties and nutrient contents to characterize the initial soil fertility status across sites, as detailed in Supplementary table 1.

Soil pH and Electrical Conductivity (EC) were measured using a 1:2 soil-to-water suspension following the method outlined by Jackson (1973). Organic Carbon (OC) was determined through the Walkley-Black wet oxidation method (Walkley & Black, 1934). Available Nitrogen (N) was estimated by the alkaline permanganate oxidation method (Subbiah & Asija, 1956). Available Phosphorus (P) was extracted using the Olsen bicarbonate method (Olsen *et al.* 1954). Available Potassium (K) was quantified by ammonium acetate extraction and flame photometry as per Jackson (1973). Available Sulfur (S) was analyzed by the turbidimetric method described by Chesnin and Yien (1950). Micronutrients including Zn, Fe, Mn, and Cu were extracted using the DTPA method followed by atomic absorption spectrophotometry following Lindsay and Norvell (1978).

The following STCR fertilizer prescription equation developed by AICRP on STCR, UAS, Bengaluru centre for Zone-5 was used for fertilizer application to STCR treatments.

$$FN = 3.84 T - 0.42 STV - 0.0027 OM$$

$$FP_2O_5 = 1.57 T - 1.17 STV - 0.0023 OM$$

$$FK_2O = 1.15 T - 0.11 STV - 0.0012 OM$$

where FN, FP_2O_5 , and FK_2O are fertilizer N, P_2O_5 , and K₂O in kg ha⁻¹, respectively; T is the yield target in q ha⁻¹; SN, SP, and SK are available soil nutrients as $KMnO_4$ -N, Bray's- P_2O_5 , and NH_4OAc -K₂O in kg ha⁻¹, respectively and OM is the amount of FYM (organic manure) added in t ha⁻¹.

To assess treatment efficacy, the following indices were computed using standard methods (Ramamoorthy *et al.* 1970):

Response Yardstick (RYS) =

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

Percent deviation =

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

Value cost ratio (VCR) =

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

Fertilizer doses for treatments T2 and T4 were computed using STCR equations that relate nutrient requirement (fertilizer N, P, K) to the target yield and soil available nutrient status. T1 and T3 doses were generated by inputting field-specific soil test data into the Dhartimitra online software, which automates STCR computations integrated with crop response databases. For T2 and T4, manual STCR calculations based on traditional equations prescribed nutrient doses without digital interface aid. Fertilizer types included urea, single superphosphate, and muriate of potash, applied in splits matching crop growth stages. T5 treatments relied on soil test laboratory approach, while T6 and T7 followed standard recommended doses and local farmer practice respectively. Fertilizer treatments were applied uniformly across respective plots based on pre-sowing soil test results to ensure site-specific nutrient management. Standard agronomic practices for irrigated Maize were followed throughout the crop cycle. Fertilizers were applied at transplanting and during subsequent growth stages as per treatment prescriptions. At physiological maturity, crop yield was recorded by harvesting, threshing, and weighing clean maize

grain, and expressed as grain yield in quintals per hectare (q ha⁻¹). Economic analysis was performed by collecting data on fertilizer costs, labor, and grain prices to compute the Value Cost Ratio (VCR) using the formula (Gross return – Cost of fertilizer) / Cost of fertilizer, indicating the relative economic efficiency of each treatment.

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.* (2023b):

AE (kg kg⁻¹) =

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

RE (kg kg⁻¹) =

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

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

Yield and nutrient uptake data were analyzed using analysis of variance (ANOVA) to determine treatment effects. Statistical analyses were performed using SAS 9.4, IBM SPSS, and Microsoft Excel. Treatment means were separated using Duncan's Multiple Range Test (DMRT) and the critical difference (CD) at a 5% significance level. Descriptive statistics (mean, range, and standard deviation) were computed for soil and yield parameters. Pearson correlation analysis was used to examine relationships among soil fertility, fertilizer input, and yield, and to validate the accuracy of software-predicted soil test values.

RESULTS AND DISCUSSION

Among the evaluated treatments, the STCR approach for a targeted yield (TY) of 70 q ha⁻¹ based on actual soil test values (T2) recorded the highest mean grain yield of 71.58 q ha⁻¹, demonstrating



statistical superiority over conventional and farmer practices (Table 1) This was followed by the STCR approach for the same target through Dhartimitra software (T1), which achieved a grain yield of 70.46 q ha⁻¹. Both treatments successfully met the prescribed yield targets with high precision. In terms of stover yield, a similar trend was observed. The highest stover yield was recorded in T2 (82.32 q ha⁻¹), followed by T1 (81.02 q ha⁻¹). Unlike the varied straw response seen in other crops, maize stover production was directly proportional to grain yield, indicating that higher nutrient targets in maize promote robust vegetative biomass alongside reproductive growth.

Moderate yield levels were observed in T4 (65.43 q ha⁻¹) and T3 (64.90 q ha⁻¹), which were aligned with the lower target of 65 q ha⁻¹. The General Recommended Dose (GRD, T6) and Soil Test Laboratory (STL, T5) approach produced grain yields of 62.56 and 60.25 q ha⁻¹, respectively. These conventional methods were significantly outperformed by the high-target STCR protocols (T1 and T2), which provided more balanced nitrogen, phosphorus, and potassium (NPK) ratios tailored to the exhaustive nature of the maize crop. The Farmer's prevailing practice (T7) resulted in a significantly lower grain yield of 55.25 q ha⁻¹, while the absolute control (T8) produced the minimum grain yield of 25.20 q ha⁻¹. The Critical Difference (CD) values confirm that the yield advantages provided by STCR approaches whether through

software or site-specific testing were statistically significant, reinforcing the reliability of targeted yield equations for maize in Alfisols (Krishna Murthy *et al.* 2024b).

The superior performance of the STCR approach at higher targets (T1 and T2) can be attributed to the scientific and balanced application of N, P₂O₅, and K₂O based on the inherent nutrient-supplying capacity of the soil and the specific requirement of the maize hybrid. This site-specific nutrient management (SSNM) ensures that fertilizers are applied in quantities that match crop demand, thereby enhancing nutrient-use efficiency and total biomass production (Krishna Murthy *et al.* 2024d).

Notably, the software-guided prescriptions (T1 and T3) through Dhartimitra proved to be as effective as traditional soil test-based calculations (T2 and T4). This highlights the utility of digital decision-support tools in simplifying complex fertilizer equations for field-level application without compromising yield accuracy (Rangaiah *et al.* 2025a). The consistent achievement of targets in T1 and T2 suggests that setting higher productivity goals (70 q ha⁻¹) effectively maximizes the genetic potential of maize (Krishna Murthy *et al.* 2025).

Conversely, the under performance of GRD (T6) and STL (T5) likely stems from their failure to account for site-specific soil fertility variations and the higher nutrient uptake required for targeted maize production (Krishna Murthy *et al.* 2024a). Suboptimal

Table 1: Quantity of fertilizers added through different nutrient management approaches and yield of Maize at 13 experimental sites of Karnataka

Treatment	Nutrient applied (kg ha ⁻¹)			Grain Yield (q ha ⁻¹)	Stover Yield (q ha ⁻¹)
	Mean of 13 locations				
	N	P ₂ O ₅	K ₂ O		
T1: STCR TY 70 q ha ⁻¹ through Dhartimitra software	159.36	68.85	69.05	70.46	81.02
T2: STCR- STCR TY 70 q ha ⁻¹ through actual soil test values	179.76	82.36	95.84	71.58	82.32
T3: STCR TY 65 q ha ⁻¹ through Dhartimitra software	142.60	75.56	72.26	64.90	74.63
T4: STCR TY 65 q ha ⁻¹ through actual soil test values	152.24	74.56	68.45	65.43	75.24
T5: Soil test laboratory approach,	102.70	70.41	43.35	60.25	69.29
T6: General Recommended Dose (GRD)	150.00	75.00	40.00	62.56	71.94
T7: Farmer’s prevailing fertilizer practice	100.00	93.12	48.75	55.25	63.54
T8: Absolute control (no fertilizer applied)	0.00	0.00	0.00	25.20	28.98
SE(m)				8.06	9.82
CD@5%				24.69	30.89

yields under farmers' practice (T7) further illustrate the consequences of imbalanced fertilization—specifically, the over-reliance on certain nutrients while neglecting others like potassium, which is crucial for maize stalk strength and grain filling (Singh & Sahdeo Nath, 2025, Krishna Murthy *et al.* 2024e). The absolute control results underscore the low inherent productivity of these Alfisols when no external nutrients are provided, with yields falling below 40% of the potential achieved through STCR-based management (Krishna Murthy *et al.* 2023a).

The response yardstick (RYS), percent deviation from target yield, and value cost ratio (VCR) of maize exhibited significant variations across the evaluated nutrient management approaches (Table 2).

The STCR-based 70 q ha⁻¹ target demonstrated the highest overall efficiency. Specifically, the Dhartimitra software approach (T1) recorded an impressive RYS of 15.22 and an extremely minimal percent deviation of only +0.65%. Both T1 and T2 maintained superior economic profiles, with T1 achieving the highest VCR of 5.28, followed by T2 at 4.76. These values indicate exceptional yield stability and significantly higher economic profitability when targeting high productivity levels in Alfisols. The STCR 65 qha⁻¹ targets (T3 and T4) also demonstrated high precision. Notably, T3 (Dhartimitra) achieved the highest target accuracy with a negligible deviation of -0.16%, while T4 recorded a deviation of +0.65%. The RYS for these targets (13.62–13.67) and VCR values (4.52–4.62) remained highly favorable, confirming the reliability of the STCR equations for maize. In contrast, the conventional Soil Test Laboratory

approach (T5) and General Recommended Dose (T6) failed to meet the anticipated productivity levels, showing negative deviations of -7.30% and -3.76%, respectively, highlighting the limitations of blanket or generalized recommendations in hitting specific production goals. The Farmer's prevailing practice (T7) was notably less effective, resulting in a significantly lower VCR (3.51) and a substantial negative deviation of -15.00% from the potential yield. The absolute control (T8) exhibited the most profound yield gap with a -61.23% deviation, underscoring the critical necessity of systematic, balanced nutrient application to bridge the yield gap in Karnataka's maize production systems.

The implementation of Soil Test Crop Response (STCR)-guided nutrient management demonstrated a marked superiority over conventional and localized practices, evidenced by substantial yield enhancements across multiple locations in Karnataka. The high-target STCR approaches (T1 and T2) notably outperformed the General Recommended Dose (RDF) by 12.63% and 14.42%, respectively. Furthermore, these precision-based protocols achieved 16.95% (T1) and 18.80% (T2) higher grain yields compared to the standard Soil Test Laboratory (STL) or LMH approaches. The most significant productivity gains were recorded over the Farmer's Practice (FP), with T2 and T1 achieving increases of 29.56% and 27.53%, respectively. Such findings highlight that utilizing site-specific nutrient management (SSNM) and digital decision-support tools like the Dhartimitra software enables farmers to optimize nutrient use efficiency and hit specific yield targets with high precision, ultimately ensuring superior economic returns and contributing to regional food security.

Table 2: Economic Efficiency and Performance Indices of Maize under Varied Nutrient Management Strategies across Karnataka

Treatments	RYS	% deviation	VCR	% Yield increase over RDF	% Yield increase over LMH	% Yield increase over FP
T ₁	15.22	0.65	5.28	12.63	16.95	27.53
T ₂	12.96	2.26	4.76	14.42	18.80	29.56
T ₃	13.67	-0.16	4.52	3.74	7.72	17.47
T ₄	13.62	0.65	4.62	4.59	8.60	18.43
T ₅	16.19	-7.30	4.54	—	—	—
T ₆	14.10	-3.76	4.66	—	—	—
T ₇	12.42	-15.00	3.51	—	—	—
T ₈	—	-61.23	—	—	—	—



The uptake of nitrogen (N), phosphorus (P), and potassium (K) by maize was profoundly influenced by the implemented nutrient management strategies across the diverse agro-climatic zones of Southern Karnataka. Among the treatments, the STCR approach for a targeted yield (TY) of 70 q ha⁻¹ based on actual soil test values (T2) achieved the highest total uptake, recording 164.56 kg ha⁻¹ of N, 37.61 kg ha⁻¹ of P, and 152.6 kg ha⁻¹ of K. These values were statistically at par with the STCR 70 q ha⁻¹ target delivered via Dhartimitra software (T1), which facilitated an uptake of 159.76, 35.5, and 147.06 kg ha⁻¹ for N, P, and K, respectively (Table 3). Both high-target protocols significantly outperformed the General Recommended Dose (T6) and Farmer's Practice (T7), illustrating the efficacy of targeted nutrient application as documented in recent validation trials on Alfisols (Krishna Murthy *et al.* 2023c; Annappa *et al.* 2025). The partitioning of these nutrients between the reproductive and vegetative components of the crop followed distinct physiological patterns. Nitrogen and phosphorus were predominantly localized within the economic sink, with the grain accounting for approximately 65% of total N and 75% of total P uptake in the leading T2 treatment. In contrast, potassium remained largely within the vegetative biomass; the stover/straw accounted for roughly 70% of total K uptake, reaching 106.82 kg ha⁻¹ in T2 (Krishna Murthy *et al.* 2023b). This retention in the straw underscores the essential role of potassium in maintaining structural integrity and osmotic regulation within the maize stalk (Singh and Sahdeo Nath, 2025).

Conversely, the Farmer's prevailing practice (T7) resulted in significantly restricted nutrient assimilation, particularly for potassium (98.75 kg ha⁻¹), while the absolute control (T8) yielded minimal nutrient mining, highlighting the inherent fertility constraints of unfertilized Alfisols.

The heightened nutrient mining observed under the STCR framework, particularly in treatments T1 and T2, is primarily attributed to the precision of site-specific nutrient management (SSNM) (Annappa *et al.* 2026). By calibrating fertilizer prescriptions based on indigenous soil nutrient supply and specific yield goals, the STCR approach ensures a balanced NPK ratio that strictly synchronizes with the physiological requirements of the maize hybrid (Krishna Murthy

et al. 2023c). This balanced application prevents the nutrient imbalances common in blanket recommendations, thereby promoting extensive root proliferation and enhancing the plant's ability to forage for nutrients across a larger soil volume (Krishna Murthy *et al.* 2024a). Furthermore, the integration of targeted yield equations often supported by organic amendments like Farmyard Manure (FYM) improves soil physical properties and microbial activity, which in turn enhances the bioavailability of nutrients like phosphorus that are otherwise easily fixed in acidic Alfisols (Rangaiah *et al.* 2025b). The effectiveness of the Dhartimitra software (T1) in matching the results of actual soil test-based calculations (T2) confirms the reliability of digital decision-support tools in managing complex site-specific data for precision agriculture. In contrast, the suboptimal uptake noted in the General Recommended Dose (T6) and Farmer's Practice (T7) underscores the limitations of imbalanced fertilization; specifically, inadequate potassium application in traditional practices likely restricted the translocation of photosynthates from source to sink, thereby depressing both total biomass and grain yield (Singh and Sahdeo Nath, 2025). Collectively, these findings validate that STCR-guided management maximizes the genetic potential of maize by optimizing the harvest index and ensuring robust nutrient remobilization during the reproductive phase (Krishna Murthy *et al.* 2024d).

The nutrient use efficiency indices in maize exhibited significant variation across the different nutrient management treatments applied across 13 locations in Karnataka (Table 4). For Nitrogen (N), the Agronomic Efficiency (AE) reached its peak in T5 (34.13 kg kg⁻¹) and was lowest in T6 (24.90 kg kg⁻¹). The Apparent Recovery Efficiency (RE) for nitrogen followed a similar trend, ranging from a high of 0.80 kg kg⁻¹ in T5 to 0.59 kg kg⁻¹ in T6. These high recovery rates suggest that site-specific approaches like the Dhartimitra software and STCR-based models allow for a more synchronized nitrogen supply relative to the crop's demand, thereby reducing losses (Dobermann *et al.* 2002). The Relative Internal Utilization Efficiency (RIUE) for nitrogen remained remarkably stable across all treatments (2.03–2.30 kg kg⁻¹), indicating that once nitrogen is absorbed, the maize plant's physiological

ability to convert it into grain yield is relatively constant, regardless of the initial application strategy (Krishna Murthy *et al.* 2026a).

Phosphorus (P) use efficiency indices showed a wide range of responses to the management treatments. The AE for phosphorus was highest in T₁ (65.73 kg kg⁻¹) and T₂ (56.31 kg kg⁻¹), while T₇ recorded the lowest value (32.27kg kg⁻¹). The RE for phosphorus was generally lower than that of nitrogen and potassium, ranging from 0.15 to 0.40 kg kg⁻¹. This pattern is consistent with phosphorus behavior in soil, where fixation and low mobility often limit immediate recovery by the crop (Syers *et al.* 2008). Despite the variation in recovery, the RIUE values for phosphorus were consistent (0.40-0.53 kg kg⁻¹), suggesting efficient internal processing of the nutrient for biomass and ear development. Potassium (K) efficiency indices were notably higher than those of nitrogen and phosphorus (Krishna Murthy *et al.* 2026b). The AE for potassium was highest in T₆ (93.39kg kg⁻¹) and T₅ (80.86 kg kg⁻¹),

significantly outperforming the other treatments. Most impressively, the RE for potassium in T₆ exceeded 2.0kg kg⁻¹ (2.14 kg kg⁻¹), indicating substantial mining of soil potassium or a highly synergistic effect under specific STCR treatments. The RIUE values for potassium were consistently high (1.79- 2.13kg kg⁻¹), highlighting the critical role of potassium in maintaining the osmotic balance and structural integrity required for high-yielding maize crops (Krishna Murthy *et al.* 2024c).

The post-harvest soil available nutrient status in maize varied significantly across the evaluated nutrient management treatments, reflecting the cumulative impact of targeted fertilizer applications and nutrient mining by the crop. The available nitrogen (N) in the soil was highest under the STCR approach for a targeted yield of 70 q ha⁻¹ based on actual soil test values (T₂) at 348.2 kg ha⁻¹, followed by the General Recommended Dose (T₆) at 329.71 kg ha⁻¹ (Fig. 1) (Supplementary table 2). The lowest residual nitrogen among fertilized

Table 3: Effect of different nutrient management approaches on uptake of major nutrients in Maize at different locations of Karnataka

Treatment	Grain			Straw			Total		
	N	P	K	N	P	K	N	P	K
T ₁	103.84	26.63	44.12	55.92	8.87	102.94	159.76	35.5	147.06
T ₂	106.96	28.21	45.78	57.6	9.4	106.82	164.56	37.61	152.6
T ₃	92.51	23	39.13	49.81	7.66	91.31	142.32	30.66	130.44
T ₄	94.6	24.23	40.1	50.94	8.08	93.56	145.54	32.31	133.66
T ₅	82.9	19.93	34.93	44.64	6.64	81.5	127.54	26.57	116.43
T ₆	87.42	21.7	37.1	47.07	7.23	86.56	134.49	28.93	123.66
T ₇	72.99	16.49	29.63	39.3	5.49	69.12	112.29	21.98	98.75
T ₈	29.77	6.11	11.39	16.03	2.03	26.59	45.8	8.14	37.98
SEm±	1.85	0.62	0.94	1.0	0.2	2.18	2.85	0.82	3.12
CD @ 5%	5.6	1.86	2.84	3.02	0.62	6.61	8.62	2.48	9.45

Table 4: Effect of different nutrient management approaches on nutrient use efficiency in Maize at 13 different locations 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	28.40	0.72	2.27	65.73	0.40	0.50	65.54	1.58	2.09
T ₂	25.80	0.66	2.30	56.31	0.36	0.53	48.39	1.20	2.13
T ₃	27.84	0.68	2.19	52.54	0.30	0.47	54.93	1.28	2.01
T ₄	26.42	0.66	2.22	53.95	0.32	0.49	58.77	1.40	2.04
T ₅	34.13	0.80	2.12	49.78	0.26	0.44	80.86	1.81	1.93
T ₆	24.90	0.59	2.15	49.81	0.28	0.46	93.39	2.14	1.98
T ₇	30.05	0.66	2.03	32.27	0.15	0.40	61.65	1.25	1.79
T ₈	—	—	—	—	—	—	—	—	—

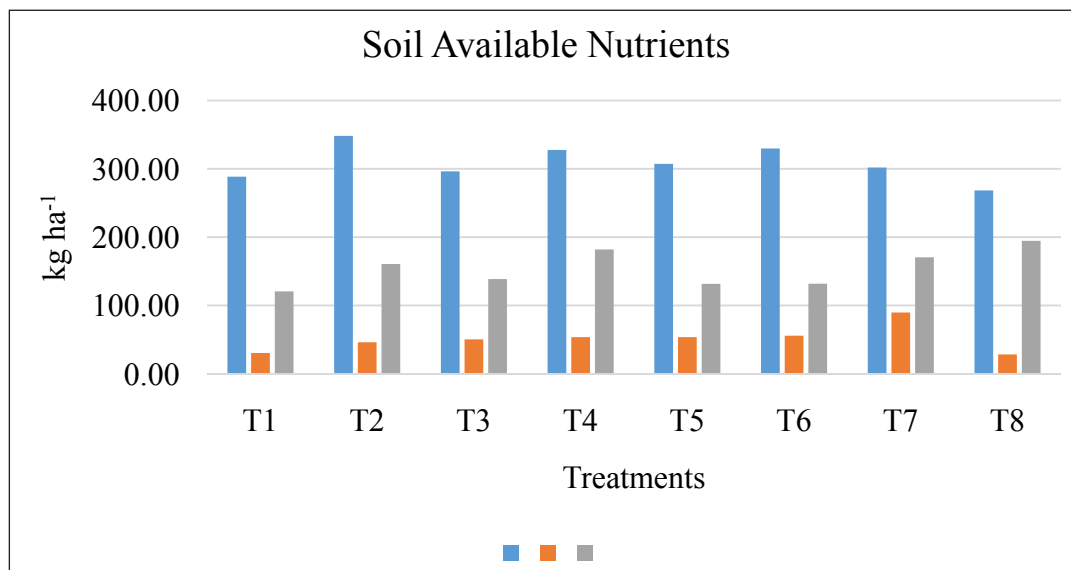


Fig. 1: Post-harvest soil available N, P₂O₅, and K₂O status (kg ha⁻¹) as influenced by different nutrient management approaches (Mean of 13 locations)

treatments was recorded in the STCR TY 70 q ha⁻¹ Dhartimitra approach (T1) at 288.6 kg ha⁻¹. This variation suggests that while higher targets provide sufficient nitrogen to meet crop demand, precision-based applications through software like Dhartimitra ensure a more synchronized uptake, minimizing excessive residual nitrogen in the soil profile.

The available phosphorus (P₂O₅) status was uniquely maintained across the treatments. The highest residual phosphorus value of 89.79 kg ha⁻¹ was recorded under the Farmer's prevailing practice (T7), which was substantially higher than the STCR-based 70 q ha⁻¹ targets (T1 and T2) recording 30.55 and 46.23 kg ha⁻¹, respectively (Fig. 1). This indicates that traditional farmer practices often lead to an inefficient buildup of phosphorus due to imbalanced application, whereas STCR-based prescriptions align phosphorus supply more closely with crop requirements. The absolute control (T8) recorded the lowest residual phosphorus at 28.36 kg ha⁻¹, confirming the exhaustion of soil reserves in the absence of external inputs (Krishna Murthy *et al.* 2023c).

For available potassium (K₂O), the post-harvest levels were profoundly influenced by the exhaustive nature of the maize crop. The highest residual level was recorded in the absolute control (T8) at 194.6 kg ha⁻¹, followed by the STCR TY 65 q ha⁻¹ approach based on actual soil test values (T4) at 182.1 kg ha⁻¹. The STCR 70 q ha⁻¹ Dhartimitra approach (T1) showed

the lowest residual potassium at 120.6 kg ha⁻¹ (Fig 1). This depletion in high-yielding treatments (T1 and T2) reflects the significant mining of potassium required to support superior grain and stover yields, underscoring the necessity of site-specific potassium management to prevent long-term soil exhaustion.

CONCLUSION

The multi-location study clearly demonstrated that the Soil Test Crop Response (STCR) approach significantly improved maize productivity, nutrient uptake, and nutrient use efficiency compared to conventional fertilizer recommendations and farmers' prevailing practices. Among the treatments, STCR-based recommendations for a targeted yield of 70 q ha⁻¹, particularly through the Dhartimitra software, recorded the highest grain and stover yields, highlighting the superiority of precision-based prescriptions over blanket or general recommended doses.

Nitrogen and phosphorus use efficiencies were optimized under STCR treatments, indicating that software-guided applications effectively synchronize nutrient supply with crop demand. Potassium efficiency was notably superior, with high recovery rates reinforcing the crop's physiological stability and stalk strength under balanced nutrient management. Beyond productivity, the research established that precision-based nutrient management through the Dhartimitra software not only optimized fertilizer use but also conserved post-harvest soil fertility,

preventing the nutrient depletion or inefficient phosphorus buildup observed under farmers' practice. Thus, the integration of STCR technology with digital decision-support platforms offers a practical, scalable, and highly efficient approach for enhancing maize production while ensuring long-term economic viability and environmental sustainability across the Alfisols of Southern Karnataka.

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