# Original Research Article

# Unravelling Soil-Crop Dynamics: Bridging Soil Test Fertilizer Dose with Hybrid Rice Yield and Nutrient Optimization Strategies in Chhattisgarh Plains

## ABSTRACT

Efficient fertilizer management is imperative in modern agriculture to optimize yields and mitigate environmental impacts. This study investigates soil test-based fertilizer recommendations for hybrid rice cultivation, focusing on nutrient uptake, fertilizer adjustment equations, and nutrient contributions from soil, fertilizers, and farmyard manure (FYM). Field experiments were conducted in Raipur, India, with 24 treatment variations involving nitrogen (N), phosphorus (P), potassium (K), and FYM levels. Soil and plant analyses were performed to assess nutrient uptake and contributions. Results revealed strong correlations between grain yields and total N, P, and K uptake, with N contributing 94-96% variability in yield. Soil test data indicated significant increases in available N, P, and K with fertilization, while disparities were observed in soil test P levels among treatments. Contributions from fertilizers, soil, and FYM varied, with FYM contributing 9.21% for N, 1.81% for P, and 6.27% for K. Ready reckoner tables for soil test-based fertilizer recommendations demonstrated reduced requirements with higher soil test values and increased yield targets. Overall, the study underscores the importance of tailored fertilizer management based on soil fertility assessments for sustainable hybrid rice production.

**Keywords**: soil test-based recommendations, nutrient uptake, fertilizer adjustment equations, farmyard manure, nutrient contributions, yield targeting, ready reckoners, sustainable agriculture.

## 1. INTRODUCTION

The necessity for precise fertilizer recommendations based on soil fertility status has become increasingly evident, driven by the emergence of fertilizer-responsive crop varieties and the escalating costs associated with fertilizers. In modern agriculture, fertilizer application is indispensable for achieving elevated crop yields. However, the economic burden of fertilizers underscores the importance of optimizing their usage. Maximizing fertilizer efficiency entails considering various factors such as crop response, soil nutrient availability, and environmental impacts. Soil testing has emerged as a vital tool for efficiently utilizing fertilizers and addressing nutrient imbalances (Hegedus et al., 2023). Over the years, several approaches have been developed within the All India Coordinated Research Project for Soil Test Crop Response Correlation (STCRC) to recommend fertilizer doses based on soil and plant analysis (Ramamoorthy and Velayutham, 1971). However, existing approaches have limitations in accurately differentiating soil fertility levels and optimizing fertilizer doses. Paddy cultivation holds significant importance in India's agricultural sector, particularly in states like Chhattisgarh, known as 'The Rice Bowl of India'. With favourable agro-climatic conditions and significant hybrid rice production, optimizing hybrid rice nutrition in Chhattisgarh's plains becomes paramount for enhancing farm productivity sustainably.

Rice is grown in Chhattisgarh in an area of 3.45 lakh hectares with a production of 9.2 million tons and productivity of 2667 kg/ha (GOI, 2020).

## 2. MATERIALS AND METHODS

### 2.1 Site details and treatment variations

The experimental site chosen for this study lies in the eastern vicinity of Raipur city, situated within the instructional farm premises of Indira Gandhi Krishi Vishwavidyalaya. Positioned at approximately 21016" N latitude and 81036" E longitude, the site stands at an altitude of 298.56 meters above mean sea level. Characterised by sub-humid climatic conditions, the area typically receives an annual rainfall ranging between 1400-1600 mm, with the bulk of precipitation occurring during the monsoon season from June to September, aligning with the principal rice-growing period lasting 3-4 months. May registers as the warmest month, while December marks the coldest. Following the harvest of the previous crop, the experimental site was meticulously prepared for the ensuing rice cultivation. To demarcate distinct boundaries for each plot, the area was subdivided into smaller units measuring 20 m2 (4m x 5m), resulting in a total of 72 plots arranged in a 24x3 configuration. Adhering to the layout and design specifications of the All India Coordinated Research Project on Soil Test Crop Response (AICRP on STCR), the experiment comprised 24 distinct treatments. Each treatment involved varying levels of four key nutrients: nitrogen (0, 60, 120, and 180 kg N ha$^{-1}$), phosphorus (0, 30, 60, and 90 kg $P_2O_5$ ha$^{-1}$), potassium (0, 20, 40, and 60 kg $K_2O$ ha$^{-1}$), and farmyard manure (FYM) administered at three levels (0, 5, and 10 tons). The experimental design aimed to investigate the impact of these nutrient variations on the growth and yield parameters of rice crops. Through meticulous planning of the layout and execution of the experiment, meticulous data collection and analysis were ensured. The varying nutrient levels were strategically chosen to provide insights into the optimal strategies for enhancing the yield and quality of hybrid rice cultivars within the experimental area.

Comprehensive Methods for Field and Soil Analysis in Hybrid Rice Cultivation.

The experimental field underwent ploughing, puddling, and levelling for rice cultivation. Soil sampling involved collecting composite samples before sowing maize and before fertilizer/FYM application and rice transplantation. Samples were air-dried, ground, sieved, and stored for analysis. Soil analysis covered pH (Piper, 1966), electrical conductivity (Bower and Wilcox, 1965), CEC (Black 1965), OC, mechanical analysis, available soil nitrogen (Subbiah and Asija 1956), phosphorus (Olsen et al. 1954), potassium (Hanway and Hiedal, 1952), and micronutrients (Lindsay and Norvell, 1978). Plant analysis post-harvest included grain and straw samples for nitrogen, phosphorus, and potassium assessment. Yield observation recorded biological, grain, and straw yields from each plot. Chemical analysis of FYM determined nitrogen, phosphorus, and potassium content (Jackson, 1963).

### 2.2 Nutrient (N/P/K) uptake

Total nutrient (N/P/K) uptake by the crop was computed using grain, straw yield and total nutrient (N/P/K) content in grain and straw by using the following formula:

Nutrient (N/P/K) uptake by grain (kg ha$^{-1}$) = Percent nutrient (N/P/K) content in grain × grain yield (q ha$^{-1}$).

Nutrient (N/P/K) uptake by straw (kg ha$^{-1}$) = Percent nutrient (N/P/K) content in straw × straw yield (q ha$^{-1}$).

$$\text{Total nutrient (N/P/K) uptake by crop (kg ha}^{-1}\text{)} = [\text{Nutrient (N/P/K) uptake by grain (kg ha}^{-1}\text{)} + \text{Nutrient (N/P/K) uptake by straw (kg ha}^{-1}\text{)}].$$

### 2.3 Basic data for fertilizer requirement

The formula used to calculate the nutrient (N/P/K) requirement for producing one quintal of grain yield (kg $q^{-1}$) is as follows:

$$\text{Nutrient (N/P/K) requirement (NR)} = \text{Total Nutrient N/P/K uptake by the crop (kg ha}^{-1}\text{)} / \text{grain yield (q/ha)}$$

The nutrient requirement was determined individually for each plot, and then the average values were calculated. These average values were reported as the amount of nitrogen (N), phosphorus (P), and potassium (K) required to produce one quintal of grain yield.

### 2.4 Percent contribution of nutrient (N/P/K) from soil (CS)

Per cent, the contribution of nutrient (N/P/K) from soil was calculated by using total nutrient uptake by crop and soil test value of that nutrient in each control plot separately and then the average was taken.

$$\text{Percent contribution of nutrient (N/P/K) from soil (CS)} = [(\text{Total nutrient N/P/K uptake kg ha}^{-1}\text{ by crop in the control plot}) / (\text{Soil test value (kg ha}^{-1}\text{) for available nutrient N/P/K in control plot})]*100$$

### 2.5 Percent contribution of nutrient (N/P/K) from FYM (CFYM)

Per cent contribution of nutrient (N/P/K) from FYM was calculated by using total nutrient uptake by crop, nutrient applied through organic manure (FYM) and soil test value of that nutrient in only FYM treated plots separately and then the average was taken.

$$\text{Percent contribution of nutrient (N/P/K) from FYM (CFYM)} = \frac{\text{Total nutrientN/P/K uptake (kg/ha) by the crop in only FYM treated plots} - \text{Total nutrientN/P/K uptake (kg/ha) by the crop in control plot}}{\text{Nutrient (N/P/K) applied (kg/ha) through FYM}} *100$$

### 2.6 Interpreting Soil Test Data for Fertilizer Application: Insights from Yield Targeting Equations and Fertilizer Adjustment Strategies"

The interpretation of soil tests for fertilizer application involves using equations derived from linear response and plateau considerations. These equations, as prescribed by previous studies, allow for adjustments in fertilizer application based on the nutrient requirements of the crop and the existing soil nutrient levels. The concept of fertilizer prescription for desired crop yields originated from the work of Troug (1960) and was further developed by Ramamoorthy et al. (1967) in India. They demonstrated that the relationship between grain yield and nutrient uptake is linear, meaning that to achieve a certain yield, a specific quantity of nutrients must be absorbed by the plant. This understanding forms the basis for estimating fertilizer requirements, considering the efficiency of nutrient contribution from soil and applied fertilizers towards meeting the crop's total nutrient uptake.

## 3. RESULTS AND DISCUSSION

### 3.1 Impact of Prior Fertilization on Soil Test Values

Before transplanting hybrid rice, a fertility gradient was established using an inductive methodology designed by Ramamoorthy et al. (1967), confirming significant increases in soil test values for available N, P, and K from $L_0$ to $L_2$ strips. While soil test N levels remained relatively stable, soil available K exhibited consistent availability, potentially due to dynamic equilibrium in the soil. Noteworthy disparities were observed in soil test P levels among the strips, likely influenced by their transformation into insoluble compounds upon fertilization.

**Table 1, Post-harvest soil test and yield of sweet corn in various fertility gradients during Rabi 2020-21 and 2021-22 before the conducting main complex experiment.**

| Fertility Strips | Post-harvest soil test values (kg/ha) 2020-21 | | | Yield of sweet corn (q/ha) | Post-harvest soil test values (kg/ha) 2021-22 | | | Yield of sweet corn (q/ha) |
|---|---|---|---|---|---|---|---|---|
| | N | P | K | | N | P | K | |
| $L_0$ | 166-234 (209) | 9-13 (11) | 427-574 (514) | 181.00 | 160-235 (205) | 8-16 (13) | 412-572 (509) | 182.48 |
| $L_1$ | 188-236 (215) | 12-23 (19) | 442-580 (526) | 190.13 | 163-237 (208) | 8-27 (20) | 425-580 (522) | 190.21 |
| $L_2$ | 198-242 (225) | 21-34 (28) | 467-589 (533) | 197.82 | 185-243 (219) | 12-39 (28) | 458-588 (528) | 200.42 |

### 3.2 Crop Response to Applied Nutrients

The study analyzed grain yield variations of hybrid rice across different fertility strips during the Kharif seasons of 2021 and 2022. In 2021, grain yields ranged from 25.18 to 81.48 q ha$^{-1}$, with higher yields observed in strips with increased soil fertility. Similarly, in 2022, yields ranged from 28.04 to 88.10 q ha$^{-1}$, indicating a positive correlation between fertility strips and grain yield. Regression analysis revealed nitrogen (N) as the primary determinant of grain yield variance, with a quadratic model fitting the data well ($R^2 = 0.87$ in 2022). This underscores the importance of N, a mobile soil nutrient, in hybrid rice productivity. Phosphorus ($P_2O_5$) and potassium ($K_2O$) fertilizers also contributed to yield variations, albeit to a lesser extent, attributed to their reactions with soil constituents (Gong et al., 2011; Mahama et al., 2016). These findings emphasize the critical role of nutrient management in optimizing hybrid rice yields.

**Table 2 Range and mean values of grain yield of sweet corn during the Kharif season, 2021 and 2022 relative to the fertility strips.**

| Fertility Strips | Grain Yield (q/ha) | | | | |
|---|---|---|---|---|---|
| | **Minimum** | **Maximum** | **Average** | **SD** | **CV (%)** |
| | | ***Kharif* Season, 2021** | | | |
| **L0** | 25.18 | 79.36 | 59.26 | 15.19 | 25.64 |
| **L1** | 26.02 | 81.20 | 62.96 | 15.35 | 24.39 |
| **L2** | 27.85 | 81.48 | 64.66 | 15.67 | 24.24 |
| **All Strips** | 25.18 | 81.48 | 62.29 | 15.36 | 24.65 |
| | | ***Kharif* Season, 2022** | | | |
| **L0** | 28.04 | 82.80 | 60.46 | 16.15 | 26.71 |
| **L0** | 29.71 | 86.70 | 63.88 | 15.95 | 24.96 |
| **L0** | 30.50 | 88.10 | 66.11 | 16.76 | 25.35 |
| **All Strips** | 28.04 | 88.10 | 63.48 | 16.23 | 25.56 |

The study revealed significant interactions between nitrogen (N), phosphorus (P), and potassium (K) in influencing grain yields of hybrid rice. Nitrogen combined with phosphorus explained 76% to 86% of yield variation, while nitrogen combined with potassium accounted for 85% of the variation. Moreover, phosphorus combined with potassium contributed to 38% to 58% of yield variation. Soil test nitrogen exhibited the highest influence on yield variation, followed by phosphorus and potassium. Thompson et al., (2008), Gulati et al., (2016), Smith et al., (2020), and Wang et al., (2023) ) investigated the relationship of combining soil test values with fertilizer application further clarified their impact on yield variation. These results underscore the crucial role of nutrient management, particularly nitrogen application, in enhancing hybrid rice productivity (Banerjee and Pal 2009, Sahu et al., 2017).

FYM showed minimal influence on grain yield, with the N+FYM combination exhibiting the most significant impact, explaining 79% to 88% of yield variation. The integration of FYM with fertilizers contributed to yield variation similarly, suggesting its potential for sustainable soil management.

### 3.3 Relationship between Nutrient Uptake and Grain Yields in Hybrid Rice:

Linear regression analysis revealed strong correlations between grain yields and total nitrogen (N), phosphorus (P), and potassium (K) uptake in hybrid rice over two cropping years. Total N uptake accounted for 94% and 96% of yield variability, followed by total P (89% and 93%) and total K (88% and 90%) uptake. Nutrient requirement (NR) is defined as the quantity of nutrients necessary for a crop to produce a specific yield. This is expressed through the equation:

$$\mathbf{Y=b_1U\text{or}U=1/b_1\times Y}$$

In this context, '$b_1$' refers to the regression coefficient about yield (Y), while 'U' stands for the total nutrient uptake. The reciprocal of '$b_1$', denoted as $1/b_1$, provides an estimation of the nutrient requirement (NR).

According to Table 3, to yield one quintal of hybrid rice grain, approximately 1.61 kg of N, 0.32 kg of P, and 2.105 kg of K were necessary, averaged over two crop years. Singh et al. (2015) noted 19.4 kg of N, 5.70 kg of $P_2O_5$, and 18.4 kg of $K_2O$ per ton of rice grain, while Xalxo et al. (2018) recorded 1.59 kg of N, 0.32 kg of P, and 1.84 kg of K per quintal of rice grain. Similarly, Sivaranjani et al. (2018) reported a requirement of 1.76 kg of N, 0.58 kg of $P_2O_5$, and 1.62 kg of $K_2O$ for one quintal of hybrid rice.

**Table 3 Relation of grain yields of hybrid rice (Y) with the total nutrient uptake (U).**

| Nutrient | 2021 | | 2022 | |
|---|---|---|---|---|
| | **$Y = b_1 U$** | **$R^2$** | **$Y = b_1 U$** | **$R^2$** |
| **N** | Y= -3.13 U | 0.94 | Y= -4.86 U | 0.96 |
| **P** | Y= 7.10 U | 0.89 | Y= 9.21 U | 0.93 |
| **K** | Y= 3.48 U | 0.88 | Y= -0.08 U | 0.90 |

**Table 4 Nutrient requirement for hybrid rice var. CG hybrid - 02.**

| Nutrient | Nutrient requirement for one quintal grain yield of hybrid rice ($kgq^{-1}$) | | |
|---|---|---|---|
| | **2021** | **2022** | **Mean** |
| **N** | 1.64 | 1.58 | 1.61 |
| **P** | 0.32 | 0.32 | 0.32 |
| **K** | 2.11 | 2.10 | 2.105 |
| **Nutrient content in FYM** | **0.4% N, 0.30 % P and 0.8 % K** | | |

### 3.4 Contribution of Nutrients from Soil, Fertilizers, and FYM to Hybrid Rice

Nutrient contributions from fertilizer N, P, and K averaged 34.61%, 22.6%, and 154.58%, respectively, over two cropping years, with the order of contribution being K > N > P. Soil contributions were 27.75% for N, 74.89% for P, and 14.73% for K, with the order being P > N > K. FYM contributions averaged 9.21% for N, 1.81% for P, and 6.27% for K, with the order being N > K > P (Deshpande et al., 2015; Ray et al., 2000).

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**Table 5 Nutrient Contributions from Fertilizer, Soil, and FYM for Hybrid Rice.**

| Contribution of Nutrients from | Nitrogen | | | Phosphorus | | | Potassium | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | Mean | 2021 | 2022 | Mean | 2021 | 2022 | Mean |
| **Fertilizer (%Cf)** | 34.98 | 34.23 | 34.61 | 22.38 | 22.82 | 22.6 | 158.61 | 150.55 | 154.58 |
| **Soil (%Cs)** | 27.24 | 28.27 | 27.75 | 74.93 | 74.85 | 74.89 | 14.23 | 15.48 | 14.73 |
| **FYM (%CFYM)** | 8.90 | 9.53 | 9.21 | 1.98 | 1.63 | 1.81 | 4.01 | 8.54 | 6.27 |

Nutrient content in FYM - 0.4% N, 0.30 % P and 0.8 % K

## 3.5 Ready Reckoners for Soil Test-Based Fertilizer Recommendation of Hybrid Rice

Derived Ready Reckoners incorporating NPK fertilizers and 5 tons of FYM showed slight reductions in fertilizer requirements compared to NPK alone. Soil test values inversely influenced fertilizer requirements, with higher values leading to decreased fertilizer needs. Higher yield targets corresponded to increased fertilizer requirements, emphasizing the importance of setting appropriate targets for balanced fertilization and soil fertility preservation (Dev et al., 1985).

**Table 6 Ready Reckoners for soil test-based fertilizer N, $P_2O_5$ and $K_2O$ recommendation for Hybrid rice (CG Hybrid -2) in Vertisol with 5 tons of FYM**

| Soil Test values (kg/ha ) | | | Yield Target of Hybrid rice (q/ha) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 60 (q/ha) | | | 70 (q/ha) | | | 80 (q/ha) | | |
| **N** | **P** | **K** | **FN** | **FP** | **FK** | **FN** | **FP** | **FK** | **FN** | **FP** | **FK** |
| 150 | 4 | 200 | 124 | 63 | 54 | 170 | 77 | 68 | 216 | 91 | 82 |
| 175 | 6 | 225 | 103 | 56 | 52 | 149 | 70 | 65 | 196 | 84 | 79 |
| 200 | 8 | 250 | 83 | 50 | 49 | 129 | 64 | 63 | 175 | 78 | 77 |
| 225 | 10 | 275 | 62 | 43 | 47 | 108 | 57 | 60 | 154 | 71 | 74 |
| 250 | 12 | 300 | 41 | 37 | 44 | 87 | 51 | 58 | 133 | 65 | 72 |
| 275 | 14 | 325 | 20 | 30 | 42 | 66 | 44 | 55 | 113 | 58 | 69 |
| 300 | 16 | 350 | 10 | 23 | 39 | 46 | 37 | 53 | 92 | 51 | 67 |
| 325 | 18 | 375 | 10 | 17 | 37 | 25 | 31 | 50 | 71 | 45 | 64 |
| 350 | 20 | 400 | 10 | 10 | 34 | 4 | 24 | 48 | 50 | 38 | 62 |
| 375 | 22 | 425 | 10 | 4 | 32 | 4 | 18 | 45 | 30 | 32 | 59 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 400 | 24 | 450 | 10 | 4 | 29 | 4 | 11 | 43 | 9 | 25 | 57 |

Where, FN, FP and FK are fertilizer N, $P_2O_5$ and $K_2O$ (Kg/ha); SN, SP and SK are soil test values (kg/ha) for $KMnO_4$ -N, Olsen's P and ammonium acetate extractable K.

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