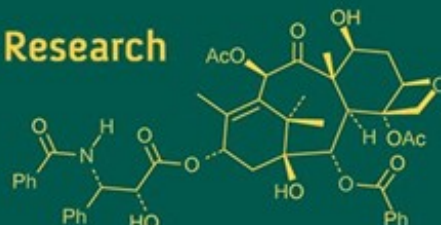


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Soil fertility and nutrient index-based fertilizer requirement for kharif crops in Chhattisgarh using soil health card data under fertilizer supply constraints

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ABSTRACT

Aim: To assess soil fertility status and develop nutrient index-based fertilizer recommendations for major Kharif crops in Chhattisgarh under fertilizer supply constraints using Soil Health Card data.

Methodology: The study analyzed more than 5.8 lakh soil samples collected under the Soil Health Card scheme during 2023–2026. Soil reaction, salinity, organic carbon, macro- and micronutrient status, and Nutrient Index Values (NIV) were evaluated to estimate fertilizer requirements for Kharif crops.

Results: Most soils were neutral in reaction and non-saline. However, soils were largely low in organic carbon and nitrogen, while phosphorus was medium and potassium was generally sufficient. Sulphur, zinc, and boron deficiencies were also observed. Nutrient Index Values indicated low nitrogen (1.21), medium phosphorus (1.82), and high potassium (2.36) fertility status. Estimated nutrient requirements were 4.26 lakh tonnes N, 2.01 lakh tonnes P₂O₅, and 0.86 lakh tonnes K₂O. Fertilizer recommendations suggested full nitrogen dose, with 25% and 50% reductions in phosphorus and potassium, respectively, supplemented through IPNS practices.

Interpretation: Integration of Soil Health Card data, nutrient index-based recommendations, and IPNS practices can improve fertilizer use efficiency, reduce input costs, and sustain soil health for Kharif crop production in Chhattisgarh.

Keywords: Soil Health Card, Soil Fertility, Nutrient Index Value (NIV), Fertilizer Requirement, Integrated Plant Nutrient System (IPNS)

Introduction

Soil is a very important natural resource that supports plant growth and provides food, fiber, and feed (FAO, 2015) [1]. In traditional farming systems, a natural balance was maintained between crop production and soil fertility through practices such as crop rotation, organic manuring, and recycling of farm residues (Prasad, 2009) [2]. However, after the Green Revolution, increasing food demand and higher crop production led to the excessive use of chemical fertilizers, pesticides, and intensive farming practices, which reduced soil, crop and humane health (Pathak, 2010; Patra *et al.* 2016; Mandal *et al.*, 2018; Vinothkanna *et al.* 2020) [3, 4, 5].

At present, there is a need for precise, sustainable, and cost-effective use of agricultural inputs. Using fertilizers based on soil nutrient status improves crop growth and yield, reduces losses, lowers costs, and increases farmers' income (Dobermann, 2007) [6]. Sustainable soil fertility management practices, including integrated use of organic and inorganic nutrient sources, are crucial for maintaining long-term soil productivity and resilience (Chowdary *et al.*, 2018; Kapoor *et al.*, 2021) [7, 8]. Soil fertility evaluation helps in better decision-making by showing how soil properties vary across locations and over time (Dandasena *et al.*, 2024) [9]. Soil testing is a scientific method to assess soil health, identify nutrient deficiencies or excesses, and recommend suitable fertilizers, helping farmers manages soils for sustainable and profitable farming (Chauhan *et al.*, 2025) [10]. The large database generated under this scheme offers a valuable opportunity to assess soil fertility status at regional and state levels and to develop targeted nutrient management

Recognizing the importance of soil fertility management, the Government of India launched the Soil Health Card (SHC) Scheme on 19 February 2015 at Suratgarh, Rajasthan. The scheme promotes soil test-based fertilizer application by providing farmers with information on soil nutrient status and site-specific nutrient recommendations. The National Productivity Council (NPC) reported that the SHC scheme reduced chemical fertilizer use by 8–10% and increased agricultural productivity by 5–6% (Patel *et al.*, 2017) [11].

Chhattisgarh, a major agricultural state in central India, is characterized by diverse soil types and predominantly rice-based cropping systems (Bhuarya *et al.*, 2015) [12]. Despite its importance in agricultural production, the state faces several challenges, including low soil organic carbon, nutrient imbalances, and ineffi

cient use of fertilizers (Netam *et al.*, 2022) [13]. In addition, variability in fertilizer availability and supply constraints highlights the need for efficient and alternative nutrient management strategies that can sustain crop productivity while reducing reliance on chemical fertilizers (Jat *et al.*, 2020; Chivenge *et al.*, 2021) [15, 14].

In this context, the present study aims to analyze Soil Health Card data to assess soil fertility status and to quantify the distribution of soil samples across different fertility categories. The study further evaluates the Nutrient Index Value (NIV) to determine the overall fertility status of major nutrients and uses this information to formulate fertilizer recommendations for *Kharif* crops. The primary objective is to develop nutrient management strategies and estimate fertilizer requirements for *Kharif* crops in Chhattisgarh for the year 2026, particularly under conditions of fertilizer supply constraints. The findings of this study are expected to support efficient fertilizer planning, promote balanced nutrient use, and contribute to sustainable agricultural development in the region.

Materials and Methods

The following materials and methods were used in this study, including soil fertility analysis based on Soil Health Card data, calculation of the Nutrient Index Value (NIV), formulation of fertilizer recommendations, and estimation of fertilizer requirements for *Kharif* crops in Chhattisgarh for the 2026 cropping season.

Soil fertility analysis

Three years of data from the Soil Health Card portal (2023–24 to 2025–26) were used to analyze 12 soil parameters, namely pH, EC, OC, N, P, K, S, Fe, Mn, Zn, Cu, and B. According to the data available on the portal, the total number of soil samples analyzed was 1,60,918 in 2023–24, 1,74,677 in 2024–25, and 2,51,671 in 2025–26. The number of samples falling under different fertility categories for each parameter was obtained from the portal. After aggregating the data across all three years, the percentage distribution of samples under different categories for each parameter was calculated. As per Soil Health Card Scheme Guidelines, the fertility classes for the different soil parameters are presented below.

Nutrient index value

The fertility status of soils with respect to available nitrogen (N), phosphorus (P), and potassium (K) was evaluated using the Nutrient Index Value (NIV) approach. The nutrient index was calculated following the standard method proposed by Ramamoorthy and Bajaj.

$$NIV = \frac{(L \times 1) + (M \times 2) + (H \times 3)}{100}$$

where *L*, *M*, and *H* represent the percentage of soil samples in low, medium, and high categories, respectively. The computed nutrient index values were interpreted using standard ratings, where values less than 1.67 indicate low fertility, values between 1.67 and 2.33 indicate medium fertility, and values greater than 2.33 indicate high fertility status.

Table 1. Fertility classes for different soil parameters

Sr. no	Soil Parameter	Categories		
1	Soil pH	Acidic < 6.5	Neutral 6.5 – 7.5	Alkaline > 7.5
2	Electrical Conductivity (dS m ⁻¹)	Non-saline < 4		Saline > 4
3	Organic Carbon (%)	Low < 0.50	Medium 0.50 – 0.75	High > 0.75
4	Available N (kg ha ⁻¹)	< 280	280 – 560	> 560
5	Available P (kg ha ⁻¹)	< 12	12 – 24	> 24
6	Available K (kg ha ⁻¹)	< 135	135 – 335	> 335
7	Available S (mg kg ⁻¹)	Deficient < 10		Sufficient > 10
8	Available Fe (mg kg ⁻¹)	< 4.5		> 4.5
9	Available Mn (mg kg ⁻¹)	< 3.5		> 3.5
10	Available Zn (mg kg ⁻¹)	< 0.6		> 0.6
11	Available Cu (mg kg ⁻¹)	< 0.2		> 0.2
12	Available B (mg kg ⁻¹)	< 0.5		> 0.5

Adjusted fertilizer recommendations

Fertilizer recommendations for major *Kharif* crops were formulated based on the Nutrient Index Value (NIV) derived from Soil Health Card data. The NIV was used to classify soil fertility into low, medium, and high categories, and the recommended dose of fertilizers (RDF) was adjusted accordingly to optimize nutrient use. For nutrients in the low category, 100% of the recommended dose of fertilizers (RDF) was applied. For medium and high categories, the RDF was reduced by 25% and 50%, respectively, and the remaining nutrient requirement was recommended to be met through Integrated

Plant Nutrient System (IPNS) approaches, including nano-fertilizers, organic manures, and biofertilizers. The general recommended dose of fertilizers (RDF) for major *Kharif* crops is given below.

Estimation of fertilizer requirements

The total fertilizer requirement for major *Kharif* crops was estimated based on the crop-wise area for the year 2025 (Table 3) and the recommended dose of fertilizers (RDF) adjusted using the Nutrient Index Value (NIV). Initially, the total nutrient requirement in terms of N, P₂O₅, and K₂O was calculated by multiplying crop area with the adjusted RDF for each crop.

Table 2. General recommended dose of fertilizers (RDF) for major *kharif* crops

Crop	N(kg ha ⁻¹)	P ₂ O ₅ (kg ha ⁻¹)	K ₂ O(kg ha ⁻¹)
Rice (Paddy)	100	60	40
Maize	120	60	40
Arhar (Pigeon pea)	20	50	20
Moong (Greengram)	20	50	20
Urd (Blackgram)	20	50	20
Groundnut	20	80	20
Soybean	20	60	20
Niger (Ramtil)	25	30	20

(Source: Srivastava *et al.*, 2024) [16]

The estimated nutrient requirements were subsequently converted into fertilizer quantities based on commonly used fertilizer sources in Chhattisgarh. Nitrogen (N) was considered to be supplied mainly through urea, diammonium phosphate (DAP), and complex fertilizer N:P:K (12:32:16). Phosphorus (P₂O₅) was supplied through single super phosphate (SSP), DAP, and N:P:K (12:32:16), while potassium (K₂O) was supplied through muriate of potash (MOP) and N:P:K (12:32:16).

First, the total phosphorus (P₂O₅) requirement was apportioned among different fertilizer sources based on their relative consumption pattern in the state, with 48% supplied through DAP, 18% through SSP, and 34% through N:P:K (12:32:16). The corresponding quantities of DAP and N:P:K (12:32:16) were then used to estimate the amount of nitrogen contributed by these fertilizers, which was deducted from the total nitrogen requirement. The remaining nitrogen requirement was met through urea.

Similarly, the potassium (K₂O) supplied through N:P:K (12:32:16) was calculated and deducted from the total potassium requirement, and the remaining potassium was estimated to be supplied through MOP. This approach ensured balanced fertilizer estimation based on nutrient requirements and prevailing fertilizer use patterns under conditions of fertilizer supply constraints.

Table 3. *Kharif* crop area in Chhattisgarh

Sr. no.	Crop	Area (000 ha)
1	Rice (Paddy)	3931.63
2	Maize	208.40
3	Arhar (Pigeon pea)	97.89
4	Moong	14.92
5	Urd	135.43
6	Groundnut	49.00
7	Soybean	29.92
8	Niger (Ramtil)	39.64
	Total	4506.83

(Source: Government of Chhattisgarh, 2025–26) [17]

Result and Discussion

Soil fertility status

The analysis of Soil Health Card data revealed important insights into the physicochemical properties and nutrient status of soils in Chhattisgarh. The distribution of soil reaction (pH), electrical conductivity (EC), organic carbon (OC), macronutrients (N, P, and K), and micronutrients is presented in Figures 1.

Soil reaction (pH) indicated that the majority of soils were neutral (89.50%), followed by acidic (10.27%) and a negligible proportion of alkaline soils (0.22%). This suggests that most soils are within a favorable pH range for nutrient availability and crop growth, although acidic soils may require liming to optimize productivity. Electrical conductivity (EC) showed that 99.41% of soils were non-saline, with only 0.59% classified as saline, indicating that salinity is not a major constraint in the region.

Organic carbon (OC) status was predominantly low (48.22%) and medium (36.65%), with only 13.44% of samples in the high category. This reflects poor organic matter content in soils, which may adversely affect soil structure, water retention, and nutrient availability. Among macronutrients, available nitrogen (N) was largely deficient, with 78.95% of samples in the low category, followed by 20.64% in medium and only 0.41% in high. This widespread nitrogen deficiency is closely associated with low organic carbon levels and continuous nutrient depletion. Available phosphorus (P) was mainly in the medium category (65.86%), followed by low (25.99%) and high (8.15%), indicating moderate phosphorus availability, possibly due to fertilizer application but limited by fixation in soils. Available potassium (K) was relatively sufficient, with 53.88% and 41.17% of samples in medium and high categories, respectively, and only 4.95% in low, suggesting adequate potassium reserves in the soils.

Sulphur (S), a secondary nutrient, showed deficiency in 35.15% of samples, while 64.85% were sufficient, indicating an emerging concern that may be linked to reduced use of sulphur-containing fertilizers and low organic matter inputs. Among micronutrients, zinc (Zn) deficiency was most prominent (45.09%), followed by boron (B) deficiency (23.17%), highlighting their potential limitation for crop productivity. In contrast, iron (Fe), manganese (Mn), and copper (Cu) were largely sufficient, with deficiency levels of 8.75%, 1.74%, and 2.68%, respectively. The results obtained from Soil Health Card data in Chhattisgarh were also supported by earlier studies conducted by Pathade *et al.* (2006) [18], Kumar *et al.* (2014) [19], Chandrakar *et al.* (2014) [20], Sahu *et al.* (2018) [21], Kumar *et al.* (2015) [22], Rajpoot *et al.* (2021) [23], Devdas *et al.* (2021) [24], Mandal *et al.* (2021) [25], Tiwari *et al.* (2023) [26], Singhal *et al.* (2022) [27], and Singh *et al.* (2006) [28].

Nutrient index values (NIV)

The Nutrient Index Values (NIV) indicate considerable variation in the fertility status of soils in Chhattisgarh with respect to major nutrients (Table 4). The NIV for available nitrogen (N) was 1.21, which falls under the low fertility category, indicating widespread nitrogen deficiency in the soils. This may be attributed to low organic matter content, continuous cropping, and inadequate application of nitrogenous fertilizers.

In contrast, the NIV for available phosphorus (P) was 1.82, placing it in the medium fertility category. This suggests a moderate level of phosphorus availability in the soils, possibly due to regular application of phosphatic fertilizers, although fixation in acidic soils may limit its effective availability to plants. The NIV for available potassium (K) was 2.36, which falls under the high fertility category, indicating that the soils are generally well supplied with potassium. This could be due to the presence of potassium-bearing minerals in the parent material and comparatively lower depletion by crops.

Adjusted fertilizer recommendations

Fertilizer recommendations for major *Kharif* crops were formulated based on the Nutrient Index Value (NIV) derived from Soil Health Card data. The NIV was used to classify soil fertility status into low, medium, and high categories, and the recommended dose of fertilizers (RDF) was adjusted accordingly. For nutrients in the low category, 100% of RDF was applied, while for medium and high categories, the RDF was reduced by 25% and 50%, respectively. Based on the NIV classification, the adjusted fertilizer doses (kg ha⁻¹) for major *Kharif* crops in Chhattisgarh are presented in Table 5.

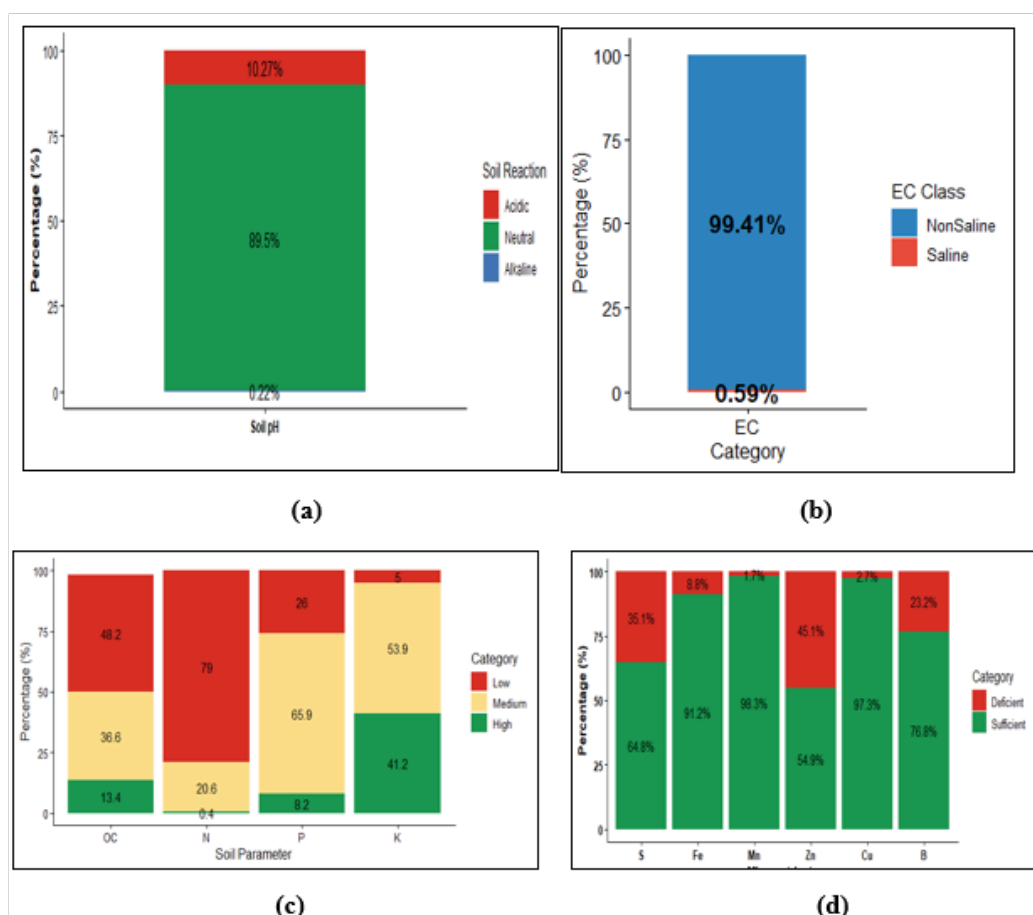


Figure 1. Distribution (%) of soil samples under different soil parameters in Chhattisgarh based on Soil Health Card data: (a) soil reaction (pH), (b) electrical conductivity (EC), (c) organic carbon (OC) and available N, P, and K, and (d) sulphur (S) and micronutrients.

The reduced fertilizer doses were supplemented through Integrated Plant Nutrient System (IPNS) approaches, including organic manures and biofertilizers, to ensure balanced nutrient supply and sustainable soil health management.

Integrated plant nutrient system (IPNS) approaches

Under conditions of fertilizer supply constraints, Integrated Plant Nutrient System (IPNS) practices were recommended for major Kharif crops in Chhattisgarh as an effective strategy to supplement reduced chemical fertilizer application. IPNS integrates organic, inorganic, and biological sources of nutrients, thereby ensuring balanced nutrient supply while reducing dependence on external fertilizers.

Table 4. Nutrient index values (NIV) and fertility rating of Chhattisgarh

Nutrient	NIV	Soil Fertility Class
N	1.21	Low
P	1.82	Medium
K	2.36	High

Green manuring with sunhemp or dhaincha (25 kg seed ha⁻¹) contributed to a saving of approximately 50 kg N ha⁻¹ in rice-based systems (Tanveer *et al.*, 2019; Dubey *et al.*, 2015) [29, 30]. Application of blue-green algae (10 kg ha⁻¹) and biofertilizers such as *Azotobacter* and *Azospirillum* (20 g kg⁻¹ seed treatment) enhanced biological nitrogen fixation, saving about 25 kg N ha⁻¹ (Mishra, 2024; Gautam *et al.*, 2022; Shukla *et al.*, 2025; Bastakoti *et al.*, 2024) [32, 33, 34, 31], while *Rhizobium* inoculation in pulse crops (25 g kg⁻¹ seed) fixed up to 60 kg N ha⁻¹ (Hamdi *et al.*, 2026) [35].

Organic sources such as farmyard manure (FYM) and vermicompost (5 t ha⁻¹ each) contributed to nearly 25% nitrogen savings, along with improvements in soil structure and microbial activity (Bharose *et al.*, 2023; Katiyar *et al.*, 2023) [36, 37]. Foliar application of nano urea

(4 ml L⁻¹, applied twice at 40–45 and 55–60 days) reduced nitrogen requirement by about 25% (Rathour *et al.*, 2024; Vasanth *et al.*, 2025) [38, 39], while foliar spray of 2% urea solution and 20% cow urine solution provided an additional saving of approximately 25 kg N ha⁻¹ (Pangaribuan *et al.*, 2023) [40].

Table 5. NIV-based adjusted fertilizer recommendations for major kharif crops

Crop	N (kg ha ⁻¹)	P ₂ O ₅ (kg ha ⁻¹)	K ₂ O (kg ha ⁻¹)
Rice (Paddy)	100	45	20
Maize	120	45	20
Arhar (Pigeon pea)	20	37.5	10
Moong (Greengram)	20	37.5	10
Urd (Blackgram)	20	37.5	10
Groundnut	20	60	10
Soybean	20	45	10
Niger (Ramtil)	25	22.5	10

For phosphorus management, application of nano DAP (seed treatment @ 5 ml kg⁻¹ seed and foliar spray @ 2 ml L⁻¹ at 30 days) resulted in up to 50% saving of P₂O₅ (Singh *et al.*, 2025; Chundawat *et al.*, 2025; Karn *et al.*, 2025) [42, 41, 43]. The use of phosphate-solubilizing bacteria (PSB) @ 20 g kg⁻¹ seed further enhanced phosphorus availability in the soil and resulted in a saving of up to 10 kg P₂O₅ ha⁻¹ (Rawat *et al.*, 2022) [44].

Beyond reducing fertilizer demand, IPNS offers multiple advantages, including improved nutrient use efficiency, enhanced soil organic car

bon, better soil physical properties, increased microbial activity, and sustained crop productivity. It also minimizes nutrient losses through leaching and volatilization, reduces environmental pollution, and lowers input costs for farmers. Therefore, IPNS serves as a sustainable and practical approach for maintaining soil fertility and ensuring crop productivity, particularly under conditions of limited fertilizer availability.

Fertilizer requirements

Fertilizer requirements were calculated based on the nutrient requirements of each crop. After estimating the total requirement of individual nutrients, the values were converted into equivalent quantities of fertilizers.

The crop-wise nutrient requirement for major *Kharif* crops based on the previous year's cropped area is presented in Table 6. The results indicate considerable variation in nutrient demand among crops, primarily due to differences in cropped area and recommended fertilizer doses. The total nutrient requirement for the *Kharif* season was estimated to be 425,705 tonnes of nitrogen (N), 200,789 tonnes of phosphorus (P_2O_5), and 86,469 tonnes of potassium (K_2O).

Table 6. Crop-wise nutrient requirement (tonnes) for *kharif* crops in Chhattisgarh

Crop	N (t)	P_2O_5 (t)	K_2O (t)
Rice (Paddy)	393,163	176,923	78,633
Maize	25,008	9,378	4,168
Arhar (Pigeon pea)	1,958	3,671	979
Moong (Greengram)	298	560	149
Urd (Blackgram)	2,709	5,079	1,354
Groundnut	980	2,940	490
Soybean	598	1,346	299
Niger (Ramtil)	991	892	396
Total	425,705	200,789	86,469

The estimate quantity of fertilizers for the *Kharif* season of 2026 is presented in Table 7. Urea accounted for the highest requirement (787,807 t), followed by N:P:K (12:32:16) (213,338 t) and DAP (209,519 t). The requirement of MOP was 87,224.22 t, while SSP had the lowest requirement (22,587 t).

Table 7. Total fertilizer requirement for *Kharif* season

Fertilizer	SSP	DAP	N:P:K (12:32:16)	Urea	MOP
Quantity (t)	22,587	209,519	213,338	787,807	87,224.22

Conclusion

The present study highlights the utility of Soil Health Card data for assessing soil fertility status and developing nutrient index-based fertilizer recommendations for *Kharif* crops in Chhattisgarh under fertilizer supply constraints. The analysis revealed that most soils are low in organic carbon and deficient in nitrogen. The Nutrient Index Values (NIV) indicated low, medium, and high fertility status for nitrogen, phosphorus, and potassium, respectively. Based on the NIV, fertilizer recommendations were rationalized by applying 100% of the recommended dose of fertilizers (RDF) for deficient nutrients, while reducing the RDF by 25% and 50% for medium and high fertility categories. To compensate for nutrient requirements under supply constraints, Integrated Plant Nutrient System (IPNS) practices were recommended. The use of green manuring, organic manures, biofertilizers, and nano-fertilizers reduced dependence on chemical fertilizers while improving soil health, nutrient use efficiency, and sustainability. The estimated fertilizer requirement showed higher demand for nitrogenous fertilizers, particularly urea, followed by complex fertilizers and DAP, while potassic fertilizer demand remained relatively lower.

These findings are important for planning fertilizer supply and distribution in the state. Overall, the study demonstrates that a combined approach of Soil Health Card-based assessment, NIV-guided fertilizer adjustment, and IPNS adoption can optimize fertilizer use, enhance crop productivity, and support sustainable agriculture under limited fertilizer availability.

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Not applicable.

Conflict of interest

The authors declare that they have no conflict of interest.

Data availability

The data supporting the findings of this study are included within the manuscript and supplementary sources cited therein.

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Disclosure statement

The authors declare that artificial intelligence (AI)-based tools were used only for language editing, paraphrasing, and plagiarism checking. Data analysis and graphical representations were performed using R Studio software. The use of these tools did not affect the originality, integrity, or scientific validity of the research. The authors take full responsibility for the content and conclusions presented in this manuscript.

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