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Composite Fertilizer Management Index (CMFI) among Major Field Crop Growers of Telangana

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HIGHLIGHTS

- CFMI contains novelty in approach as it consists of planning, purchasing, practising and performance dimensions with 22 underlying indicators, which include FBMPs.
- The comparative analysis was done across six major field crops of Telangana.
- Advanced statistical tools like MGLM and Kruskal wallis test were used in testing hypothesis and identifying determinants of fertilizer management.

ARTICLE INFO

Keywords: Fertiliser use, Manures, Nutrient management, Determinants, Factors, Comparative analysis, FBMPs, GAPs.

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ABSTRACT

The study was conducted during 2023–2025 to develop a composite fertilizer management index (CFMI) for major field crops of Telangana, encompassing planning, purchasing, practicing, and performance dimensions. The research design involved 360 farmers across six major field crops *i.e.* paddy, cotton, maize, red gram, soybean, and Bengal gram. Data on 22 indicators were collected from farmers, normalised and analyzed using Principal Component Analysis (PCA), Kruskal-Wallis test, and Multivariate General Linear Model (GLM). Results revealed that maize farmers ranked highest in overall fertilizer management (CFMI = 0.49), followed by paddy (0.48), red gram (0.46), cotton (0.44), soybean (0.30), and Bengal gram (0.29). Significant difference in fertiliser management across crops (χ^2 = 123.136, $p < 0.01$) was found. Education, farming system, experience in selected crop cultivation, manure and fertilizer availability, social participation, extension contact, scientific orientation, sustainability orientation and economic motivation were key determinants of CFMI (R^2 = 0.643). The findings highlight the need to enhance farmers' knowledge and attitudes toward efficient fertilizer practices, raise awareness of health and environmental impacts, and strengthen input availability and institutional linkages to promote balanced nutrient management and improve soil health, crop productivity, and resource use efficiency.

INTRODUCTION

Fertilizers are important inputs for increasing the production and productivity of crops. Indian soils are deficient in organic carbon, N, P, K, B, Cu, Fe, Mn, S and Zn nutrients, respectively (Khurana & Kumar, 2022). In the consumption of plant nutrients (NPK/ha) in major states of India during 2019, Telangana reported the top (Srinivasarao, 2021). The ratio of N, P, and K fertiliser use indicates noticeable disparities across states, highlighting potential nutrient imbalances across farming systems (Chand & Pandey, 2008). In Telangana, fertilizer use patterns clearly reflect this imbalance, with excessive nitrogen application reported in most

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districts, excessive phosphatic fertilizer use in some districts, and consistent deficiency of potassic fertilizers across all districts. Furthermore, none of the districts recorded 75 to 100% area coverage under the use of farmyard manure (FYM), emphasizing the declining reliance on organic nutrient sources (Bora, 2022). In terms of solid and liquid biofertilizer production during 2020-21, Telangana ranked 13th and 12th among all states and union territories, respectively, with production levels below 5,000 tonnes (Khurana & Kumar, 2022). It has been observed that although chemical fertilizer use among farmers is high, awareness of its impact on soil health remains low (Hussain et al., 2017). These trends highlight an alarming scenario, making it essential to examine these patterns at a micro level. It will help to understand how nutrient imbalances are reflected across different crops and to identify the factors responsible for them. The results of this analysis may provide insights into existing practices of fertilizer planning, purchasing, application, and performance. They can also help explain the reasons behind both efficient and inefficient management. Such insights can guide policymakers in designing targeted interventions, capacity development programs, and infrastructural improvements, including subsidies and soil testing facilities. The Government of India has launched a National Mission on Soil Health Card to promote soil test based, balanced and judicious fertilizer application in the country (PIB, 2021).

There was no early study reported in the area consisting of planning, purchasing, practicing and performance of fertilizers in major field crops. Considering this, a fertilizer management index was developed to enable crop wise comparison, which can also be adapted to other crops with minor modifications. In this context, the study aimed to analyze the fertilizer management by farmers in major field crops of Telangana and to examine the relationship between independent variables and fertilizer management. Accordingly, the following hypotheses are formulated: (i) there is no significant difference in fertilizer management across farmer groups, and (ii) there exists a significant association between independent variables and fertilizer management. The study was confined to one crop per district, limiting the generalization of findings to all major field crop farmers of Telangana. The sample size was restricted to 360 farmers, and the results are therefore context-specific. The findings relied on respondents expressed opinions and recall, which may involve response bias. Additionally, the use of ex-post facto and exploratory research designs entails inherent methodological limitations.

METHODOLOGY

The study was carried out during 2023-2025. The Telangana state was purposively selected. Based on the area under cultivation during previous five years six major field crops *i.e.* paddy, cotton, maize, red gram, soybean and Bengal gram were selected purposively. For each crop, 1 district was selected randomly among the cultivating districts. From each district, 2 mandals were randomly selected. From each mandal, 3 villages were randomly selected. From each village, 10 farmers were selected randomly. Thus, a total of 6 districts, 12 mandals, 36 villages and 360 farmers were selected randomly for the study in a way that each district represents 60 farmers cultivating the respective crop. A total of twenty-five independent variables, two other variables (knowledge and attitude towards Fertilizer Best Management Practices) and one dependent variable (Composite Fertilizer Management Index) were selected for the study.

Development of Composite Fertilizer Management Index

Large number of indicators were identified from studying review of literature and expert consultations and 22 indicators were finalized using relevancy ratings received by 37 experts out of 64 experts (Jairu et al., 2023; Khalkho & Ghosh, 2023; Chandra & Ghadei, 2024) and they were organised under 4 dimensions (Ranjan et al., 2025). The data from farmers was collected on these indicators. The indicators were uniform across crops however, number of indicators and the unit of measurement between the indicators was different. Hence, they were normalized by subtracting the minimum value from the observed value and dividing by range (Kale et al., 2016). Principal Component Analysis (PCA) was employed on normalized data with varimax rotation using Statistical Software for Social Sciences 20 (SPSS 20). The communality values obtained through PCA indicated the proportion of variance explained by all the indicators together. All these values shown communality value of 0.6 (Maiti et al., 2015). The method followed by National University of Educational Planning and Administration (2009) used to assign weights to each indicator for development of Composite Fertilizer Management Index (CFMI). Index validity was measured by content validity, and construct validity using KMO measure of sampling adequacy (0.657) and Bartlett's Test of Sphericity $p < .01$. The index was calculated by using following formula. The possible range of CFMI was 0 – 1.

$$\text{CFMI} = \frac{\sum_{i=1}^{n} W_i X_i}{\sum_{i=1}^{n} W_i}$$

X_i = is the index value of the concerned indicator
W_i = Weights associated with X_i indicator

Initially, Kruskal Wallis test was performed to test the significant difference in CFMI across the six major field crops. Multiple pairwise comparison using Dunns procedure was performed to test the significant difference in CFMI between each pair of crops. It was done by using SPSS 20. Further, the Pearson correlation coefficient was calculated to assess the correlation between determinants and CFMI of each crop and overall. After finding similarities in results across crops stepwise regression was performed to identify the most significant variables. Then, a Multivariate General Linear Model was used to test the significant variables with CFMI. No significant interaction effect (crop × variable) was found, suggesting that the variables were consistently associated across farmer groups, with no deviation in their relationships among the groups. Further, the univariate general linear model result was calculated to find the effect of independent variables on CFMI.

RESULTS

The PCA results produced nine principal components (PCs) with eigenvalues greater than one, as illustrated in the scree plot (Figure 1). Together, these nine components explained nearly 75%

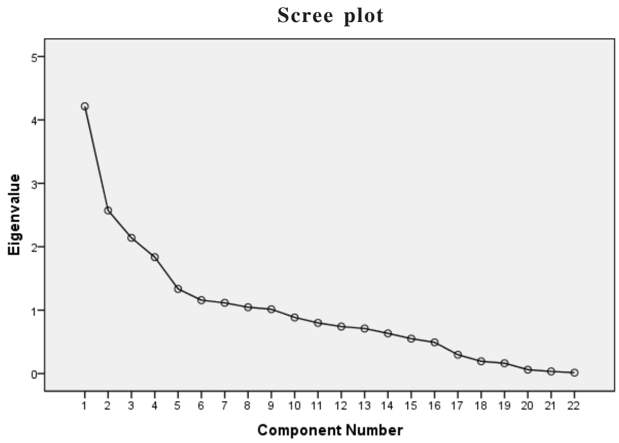

Figure 1. Scree plot of eigenvalue

Table 1. Eigen values and extraction of variability

Principal component	Extraction sums of squared loadings		
	Eigen value	% of Variance	Cumulative %
1	4.214	19.157	19.157
2	2.571	11.687	30.844
3	2.140	9.728	40.571
4	1.835	8.343	48.914
5	1.334	6.065	54.979
6	1.157	5.260	60.240
7	1.115	5.069	65.309
8	1.046	4.754	70.063
9	1.014	4.609	74.672

of the total variation in the standardized data (Table 1). The eigenvalues and factor loadings represented the respective weights assigned to each indicator for developing the index. The computed index values for individual indicators, dimensions, and the overall Composite Fertilizer Management Index for each crop are summarised in Table 2.

Composite Fertilizer Management Index

Maize farmers ranked first (x= 0.49, rank-I), followed by paddy (x= 0.48, rank-II), red gram (x= 0.46, rank-III), cotton (x= 0.44, rank-IV), soybean (x= 0.30, rank-V) and Bengal gram (x= 0.29, rank-VI).

Dimension-wise index values

In case of planning dimension, paddy farmers ranked first (x=0.40, rank-I), followed by maize (x=0.38, rank-II), cotton (x=0.35, rank-III), red gram (x=0.30, rank-IV), soybean (x=0.21, rank-V) and Bengal gram (x=0.20, rank-VI) farmers. In case of purchasing dimension, paddy farmers ranked first (x=0.54, rank-I), followed by maize (x=0.52, rank-II), red gram (x=0.51, rank-III), cotton (x=0.46, rank-IV), Bengal gram (x=0.25, rank-V) and soybean (x=0.25, rank-VI) farmers. In the case of practicing dimension, maize farmers ranked first (x=0.55, rank-I), followed by red gram (x=0.53, rank-II), paddy (x=0.49, rank-III), cotton (x=0.46, rank-IV), Bengal gram (x=0.37, rank-V) and soybean (x=0.35, rank-VI) farmers. In case of performance dimension, cotton farmers ranked first (x=0.55, rank-I), followed by maize (x=0.51, rank-II), red gram (x=0.49, rank-III), Bengal gram (x=0.48, rank-IV), paddy (x=0.48, rank-V) and soybean (x=0.47, rank-VI) farmers.

Indicator-wise index values

In case of planning manures, cotton farmers ranked first (x=0.33, rank-I), followed by maize (x=0.25, rank-II), red gram (x=0.24, rank-III), paddy (x=0.23, rank-IV), soybean (x=0.06, rank-V) and Bengal gram (x=0.06, rank-V). In case of planning fertilizes, red gram farmers ranked first (x=0.70, rank-I), followed by paddy (x=0.67, rank-II), maize (x=0.65, rank-III), cotton (x=0.53, rank-IV), Bengal gram (x=0.40, rank-V) and soybean (x=0.39, rank-VI). In case of planning of nutrient deficiency and adverse condition management, paddy farmers ranked first (x=0.31, rank-I), followed by maize (x=0.23, rank-II), cotton (x=0.23, rank-II), soybean (x=0.17, rank-IV), Bengal gram (x=0.16, rank-V) and red gram (x=0.07, rank-VI). In case of planning of fertilizer transport, paddy farmers ranked first (x=0.58, rank-I), followed by maize (x=0.43, rank-II), cotton (x=0.41, rank-III), soybean (x=0.30, rank-IV), red gram (x=0.26, rank-V) and Bengal gram (x=0.23, rank-VI). In case of planning of fertilizer storage, maize farmers ranked first (x=0.36, rank-I), followed by paddy (x=0.30, rank-II), soybean (x=0.29, rank-III), cotton (x=0.25, rank-IV), Bengal gram (x=0.24, rank-V) and red gram (x=0.24, rank-V). In case of planning of fertilizer handling, paddy farmers ranked first (x=0.24, rank-I), followed by maize (x=0.21, rank-II), cotton (x=0.17, rank-III), Bengal gram (x=0.05, rank-IV), soybean (x=0.04, rank-V) and red gram (x=0.02, rank-VI). In case of planning of fertilizer disposal, maize farmers ranked first (x=0.40, rank-I), followed by cotton (x=0.37, rank-II), paddy (x=0.36, rank-III), soybean (x=0.33, rank-IV), red gram (x=0.30, rank-V) and Bengal gram (x=0.30, rank-V).

In case of purchasing of manures, cotton farmers ranked first (x=0.48, rank-I), followed by red gram (x=0.39, rank-II), maize (x=0.28, rank-III), paddy (x=0.26, rank-IV), Bengal gram (x=0.08, rank-V) and soybean (x=0.08, rank-V). In case of purchasing nitrogenous fertilizers, paddy farmers ranked first (x=0.66, rank-I), followed by maize (x=0.59, rank-II), Bengal gram (x=0.53, rank-III), cotton (x=0.45, rank-IV), soybean (x=0.38, rank-V) and red gram (x=0.20, rank-VI). In case of purchasing of phosphatic fertilizers, maize farmers ranked first (x=0.70, rank-I), followed by red gram (x=0.66, rank-II), paddy (x=0.63, rank-III), soybean (x=0.57, rank-IV), Bengal gram (x=0.53, rank-V) and cotton (x=0.50, rank-VI). In case of purchasing of potassic fertilizers, paddy farmers ranked first (x=0.77, rank-I), followed by red gram (x=0.76, rank-II), maize (x=0.70, rank-III), cotton (x=0.42, rank-IV), Bengal gram (x=0.02, rank-V) and soybean (x=0.00, rank-VI).

In case of practicing manure application, cotton farmers ranked first (x=0.48, rank-I), followed by red gram (x=0.38, rank-II), maize (x=0.29, rank-III), paddy (x=0.28, rank-IV), Bengal gram (x=0.08, rank-V) and soybean (x=0.07, rank-VI). In case of practicing nitrogenous fertilizer application, Bengal gram ranked first (x=0.85, rank-I), followed by maize (x=0.80, rank-II), red gram (x=0.67, rank-III), soybean (x=0.62, rank-IV), cotton (x=0.55, rank-V) and paddy (x=0.37, rank-VI). In case of practicing phosphatic fertilizer application, red gram farmers ranked first (x=1.00, rank-I), followed by soybean (x=0.90, rank-II), Bengal gram (x=0.84, rank-III), cotton (x=0.70, rank-IV), maize (x=0.68, rank-V) and paddy (x=0.51, rank-

Table 2. Indicator-wise index values of Composite Fertilizer Management Index

S.No.	Indicator-wise index values	Paddy Index (Rank)	Cotton Index (Rank)	Maize Index (Rank)	Red gram Index (Rank)	Paddy Index (Rank)	Soybean Index (Rank)	Overall Index (Rank)
Composite fertilizer management index		0.48 (II)	0.44 (IV)	0.49 (I)	0.46 (III)	0.29 (VI)	0.30 (V)	0.41
D1	*Planning*	0.40 (I)	0.35 (III)	0.38 (II)	0.30 (IV)	0.21 (V)	0.20 (VI)	0.31 (IV)
1	Manures	0.23 (IV)	0.33 *(I)*	0.25 (II)	0.24 (III)	0.06 (V)	0.06 (V)	0.20 (XIX)
2	Fertilizers	0.67 (II)	0.53 (IV)	0.65 (III)	0.70 *(I)*	0.39 (VI)	0.40 (V)	0.56 *(IV)*
3	Nutrient deficiency and adverse condition management	0.31 *(I)*	0.23 (II)	0.23 (II)	0.07 (VI)	0.17 (IV)	0.16 (V)	0.19 (XX)
4	Fertilizer transport	0.58 *(I)*	0.41 (III)	0.43 (II)	0.26 (V)	0.30 (IV)	0.23 (VI)	0.37 (XIV)
5	Fertilizer storage	0.30 (II)	0.25 (IV)	0.36 *(I)*	0.24 (V)	0.29 (III)	0.24 (V)	0.28 (XVI)
6	Fertilizer handling	0.24 *(I)*	0.17 (III)	0.21 (II)	0.02 (VI)	0.04 (V)	0.05 (IV)	0.12 (XXII)
7	Fertilizer disposal	0.36 (III)	0.37 (II)	0.40 *(I)*	0.30 (V)	0.33 (IV)	0.30 (V)	0.34 (XV)
D2	*Purchasing*	0.54 (I)	0.46 (IV)	0.52 (II)	0.51 (III)	0.22 (VI)	0.25 (V)	0.42 (III)
8	Manures	0.26 (IV)	0.48 *(I)*	0.28 (III)	0.39 (II)	0.08 (V)	0.08 (V)	0.26 (XVII)
9	Nitrogenous fertilizers	0.66 *(I)*	0.45 (IV)	0.59 (II)	0.20 (VI)	0.38 (V)	0.53 (III)	0.47 (IX)
10	Phosphatic fertilizers	0.63 (III)	0.50 (VI)	0.70 *(I)*	0.66 (II)	0.57 (IV)	0.53 (V)	0.58 *(III)*
11	Potassic fertilizers	0.77 *(I)*	0.42 (IV)	0.70 (III)	0.76 (II)	0.00 (VI)	0.02 (V)	0.44 (XI)
D3	*Practicing*	0.49 (III)	0.46 (IV)	0.55 (I)	0.53 (II)	0.35 (VI)	0.37 (V)	0.46 (II)
12	Manure application	0.28 (IV)	0.48 *(I)*	0.29 (III)	0.38 (II)	0.07 (VI)	0.08 (V)	0.26 (XVII)
13	Nitrogenous fertilizer application	0.37 (VI)	0.55 (V)	0.80 (II)	0.67 (III)	0.62 (IV)	0.85 (I)	0.64 *(II)*
14	Phosphatic fertilizer application	0.51 (VI)	0.70 (IV)	0.68 (V)	1.00 *(I)*	0.90 (II)	0.84 (III)	0.77 *(I)*
15	Potassic fertilizer application	0.78 (III)	0.38 (IV)	0.88 (II)	0.94 *(I)*	0.00 (VI)	0.03 (V)	0.50 (VII)
16	Nutrient deficiency and adverse condition management	0.53 *(I)*	0.45 (II)	0.42 (III)	0.28 (VI)	0.32 (V)	0.39 (IV)	0.40 (XIII)
17	Fertilizer transport	0.67 *(I)*	0.50 (III)	0.56 (II)	0.42 (IV)	0.41 (V)	0.40 (VI)	0.49 (VIII)
18	Fertilizer storage	0.45 (III)	0.38 (V)	0.51 *(I)*	0.37 (VI)	0.47 (II)	0.42 (IV)	0.43 (XII)
19	Fertilizer handling	0.58 (II)	0.56 (III)	0.61 *(I)*	0.52 (V)	0.53 (IV)	0.51 (VI)	0.55 *(V)*
20	Fertilizer disposal	0.25 (II)	0.18 (III)	0.26 *(I)*	0.15 (V)	0.14 (VI)	0.16 (IV)	0.19 (XX)
D4	*Performance*	0.48 (V)	0.55 (I)	0.51 (II)	0.49 (III)	0.47 (VI)	0.48 (IV)	0.50 (I)
21	Manures	0.41 (VI)	0.58 *(I)*	0.43 (V)	0.45 (IV)	0.47 (II)	0.47 (II)	0.46 (X)
22	Primary macro nutrient fertilizers	0.55 (II)	0.52 (IV)	0.59 *(I)*	0.54 (III)	0.48 (VI)	0.50 (V)	0.53 (VI)

Index value range 0 – 1.

VI). In case of practicing potassic fertilizer application, red gram ranked first (*x*=0.94, rank-I), followed by maize (*x*=0.88, rank-II), paddy (*x*=0.78, rank-III), cotton (*x*=0.38, rank-IV), Bengal gram (*x*=0.03, rank-V) and soybean (*x*=0.00, rank-VI). In case of practicing nutrient deficiency and adverse condition management, paddy farmers ranked first (*x*=0.53, rank-I), followed by cotton (*x*=0.45, rank-II), maize (*x*=0.42, rank-III), Bengal gram (*x*=0.39, rank-IV), soybean (*x*=0.32, rank-V) and red gram (*x*=0.28, rank-VI). In case of practicing fertilizer transport, paddy farmers ranked first (*x*=0.67, rank-I), followed by maize (*x*=0.56, rank-II), cotton (*x*=0.50, rank-III), red gram (*x*=0.42, rank-IV), soybean (*x*=0.41, rank-V) and Bengal gram (*x*=0.40, rank-VI). In case of practicing fertilizer storage, maize farmers ranked first (*x*=0.51, rank-I), followed by soybean (*x*=0.47, rank-II), paddy (*x*=0.45, rank-III), Bengal gram (*x*=0.42, rank-IV), cotton (*x*=0.38, rank-V) and red gram (*x*=0.37, rank-VI). In case of practicing fertilizer handling, maize farmers ranked first (*x*=0.61, rank-I), followed by paddy (*x*=0.58, rank-II), cotton (*x*=0.56, rank-III), soybean (*x*=0.53, rank-IV), red gram (*x*=0.52, rank-V) and Bengal gram (*x*=0.51, rank-VI). In case of practicing of fertilizer disposal, maize farmers ranked first (*x*=0.26, rank-I), followed by paddy (*x*=0.25, rank-II), cotton (*x*=0.18, rank-III), Bengal gram (*x*=0.16, rank-IV), red gram (*x*=0.15, rank-V) and soybean (*x*=0.14, rank-VI).

In case of performance of manures, cotton farmers ranked first (*x*=0.58, rank-I), followed by soybean (*x*=0.47, rank-II), Bengal gram (*x*=0.47, rank-II), red gram (*x*=0.45, rank-IV), maize (*x*=0.43, rank-V), and paddy (*x*=0.41, rank-VI). In case of the performance of primary macronutrient fertilizers, maize farmers ranked first (*x*=0.59, rank-I), followed by paddy (*x*=0.55, rank-II), red gram (*x*=0.54, rank-III), cotton (*x*=0.52, rank-IV), Bengal gram (*x*=0.50, rank-V) and soybean (*x*=0.48, rank-VI).

Table 3. Pairwise comparison of farmer groups on CFMI based on mean rank as per Kruskal-Wallis test

Farmer groups	Mean rank	P	C	M	R
Paddy	230.60				
Cotton	202.07				
Maize	242.10				
Red gram	215.58				
Soybean	91.10	**	**	**	**
Bengal gram	101.55	**	**	**	**

* Significance at 0.05 level of probability, ** Significance at 0.01 level of probability

χ^2 (5) = 123.136, $p < 0.01$, P – Paddy, C – Cotton, M – Maize, R - Red gram

The results presented in Table 3. the Kruskal-Wallis test, revealed a significant difference in composite fertilizer management levels among farmer groups at the 0.01 level of probability (÷² = 123.136, *df* = 5). Further, multiple pair-wise comparisons using Dunn's procedure confirmed a statistically significant difference between soybean ($p < 0.01$) and Bengal gram ($p < 0.01$) farmers compared to maize, paddy, red gram and cotton farmers.

Relationship between independent variables and fertilizer management

The results of the Multivariate General Linear Model (GLM) analysis from Table 4. were examined to understand the collective influence of several independent variables on three key dependent variables: knowledge, attitude, and fertilizer management. Wilks' Lambda values, significance levels (p-values), and Partial Eta Squared statistics were used to assess the multivariate significance and effect sizes of predictors. The analysis revealed that all included predictors significantly influenced the dependent variables ($p < .05$), suggesting that these factors together explain substantial variance in farmers' knowledge, attitudes, and fertilizer management.

Among these, education (Wilks' Lambda = 0.855, p = 0.000, η^2 = 0.145), social participation (Wilks' Lambda = 0.900, p = 0.000, η^2 = 0.100), scientific orientation (Wilks' Lambda = 0.927, p = 0.000, η^2 = 0.073), farming system (Wilks' Lambda = 0.929, p = 0.000, η^2 = 0.071) , manure and fertilizer availability (Wilks' Lambda = 0.934, p = 0.000, η^2 = 0.066), experience in selected crop cultivation (Wilks' Lambda = 0.932, p = 0.000, η^2 = 0.068), extension contact (Wilks' Lambda = 0.942, p = 0.000, η^2 = 0.058), economic motivation (Wilks' Lambda = 0.950, p = 0.001, η^2 = 0.050), capital availability (Wilks' Lambda = 0.959, p = 0.003, η^2 = 0.041), sustainability orientation (Wilks' Lambda = 0.966, p = 0.008, η^2 = 0.034), institutional access (Wilks' Lambda = 0.958, p = 0.002, η^2 = 0.042), access to information on fertilizers (Wilks' Lambda = 0.966, p = 0.009, η^2 = 0.034) and farmer groups (Wilks'

Table 4. Multivariate General Linear Model analysis of variables with fertilizer management

Effect	Wilks' Lambda	*F*	Sig.	Partial Eta Squared
Education	0.855	19.173	0.000	0.145
Experience in selected crop cultivation	0.932	8.262	0.000	0.068
Social participation	0.900	12.644	0.000	0.100
Extension contact	0.942	6.999	0.000	0.058
Source of information on fertilizers	0.966	3.936	0.009	0.034
Scientific orientation	0.927	8.972	0.000	0.073
Economic motivation	0.950	5.973	0.001	0.050
Sustainability orientation	0.966	3.967	0.008	0.034
Institutional access	0.958	5.022	0.002	0.042
Capital availability	0.959	4.806	0.003	0.041
Manures and fertilizers availability	0.934	7.994	0.000	0.066
Farming system	0.929	8.599	0.000	0.071
Farmer groups	0.620	11.847	0.000	0.147

Table 5. Between-Subjects Effects (Univariate) of determinants with fertilizer management by farmers

Source	b value	Standard error (SEb)	*t*-value	*F*	Sig.	Partial Eta Squared	VIF values
Corrected model				36.165	0.000	0.643	
Education	0.014	0.003	4.545	20.659	0.000	0.057	1.777
Experience in selected crop cultivation	0.037	0.008	4.478	20.051	0.000	0.055	1.575
Social participation	0.025	0.008	2.989	8.935	0.003	0.025	1.421
Extension contact	0.003	0.001	2.471	6.104	0.014	0.018	1.460
Source of information on fertilizers	0.002	0.001	1.226	1.502	0.221	0.004	1.475
Scientific orientation	0.003	0.001	2.535	6.425	0.012	0.018	1.577
Economic motivation	0.003	0.001	2.296	5.274	0.022	0.015	1.572
Sustainability orientation	0.004	0.002	2.266	5.135	0.024	0.015	1.411
Institutional access	0.000	0.001	.354	.125	0.724	0.000	1.390
Capital availability	0.001	0.001	1.473	2.170	0.142	0.006	1.562
Manures and fertilizers availability	0.002	0.001	3.327	11.070	0.001	0.031	1.420
Farming system	0.052	0.012	4.485	20.117	0.000	0.056	1.196
Farmer Groups				31.899	0.000	0.318	
Paddy	0.126	.018	7.200				
Cotton	0.141	.019	7.576				
Maize	0.131	.018	7.254				
Red gram	0.203	.019	10.765				
Soybean	0.032	.018	1.772				
Bengal gram	0.000	0.000	0.000				

R Squared = 0.643 (Adjusted R Squared = 0.625); Computed using alpha = 0.05; Durbin-Watson =1.724

Lambda = 0.620, p = 0.000, η^2 = 0.147) showed a strong multivariate effect indicating that these variables are significant determinants across all three dependent variables.

The univariate results from multivariate General Linear Model are presented in Table 5. These results indicate how each dependent variable is influenced individually by the predictors, while controlling for other variables in the model. For each outcome *i.e.* knowledge, attitude and fertilizer management. The corrected model was statistically significant, with R-squared values indicating that 64.30% in fertilizer management was explained by the predictors. Among the predictors, education showed a highly significant positive effect on fertilizer management (F = 20.659, p = 0.000) with moderate effect size (partial eta squared 0.057).

Similarly, experience in selected crop cultivation (F = 20.051, p = 0.000), farming system (F = 20.117, p = 0.000), manures and fertilizers availability (F = 11.070, p = 0.001), social participation (F = 8.935, p = 0.003), extension contact (F = 6.104, p = 0.014), scientific orientation (F = 6.425, p = 0.012), economic motivation (F = 5.274, p = 0.022) and sustainability orientation (F = 5.135, p = 0.024) were significantly associated with improvements in fertilizer management. Among categorical predictors, farmer groups demonstrated a strong and significant effect on fertilizer management (F = 31.899, p = 0.000, partial eta squared = .318), indicating substantial variability in fertilizer management among different crop-based farmer categories. Overall, the GLM results underscore the multidimensional influence of educational, social, psychological, and institutional factors on fertilizer management of farmers.

DISCUSSION

The overall planning level varied across crops. Soybean and Bengal gram farmers showed poor planning, mainly due to using manure for other crop simultaneously grown by them and avoiding potassic fertilizers. Unavailability of cattle, insufficient finance, and lack of local manure markets constrained their preparedness. In contrast, red gram, paddy, maize, and cotton farmers planned better owing to advance budgeting, labour planning, and experience-based decisions on fertilizer types and quantities. Group purchasing, early scheduling, and consideration of previous results contributed to their efficiency. However, planning for managing nutrient deficiencies, fertilizer storage, transport, and adverse conditions remained minimal, leading to low index values in these indicators. These results are supported by Li & Shang (2021).

Paddy, maize, and red gram farmers performed better in purchasing practices due to timely procurement of manures and NPK fertilizers at lower costs, often through group purchases (Dwivedi et al., 2021). Cotton farmers ranked lower as many ignored potassic fertilizer purchases. Bengal gram and soybean farmers also scored poorly, reflecting neglect in manure and potassic fertilizer procurement (Dwivedi et al., 2020). Farmers with self-sourced manures incurred lower costs and displayed better planning. Paddy farmers excelled in nitrogenous fertilizer purchasing, while maize and red gram farmers performed better in phosphatic and potassic fertilizers. In contrast, soybean and Bengal gram farmers almost completely avoided potassic fertilizers, resulting in the lowest scores (Akomdo et al., 2023).

Practicing of fertilizer management showed wide variation among crops. Soybean and Bengal gram farmers recorded low index values due to limited manure use (Dessie et al., 2023; Tovihoudji et al., 2023), while maize and cotton farmers applied manure in small but timely quantities. Maize, Bengal gram, and red gram farmers followed the recommended rates and methods for nitrogenous fertilizer (Dwivedi et al., 2020; Akomdo et al., 2023), whereas paddy farmers applied excess quantities at improper times, reflecting gaps in knowledge and fear of crop failure with recommended doses (Dwivedi et al., 2021). For phosphatic fertilizers, red gram and soybean farmers achieved higher scores by adhering to recommended quantities, timing, and methods. Paddy farmers ranked lower due to excessive application and improper timing (Patil, 2013). In potassic fertilizer use, red gram, maize, and paddy farmers performed better by applying optimal amounts, while soybean, Bengal gram, and cotton farmers avoided potassic fertilizers altogether (Patil, 2013; Dwivedi et al., 2020). Nutrient deficiency and adverse condition management were poorly practiced, as most farmers could not identify deficiencies or adopt mitigation measures (Kumaresh & Praveena, 2012; Sarada & Suneel Kumar, 2013). Only a few paddy, maize, and cotton farmers managed deficiencies effectively. In transport and storage, paddy farmers who purchased fertilizers through cooperatives maintained safer practices, including covered transport and proper storage (Ngoya et al., 2023). However, most farmers neglected FIFO (First Expiry, First Out) and record-keeping systems (Ranabhat et al., 2021). In handling, some farmers partially followed safety measures such as using protective clothing, avoiding eating during application, and cleaning equipment afterward, but overall compliance was low. Disposal practices were also weak as most farmers discarded leftovers and containers carelessly, contributing to lower scores (Sai et al., 2019). These findings align with earlier studies emphasizing inadequate post-purchase fertilizer management among smallholders.

Cotton, maize, and red gram farmers ranked first, second, and third, respectively in performance due to their comparatively balanced fertilizer practices. Cotton farmers' use of manures and adherence to recommended NPK applications contributed to better crop performance. Maize and red gram farmers followed proper nitrogenous and phosphatic fertilizer use but occasionally deviated in potassic fertilizer management. Soybean and Bengal gram farmers, who reused residual nutrients from previous crops and avoided potassic fertilizers, ranked lower. The mismatch between actual practice and perceived performance suggests that farmers judged crop health visually rather than based on scientific nutrient assessment, leading to overestimated performance ratings. These results are in accordance with the findings of the Kumaresh and Praveena (2012) and Dwivedi et al. (2020).

CONCLUSION

Education, farming system, experience in crop cultivation, availability of manures and fertilizers, social participation, extension contact, scientific and sustainability orientation, and economic motivation consistently influence efficient fertilizer management. The Composite Fertilizer Management Index developed in this research serves as a reliable tool for assessing and comparing fertilizer management among crops. The findings confirm that enhancing farmers' knowledge and attitude toward best fertilizer management practices, improving awareness of health and environmental impacts, and strengthening input availability and institutional linkages can improve fertilizer planning, purchasing, and application efficiency. These results underscore the importance of promoting balanced and sustainable nutrient management practices to enhance soil health, crop productivity, and resource use efficiency in the region.

DECLARATIONS

Ethics approval and informed consent: The study adhered to established ethical principles of social science research. Informed consent was sought from the respondents for the study.

Competing Interest: The Authors have no competing interests.

Conflict of interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The authors declare that during the preparation of this work, they thoroughly reviewed, revised, and edited the content as needed. The authors take full responsibility for the final content of this publication.

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