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Balancing Technology and Sustainability: Patterns, Drivers, and Innovations in Fertilizer Use for Paddy Cultivation in Kerala's Kole Lands

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ABSTRACT

One of the key issues that leads to the decline in soil health is unscientific chemical nutrient management. This micro-level study explores the patterns of chemical fertiliser use, expenditure levels, and the factors influencing farmers' decisions on soil nutrient management in paddy cultivation in the Kole lands of Kerala. Farmers frequently deviate from recommended nutrient application practices, often exceeding the suggested levels for major nutrients while neglecting secondary nutrients and micronutrients. The timing of nutrient application also significantly diverges from scientific recommendations. Socioeconomic factors such as farmers' age and education level lead to higher chances of increasing expenditures, while household income and the maximum education level within the family members tend to reduce the chances of higher expenditure. The study highlights the crucial role of socio-economic variables in shaping expenditure decisions related to chemical fertiliser use. It also underscores the influence of educated family members on scientific decision-making, suggesting a need to redesign extension policies to incorporate them as agents of change. As a forward-looking recommendation, the study proposes the integration of modern technologies to address the challenge of poor soil nutrient management. Sensors capable of measuring soil pH, moisture, temperature, and select nutrient parameters can provide site-specific real-time data, which can be transmitted via Internet of Things (IoT) platforms to centralised databases. Coupled with remote sensing technologies such as satellites and drones, it becomes possible to generate high-resolution imagery that captures spatiotemporal variations in soil and crop conditions. Artificial intelligence (AI) and machine learning (ML) algorithms can analyse this multilayered data to detect patterns, assess nutrient deficiencies, and predict soil health trends. AI-driven decision support systems can then generate personalised recommendations for farmers. These insights can be disseminated via region-specific SMS alerts to farmers, their families, extension personnel, and input service providers. To enable effective adoption of these digital innovations, the study emphasises the need for targeted training programs that include not only farmers but also their educated family members, thereby fostering a holistic approach to sustainable soil health management in the Kole ecosystem.

Keywords: Decision making, factors influencing, logit regression, fertiliser use

JEL codes: C25, Q12, Q15, Q16, Q18

I

INTRODUCTION

The Green Revolution in India marked a significant turning point in the nation's agricultural landscape, characterised by the widespread adoption of high-yielding dwarf varieties of wheat and rice (Evenson and Gollin, 2003). This transformation, facilitated by the adoption of modern technologies such as chemical fertilisers and innovative irrigation methods, played a pivotal role in enhancing crop yields, alleviating food scarcity, and driving economic growth (Pingali, 2012). However, the rapid increase in fertiliser use during this period, as evidenced by the substantial rise in India's fertiliser consumption over the decades, has raised concerns regarding its environmental and economic implications (FAI, 2022). These issues,

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commonly referred to as ‘second-generation problems’, include soil degradation, depletion of natural resources, and declining soil fertility (DFI, 2018). There are reports of high acidity, low soil carbon, major, minor and micronutrient imbalances and low microbial activity in soils of India (Lenka et al., 2016), which is largely attributed to unscientific management practices (Karunakaran, 2013; Bora, 2022). Moreover, heavy dependence on fertiliser subsidies has placed considerable strain on the country's resources, highlighting the urgent need to adopt scientifically sound fertiliser management practices to ensure agricultural sustainability (Gulati and Banerjee, 2015).

In the context of Kerala's agricultural landscape, concerns regarding soil quality, nutrient imbalances, and declining crop productivity have been well-documented (GOK, 2013; Bora, 2022). At the same time, studies underline the prospects of maintaining soil fertility by following site-specific scientific management protocols (Sahrawat and Wani, 2013). Despite heavy investments in public extension systems for creating farmer education and testing soil health, crop management practices are generally reported to be far from scientific prescriptions, even in states like Kerala, where literacy levels are very high. The unscientific nutrient management practices, apart from causing fertility impacts and sustainability issues, lead to serious environmental issues. Kole lands, which are a sensitive wetland agroecosystem situated below MSL and that substantially contribute to the food security of the state (Safnathmol, 2020; Anusree et al., 2023), play a major role in the flood control, groundwater recharge and biodiversity conservation. It is part of the Vembanad-Kole wetlands, one of the Ramsar Sites in the state of Kerala,India. This study tries to understand the nutrient use behaviour and the factors that lead to decision-making on expenditure on chemical fertiliser management in this highly fertile rice production system in Kerala.

II

MATERIALS AND METHODS

2.1 Study Area and Sampling Design

The study was conducted in the Kole lands of Thrissur district, Kerala State, India. Kole lands are agroecosystems that are located below MSL and hence remain waterlogged for nearly six months a year. The ecosystem is categorised as Agro-Ecological Unit (AEU) - 6, classified based on climate, geography, land use pattern and soil properties (KAU, 2018). Water management is the most important aspect of Kole rice farming, and the cultivation is initiated by the draining of water. The ecosystem is characterised by a criss-cross of major canals and inner channels which function as the drainage system, water storage system and later on, as an irrigation source. While water that is pumped out is stored in the major canals, the same water is the irrigation source at later stages of crop growth.

The main rice crop in the region is the summer crop (Puncha in local parlance). The paddy fields are divided into blocks of continuous area demarcated by bunds known as “Padashekaram or Padavu”, with an area ranging from 10 to 300 ha. There are 202 Padashekarams comprising an area of 12,638 ha in the Kole ecosystem in Thrissur district and 51 Padashekarams in Malappuram district (1921 ha), totalling 14559 ha (Devi, 2023). Kole paddy farming is a collective activity with a democratically elected body called Padashekara Samiti, which oversees the collective operations.

The list of farmers who have done soil test were gathered from the Soil Test Laboratory, Thrissur, under the Department of Agriculture Development and Farmer`s Welfare, Government of Kerala as well as Department of Soil Conservation and Soil Survey, Government of Kerala, and from Radio Tracer Laboratory, Kerala Agricultural University. The list was then arranged Block Panchayat /Grama Panchayat wise. From among this list spread across five Block Panchayats (BPs), two BPs were randomly selected. For the sample selection of respondent farmers, two Grama Panchayats (GPs) were selected randomly from each selected BPs. From each of the selected GPs, five Padashekaram were randomly chosen. Thus, from the selected 20 Padashekarams, five farmers each were randomly identified as the sample respondents, i.e., the total number of respondent farmers was 100, following the multistage random sampling technique. The selected BP were Puzhakkal and Cherpuand the GPs were Tholur and Adatt of the Puzhakkal BP and Paralam and Cherpu GPs of Cherpu BP. The primary data was collected by personal interview method using a structured and pretested interview schedule. The sample respondents were post-stratified into three groups based on the operational area as Marginal farmers (MF: 0-1 ha), Small farmers (SF: 1- 2 ha), and Large farmers (LF: more than 2 ha).

2.2 Analytical Tools

Apart from the standard tools like averages and percentages, econometric tools were employed. The binomial logistic regression method is the common method to quantify the role of personal, social, and economic factors that lead to behavioural aspects of management decision-making (Noorhosseini-Niyaki and Allahyari, 2012;Gregory and Sewando, 2013; Sperandei, 2014). The method helps to forecast the probability of an observation falling into any of two categories (1 and 0) of a dichotomous dependent variable. This prediction is based on independent variables, which can be either continuous or categorical. Logistic regression is categorised as a generalised linear model due to its dependency on the sum of inputs and parameters to determine outcomes. Due to its applicability in various fields of research, the method is widely applied in the agricultural sector also (Zhu et al., 2022; Agarwal, 2022).

The model is explained as follows:

$$P_i = \text{E(Y=l/X}_\text{i}\text{)} = \frac{1}{1+e^{-(\alpha+\beta_i X_i)}}$$

Where,

Pi is the probability

Xi is the vector of independent variables.

βi are the coefficients to be estimated

$$P_i = \frac{1}{1+e^{-Z_i}} = \frac{e^Z}{1+e^Z}$$

Where, $Z_i = \alpha + \beta_i X_i$

$1 - P_i = \frac{1}{1+e^{Z_i}}$ is the probability of the respondent to be grouped above or below arithmetic mean with respect to the expenditure in chemical fertilizer of the sample.

$$\frac{P_i}{1-P_i} = e^{Z_i}$$

Taking logarithm on both sides, the model is

$$L_i = \ln\left(\frac{P_i}{1-P_i}\right) = Z_i = \alpha + \beta_i X_i$$

Where {P/(l-P)} is called as the odds ratio and the quantity log [P/(1-P)]is known as the log odds or the logit of P. The dependent variable considered for this logistic regression analysis is described in Table 1.

III

RESULTS AND DISCUSSION

The Kole lands receive a deposition of fertile forest soil high in organic content, as the rivers originating from the Western Ghats drain during the rainy season. There has been a widespread practice of application of organic matter, green manures and green leaf manures, and earlier reports highlight the rich organic carbon content in the Kole ecosystem (Hameed, 1975). The adoption of modern technologies, like improved and High-Yielding Varieties (HYV), led to the application of chemical fertilisers. Studies by Muraleedharan (1987) and Mohandas (1994) estimated the proportion of chemical fertiliser cost at 17 to 19 per cent of the total cost and identified it as a significant determinant of income and production. Later on, the extensive unscientific application of chemical fertilisers coupled with limited supplements of organic manure has resulted in production and cost inefficiencies.

TABLE 1. DETAILS OF THE VARIABLES

Y= The expenditure in chemical fertilizer -1, for those farmers, whose expenditure on chemical fertilizer is more than the arithmetic mean of the sample.
0, for those farmers, whose expenditure on chemical fertilizer is less than the arithmetic mean of the sample.

Sl. No	Particulars	Unit	Expected sign	Rationale
1	Age	Years	–	Age is expected to give insights to follow recommended fertilizer dose
2	Education of respondent	Years of schooling	–	Educated farmers are expected to follow scientific prescription
3	Education of family members	Years of schooling	–	Education of family members tend to influence the scientific decision making
4	Main occupation	Self employed Agriculture alone	+	If the main occupation is agriculture alone, there is the chance of expectation of higher yield through higher fertilizer application
5	Experience	Years	–	Experience gives insights to follow scientific prescription
6	Operational area	Area (ha)	–	Resource use reduces with an increase in the landholding
7	Income	Below ₹ 2 lakhs Above ₹2 lakhs	+	At higher levels of income, the tendency to spend more on chemical fertilizers increases
8	Credit	Own Money Credit	+	As credit is supposed to create more income, farmer would prefer for higher yield using more fertilizers
9	Family size	Number	-	As household consumption increases, the expenditure on chemical fertilizer would decrease
10	Knowledge level	Score based on responses to statements that tested the farmer knowledge 1, for correct answer and 0 otherwise. (score: summation of correct answers) (Appendix 1).	–	Knowledge on the scientific farming practices abstains farmer from unscientific fertilizer use

There are reports that the application levels of chemical fertilisers are more than double the state average, and organic manure use is depleting (Srinivasan, 2012). The State Planning Board in 2010, while assessing the soil fertility status, indicated depleting organic carbon, elevated acidity, and deficiency and imbalance of nutrients in the Kole region. Recent studies based on soil analysis also highlight the problems in soil fertility in the region. The 2018 floods have affected the physical, chemical, and biological properties of the ecosystem. Despite increased organic matter and phosphorus levels, micronutrients like Boron (B) were found deficient (Safnathmol, 2020). The unscientific use of fertilisers is reported to cause an imbalance in primary and secondary nutrients, surplus nitrogen, and deficiency of potassium (K) and boron (B) (Anusree et al., 2023). This impacts the sustainability, ecology, agriculture, and social life in the region and demands more in-depth studies on farmer practices, behaviour and economic aspects of soil nutrient management practices. The paper analyses the major aspects of chemical properties of soil, viz. soil acidity, organic content and nutrient status and related expenditure behaviour.

3.1 Soil Fertility Management- Soil Amelioration

The soil acidity is a crucial parameter that reflects the soil health, and pH below the value of 5.5 needs to be ameliorated to ensure conducive crop growth. The recent studies based on soil analysis by Safnathmol, 2020 and Anusree et al., 2023, reports a low pH of the soils in Kole ecosystem. According to soil test data gathered from soil test laboratories in this study, the soil pH in the farms of the respondent farmer`sranged from 3.4 to 5.9, with an average pH of 4.6 (Table 2). This pH level indicated the need for soil amelioration to create conditions suitable for crop growth. KAU, 2016 (Package of Practice Recommendations of Kerala Agricultural University) provides a general recommendation of applying 600 kg/ha of lime in two split doses. The first dose, comprising 350 kg/ha, is recommended as basal dressing during the initial ploughing, while the second dose of 250 kg/ha is advised as top dressing approximately one month after sowing or transplanting. The scientific recommendation, as per soil test data, is higher at 625 kg/ha with a variation from 597 kg/ha to 640 kg/ha in three size groups of farmers. However, the farmers were applying less than the general recommendation and that based on the soil test data. On average, farmers applied 391 kg/ha of lime as a single dose immediately after land preparation, which was less than 37 per cent of the recommended level based on the soil test data.

3.2 Soil Organic Manure

A high level of OM content is considered the major reason for the very high fertility of the Kole agroecosystem (Hameed, 1975). This high OM status was due to the deposits of the drainage of the rivers, as well as organic matter supplements. Subsequently, the application levels of OM were reduced. However, in the post-flood of 2018 and 2019, during which the Kole ecosystems experienced topsoil deposits and high waterlogging, the soil organic matter content improved (Safnathmol, 2020; Anusree et al., 2023).

Based on the soil test reports in our study, the organic carbon content ranged from 0.18% (low) to 3.96% (high), with an average of 1.56% (medium). According to KAU (2016), the recommended application rate of organic manure is 5 tons per hectare. However, actual application rates were significantly lower, averaging 517 kg/ha, which is roughly 10 per cent of the recommendation. Significant variations in application rates were observed across different farmer categories-MF applied 903 kg/ha, SF at 320 kg/ha, and LF applied only 84 kg/ha.

TABLE 2. SOIL FERTILITY MANAGEMENT IN KOLE RICE FARMING: ORGANIC MANURES AND SOIL AMELIORANTS (KG/HA)

Farmer class	Average organic matter content (per cent)		Observed pH (average)		Soil ameliorants (Lime/Dolomite)	
MF	1.44	903	4.60	640	410	36
SF	1.60	320	4.64	625	373	40
LF	1.74	84	4.73	597	377	37
Average	1.56	517	4.65	625	391	37

3.3 Application of Plant Nutrients

The High-Yielding Varieties (HYV) are known for the higher nutrient demand for optimal growth and yield. The widely adopted rice variety in Kole lands is 'Uma and Jyothi', which are medium-duration, high-yielding rice varieties released by KAU. KAU (2016) recommends nutrient management at a rate of 110:45:45 kg/ha of NPK for these varieties. According to guidelines for direct-seeded rice in wetlands, nitrogen (N) is to be applied in three equal doses: as a basal application, during tillering, and at the panicle initiation stage. Phosphorus (P) is to be applied solely as a basal dose to support effective root development, and Potassium (K) in two equal split doses - basal application and at panicle initiation stage. Additionally, borax at 25 kg/ha to address boron (B) deficiency, $MgSO_4$ at 100 kg/ha for magnesium (Mg) deficiency, and CuSO4 at 1 kg/ha for copper (Cu) deficiency is also prescribed (KAU, 2016).

Table 3 provides data on the application levels of major nutrients across different farmer classes. Nitrogen application averaged at 110.73 kg/ha, closely aligning with the recommended 110 kg/ha. However, the average phosphorus application was 63.44 kg/ha, exceeding the recommended 45 kg/ha, indicating an over-application. Notably, there was a significant variation in potassium usage, with farmers applying an average of 98.36 kg/ha, more than double the recommended 45 kg/ha. Further, the data shows variation in potassium application among farmer classes, with marginal (MF) and large farmers (LF) using more potassium than small farmers (SF). Mohandas (1994) also noted deviations between the general recommendation (70:35:35 kg/ha) and actual farmer practices in Kole lands, where farmers, despite generally adhering to the recommended nitrogen dosage, tended to apply more phosphorus and potassium.

TABLE 3. SOIL FERTILITY MANAGEMENT IN KOLE RICE FARMING NUTRIENTS (KG/HA)

Farmer class	N	P_2O_5	K_2O	S
MF	111.97	61.24	99.16	27.59
SF	109.49	64.98	92.70	26.46
LF	110.13	65.41	103.96	19.05
Average	110.73	63.44	98.36	25.10

The soil test data indicate that the soil nitrogen (N) status across all farmer classes is medium, ranging from 40.5 kg/ha to 891 kg/ha. The soil test-based recommended average application level for N was approximately 73.38 kg/ha across all farmer size groups, which are 33%, lower than the general recommendation. In contrast, farmers' actual average application was 110.73 kg/ha, exceeding the recommended level by 50.9%. Specifically, marginal farmers (MF) applied 51% more than recommended, while small farmers (SF) and large farmers (LF) applied 49% and 53% more, respectively, showing no significant difference among the size classes (Table 4). This finding corroborates earlier reports of high soil N content (Anusree et al., 2023). Among the sample respondents, 75% applied N in excess of the soil test-based recommendations, 14% applied below the recommended dose, and only 11% adhered to the recommendations. Deviations within 10% of the recommended levels were considered as compliance with the scientific prescription based on soil test data.

TABLE 4. COMPARISON OF NUTRIENT APPLICATION WITH SCIENTIFIC RECOMMENDATION: NITROGEN (N) IN KG/HA

Farmer class	Soil N status as per Soil test data	Recommended level as per soil test	Application level	Excess from recommended level (Per cent)
MF	324.15	74.12	111.97	51
SF	342.72	73.45	109.49	49
LF	391.50	71.96	110.13	53
Average	346.75	73.38	110.73	51

In the case of P_2O_5, the recommended level based on soil testing was mostly in tune with the general recommendation level. The soil test data signals a medium status (range: 2-26 kg/ha) (Table 5), and the average recommendation amounts to an application of 42.30 kg/ha. Generally, the farmers apply 50 per cent higher than the recommendation where the MF applying 39 per cent and SF and LF with 61.2 and 56 per cent higher levels respectively i.e. higher farm size group (SF and LF) tended to apply higher levels. In the surveyed population, 69 per cent of participants were found to exceed the prescribed levels based on testing, while 18 per cent applied lesser quantity. Only 13 per cent of respondents adhered to the recommendations.

TABLE 5. COMPARISON OF NUTRIENT APPLICATION BY FARMERS WITH SCIENTIFIC RECOMMENDATION: PHOSPHORUS (P2O5) IN KG/HA

Farmer class	Soil P status as per soil test data	Recommended level as per soil test data	Average application level	Excess from recommended level (Per cent)
MF	10.98	43.99	61.24	39
SF	14.49	40.20	64.98	61
LF	12.50	41.94	65.41	56
Average	12.45	42.30	63.44	50

The disparity becomes more visible in the case of K (Table 6), where the application level of 98.36 kg/ha is more than 164 per cent of the soil test-based recommended dosage of 37.22 kg/ha. The general recommendation is 45 kg/ha. Remarkably, LF applied 206 per cent more K, whereas SF and MF applied 150 and 153 per cent higher than the soil test-based recommended levels. 89 per cent of respondents surpassed the recommended levels determined through soil testing. In contrast, 8 per cent fell below the suggested recommendation, and a mere 3 per cent adhered to the recommendations.

TABLE 6. COMPARISON OF NUTRIENT APPLICATION WITH SCIENTIFIC RECOMMENDATION: POTASSIUM (K2O) IN KG/HA

Farmer class	Soil K status as per soil test data	Recommended level as per soil test	Application level	Excess from recommended level (Per cent)
MF	161.05	39.10	99.16	153
SF	174.40	37.20	92.70	150
LF	221.94	33.93	103.96	206
Average	180.41	37.22	98.36	164

3.4 Schedule of Application of Plant Nutrients

The nutrient supply should be strategically scheduled to complement specific critical stages of crop growth, ensuring optimal and healthy crop development. Furthermore, adopting a split application approach, particularly for nutrients like N, proves beneficial in minimising leaching losses, contributing to more efficient utilisation and minimal ecological damage. The KAU (2016) prescription suggests three equal split applications of N, one basal dressing of P2O5 and two equal split doses of K2O at specific crop growth stages. Contrary to this, farmers opt for three split doses of all three nutrients. The stages of application were basal dressing (within

18 days after sowing/transplanting), top dressing-1 (within 37 days of sowing/transplanting) and top dressing-2 (Within 55 days of sowing/transplanting).

Although nitrogen (N) is applied in three split doses by all farmer groups (Table 7), there were notable differences in the ratios between these doses. On average, 79% of farmers apply N primarily in the first two doses: the basal application and the first top dressing. MF follow a ratio of 3.3:5.4:2.0, SF follow 4.5:3.7:1.8, and LF apply 3.7:4.0:2.4, respectively, across basal, first top dressing, and second top dressing. These ratios show that both the basal dressing and first top dressing are more N-intensive compared to the second top dressing. In essence, on average, 38% of N is applied during the basal application, 42% during the first top dressing, and 20% during the second top dressing. The basal application typically occurs between 8-25 days after sowing (DAS), followed by the second dose between 30-45 DAS during the tillering stage, and the third dose from 45-80 DAS during the panicle initiation stage. Although the application ratios deviate from the recommended pattern, the timing aligns with the scientific suggestion of three split N dosages across farmer groups (Fig. 1).

TABLE 7. SOIL FERTILITY MANAGEMENT IN KOLE RICE FARMING: SCHEDULE OF NUTRIENT APPLICATION BY FARMERS (KG/HA)

Chemical Nutrients	Schedule of application	MF	SF	LF	Average
N	Basal Dose	37.16 (33)	49.28 (45)	40.19 (37)	41.65 (38)
N	TD-1	52.92 (54)	40.13 (37)	43.77 (40)	46.65 (42)
N	TD-2	21.88 (20)	20.06 (18)	26.46 (24)	22.44 (20)
N	Total	111.97 (100)	109.49(100)	110.13(100)	110.73(100)
P_2O_5	Basal Dose	30.47 (50)	38.4 (59)	25.29 (39)	31.52 (50)
P_2O_5	TD-1	27.57 (45)	21.44 (33)	35.28 (54)	27.93 (44)
P_2O_5	TD-2	3.2(5)	5.14 (8)	4.84 (7)	3.99 (6)
P_2O_5	Total	61.24 (100)	64.98 (100)	65.41 (100)	63.45 (100)
K_2O	Basal Dose	23.09 (23)	21.63 (23)	24.42 (24)	22.93 (23)
K_2O	TD-1	46.59 (47)	41.50 (45)	48.56 (47)	45.46 (46)
K_2O	TD-2	29.48 (30)	29.57 (32)	30.98 (30)	29.98 (31)
K_2O	Total	99.16 (100)	92.70 (100)	103.96(100)	98.37 (100)

**Values in parenthesis represent the percentage of the total*

Phosphorus (P), to be ideally applied as a single basal dose due to its role in root development, is instead applied in three split doses (Figure 2). MF follow a ratio of 5.0:4.5:0.5, SF uses 5.9:3.3:0.8, and LF apply 3.9:5.4:0.7. Applying P in later stages is ineffective for crop utilisation and can contribute to soil health issues and increased cultivation costs without any additional yield gains.

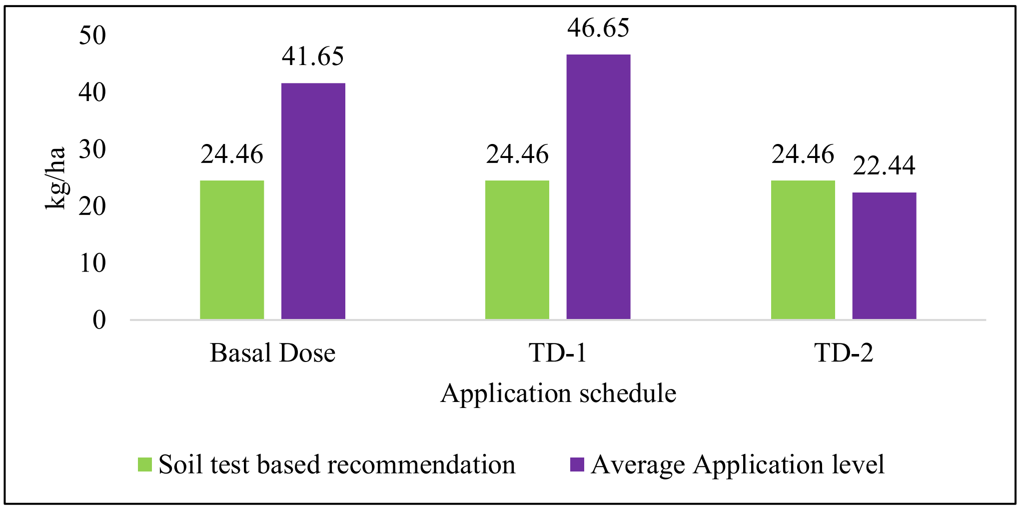

FIGURE 1. COMPARISON OF THE APPLICATION SCHEDULE OF NUTRIENTS: N

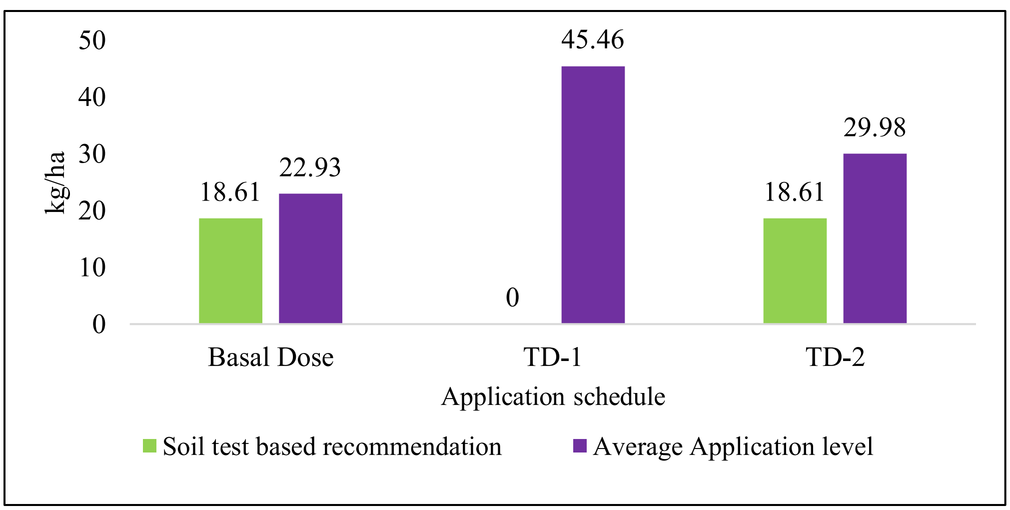

FIGURE 2. COMPARISON OF THE APPLICATION SCHEDULE OF NUTRIENTS: P_2O_5

For potassium (K), which is essential for mitigating abiotic and biotic stress, the recommended practice is to apply it in two equal splits: as a basal dressing and as a second top dressing during the panicle initiation stage. However, all farmers apply

K in three splits (Figure 3), at ratios of 2.3:4.6:3.1 overall, with MF at 2.3:4.7:3.0, SF at 2.3:4.5:3.2, and LF at 2.4:4.7:3.0. Notably, nearly 50% of the K_2O is applied as a second dose when it should not be applied at all.

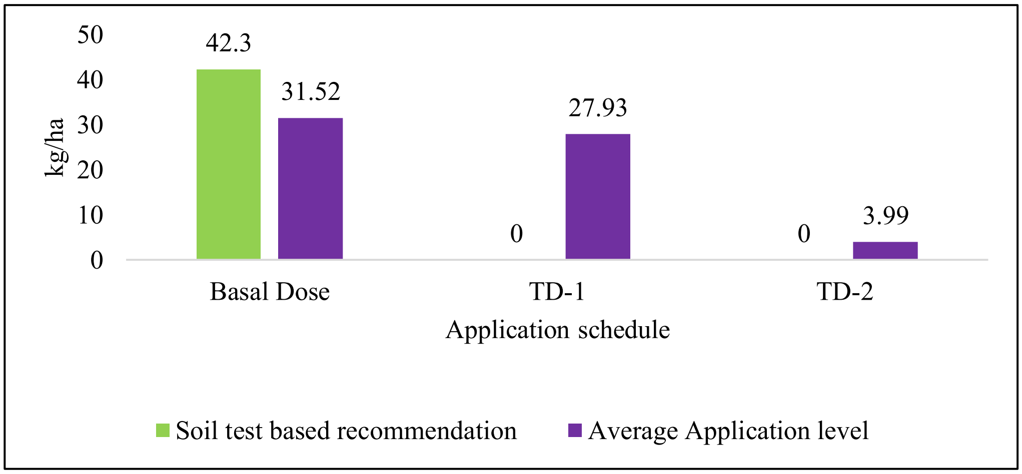

FIGURE 3. COMPARISON OF THE APPLICATION SCHEDULE OF NUTRIENTS: K_2O

These findings underscore a widespread divergence from recommended nutrient application practices and the suggested schedule of application. While the timing of nitrogen application aligns with scientific guidelines, the ratios deviate significantly from recommendations, leading to potential inefficiencies. The deviations are more pronounced for phosphorus and potassium, with P being applied unnecessarily in later stages and K being applied in an additional split dose. Such practices not only contribute to higher cultivation costs but may also pose risks to soil and ecosystem health. On average, the input-wise cost of chemical fertilizers was calculated as ₹12,906/ha, which is around 14 per cent of the total cost A1. Meanwhile, the cost of chemical fertilizers and their application amounted to ₹18110/ha (20 per cent of total cost A1). While we generally hypothesise rational expenditure behaviour among the farmers, our field-level results present a different picture.

3.5 Factors Influencing Decision-Making on the Cost of Fertilizer Application

The expenditure decision on soil nutrient supplements is influenced by various social, economic, and historical behavioural factors (Adesina, 1996; Nkamleu and Adesina 2000). This section analyses the major factors that lead to the decision-making in this aspect. We analysed this aspect by employing the Logit Regression and the parameters and estimators are furnished in Table 8. The model was observed to be a good fit with Nagelkerke's R^2 of 0.22 and McFadden's R^2 of 0.13. The signs of some of the independent variables were in conformity with the hypothesis except the age and education of the respondents, credit, family size and knowledge level. Four out of ten variables viz. age and education of the respondent, maximum education of the household members and household annual income is proved to be of significant influence on the probability of higher expenditures in chemical fertilizer application. As inferred from the Odds ratio, the education of the respondent, was 1.19. This indicates that, as one unit increase in the education of the respondent, the odds in favour of investing in fertilizer application increases by 1.19 or about 19 per cent. Also, with one unit increase in the age of the respondent, the odds in favour of investing in fertilizer applications increase by 1.06 or 6 per cent. The Odd ratios of maximum education of family members and household income was 0.67 and 0.25, which showed that, one unit increase in the corresponding variables, the odds of increase in expenditure in fertilizer applications decreases by 33 per cent and 75 per cent respectively.

TABLE 8. LOGIT ESTIMATES OF FACTORS INFLUENCING DECISION-MAKING ON THE EXPENDITURE IN FERTILISER APPLICATION

Variables	Coefficients	Standard Error	Odd's Ratio	Wald Statistic	p value	VIF
Age	0.06*	0.03	1.06	2.80	0.09	1.91
Education of respondent	0.17**	0.08	1.19	4.31	0.03	1.48
Maximum Education of family members	-0.39**	0.17	0.67	4.90	0.02	1.42
Main occupation	0.27	0.48	1.31	0.31	0.57	1.20
Years of experience	-1.48	1.84	0.22	0.65	0.42	1.66
Land	-0.18	0.13	0.83	1.77	0.18	1.13
Income	-1.37*	0.70	0.25	3.83	0.05	1.42
Credit	-0.072	0.46	0.93	0.02	0.87	1.11
Family size	0.40	0.25	1.50	2.48	0.11	1.35
Knowledge level	0.05	0.03	1.05	2.10	0.14	1.14
Constant	1.87	3.54	6.54	0.28	0.59	-
Nagelkerke's R^2	0.22	0.22	0.22	0.22	0.22	
McFadden R^2	0.13	0.13	0.13	0.13	0.13	

*** Significant at 5 per cent level * Significant at 10 per cent level*

While the farmer characteristics like age and education level exert a positive influence on decision making, the household level attributes favour a lower level of expenditure. Aged farmers and educated ones generally tend to spend more on chemical fertilisers, probably due to their expectations of higher yield. The training and policy support, especially during the initial years of the introduction of HYVs, might have influenced their decision-making behaviour in favour of higher levels of expenditures in chemical sources. The average age of the farmer respondents was 61 years, and they mainly depend on the farm income as a major source of household income. They must have resorted to higher levels of fertiliser application in the expectation of higher returns, facilitated by the subsidised price of fertilisers. Most of these farmers were also members of the Primary Agricultural Credit Societies of the locality, and these agencies also run the fertiliser depots. So, there is an operational facility to avail credit and purchase chemical fertilisers. It is quite interesting to note that a higher level of education among family members increases the odds of reducing the application expenses. The educated children in many households have secured better jobs, and that might have improved the household income. In such cases, the dependence on farming as a major source of income has come down. Moreover, the earning siblings might also be influencing the farming decisions. That explains the significance of family income and the education of family members as a strong determinant in decision-making. Currently, the target group for training and extension support on soil health management is confined to the farmers. The results of our study highlight a shift in this policy, and the target group may be widened to include the farm family members who influence the farm management decision-making as well.

IV

CONCLUSIONS

Our study reconfirms the earlier reports on the unscientific nature of chemical fertiliser use in agriculture and quantifies the extent of deviation in nutrient application in one of the very fragile agroecosystems of Kerala. The study underscores the pivotal role of socio-economic factors in shaping expenditure decisions in chemical fertiliser application. The role of educated members of the farm households in scientific decision-making is proven, which raises the need for redesigning our extension policy to accommodate the farm family members as agents of change.

Further to it, implementing modern technologies like sensors, remote sensing, and AI can revolutionise real-time soil quality monitoring and communication with farmers. Soil sensors installed in fields can measure pH, moisture, nutrient levels, and temperature, transmitting data via IoT to central databases. Remote sensing using satellites and drones can monitor large areas and provide high-resolution images for detailed analysis. AI and machine learning can process this data, identifying patterns and predicting soil health trends, while AI-powered decision support systems offer actionable recommendations. Real-time advisories can be communicated to farmers / family members/extension officers as well as the fertiliser retailers via SMS, ensuring delivery of timely, region-specific information. Transitioning to this system involves developing robust network infrastructure, utilising cloud platforms for data storage and processing, and establishing regional hubs to disseminate tailored advisories efficiently, replacing the existing laborious processes. Extensive targeted training programs for farmers and educated family members are proposed for informed decision-making in soil health management, by which we can ensure sustainable expenditure decisions, ultimately facilitating sustainable agricultural production.

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APPENDICES

TABLE 1A. FARMERS' KNOWLEDGE LEVEL ON CONTENT OF FERTILIZERS

Sl. No	Question	Farmers who furnished correct answer (in per cent)
A	State the major nutrients in the following fertilizers	
1	Urea	73
2	Factomphos	70
3	Muriate of Potash	70
4	Di Ammonium Phosphate	52
5	MgSO4	44
6	Rajphos	46
7	Sulphate of potash	44
8	Borax	43
9	Lime	55
10	Green leaf manure	57
B	State the major fertilizer that can supply the following Nutrients	
1	Nitrogen	76
2	Phosphorous	75
3	Potassium	76
4	Calcium	59
5	Magnesium	44
6	Sulphur	28
7	Iron	5
8	Manganese	21
9	Zinc	24
10	Copper	15
11	Boron	45

TABLE 2. FARMERS' KNOWLEDGE LEVEL OF SOIL FERTILITY MANAGEMENT PRACTICES AND FIELD OBSERVATIONS

Sr No.	Statements	True	DK*	False
1	Phosphatic fertilisers are to be applied only as basal dose	92	2	6
2	The soil should be moist at the time of fertiliser application	12	0	87
3	Chemical fertilizers and lime can be applied together	12	0	87
4	FYM and chemical fertilizers can be applied together.	29	3	67
5	K and Mg fertilizers can be applied together	11	52	37
6	Excess Chemical fertilisers can harm the soil microorganisms	95	4	1
7	Soil microbes are essential for plant growth	97	3	0
8	The thin, reddish film in the field indicates Iron (Fe) toxicity.	91	4	5
9	The application of lime can correct iron toxicity	100	0	0
10	Excess fertilizer application leads to aquatic weed growth	85	12	3
11	The application level of chemical fertilisers in *Kole* lands is in excess	86	11	3

**DK-Don't Know*

TABLE 3A. STATEMENT OF THE FARMERS REGARDING SOIL TEST PARAMETERS

Sl. No	Statements	True	DK*	False
1	Organic matter content in soil is understood by Organic carbon value in soil test data	5	92	1
2	EC reflects the salinity level of the soil	7	89	2
3	We can get the same yield if fertiliser is applied as per the soil test results	67	27	6

**DK-Don't Know*

TABLE 4A. FARMERS' KNOWLEDGE LEVEL OF SOIL FERTILITY MANAGEMENT PRACTICES AND FIELD OBSERVATIONS

Sl. No.	Statement of the farmer on the ideal range of the following parameters in the soil test data	Correct response (in per cent)
1	pH	4
2	Electronic Conductivity (EC)	0
3	Organic Carbon (OC)	0
4	Nitrogen	0
5	Phosphorous	0
6	Potassium	0
7	Calcium	0
8	Magnesium	0
9	Sulphur	0
10	Iron	0
11	Manganese	0
12	Zinc	0
13	Copper	0
14	Boron	0

TABLE 5A. COST OF CULTIVATION (INPUT WISE)- ₹/HA

Particulars	MF	SF	LF	Average
Hired Human Labour	27108 (28.8)*	26290 (29.6)	22895 (27.6)	25801 (28.8)
Machine labour	20798 (22.1)	18978 (21.4)	18624 (22.5)	19690 (22.0)
Seed/Seedling	4580 (4.9)	4587 (5.2)	4470 (5.4)	4554 (5.1)
Soil Ameliorants	5609 (6.0)	4865 (5.5)	4966 (6.0)	5217 (5.8)
Organic manure	3682 (3.9)	2070 (2.3)	1291 (1.6)	2584 (2.9)
Chemical fertilizer	13204 (14.0)	12821 (14.5)	12485 (15.1)	12906 (14.4)
Pesticides	3041 (3.2)	3844 (4.3)	4554 (5.5)	3669 (4.1)
Weedicide	4044 (4.3)	4071 (4.6)	3793 (4.6)	3990 (4.5)
Miscellaneous	2228 (2.4)	1773 (2.0)	1760 (2.1)	1970 (2.2)
Marketing charges	4257 (4.5)	4221 (4.8)	3061 (3.7)	3947 (4.4)
Land tax and irrigation cess	1450 (1.5)	1450 (1.6)	1450 (1.8)	1450 (1.6)
Interest on working capital	3985 (4.2)	3758 (4.2)	3506 (4.2)	3795 (4.2)
Total cost A1	93985 (100)	88729 (100)	82856 (100)	89574 (100)
Yield	6713	6593	6647	6659
Returns from the sale of grain	189308	185909	187440	187787
Returns from the sale of straw	7280	8689	8344	7983
Gross Return	196588	194598	195783	195770
Net returns	102603	105869	112927	106196
B: C ratio	2.09	2.19	2.36	2.18

**Values in parenthesis represent the proportion to cost A1*