Promoting 4R Nutrient Stewardship through Behavior Change: A Case Study of Smallholder Farmers in Telangana, India

ABSTRACT

Background: Smallholder farmers play a vital role in global food security and soil degradation is one of the most significant challenges, leading to the loss of livelihoods and substantial economic losses among smallholder farmers. The efficient use of nitrogen (N), phosphorus (P) and potassium (K) fertilizers for food security while preserving the environment is highly essential. The dissemination of the 4R principles (right nutrient source at the right rate, right time, and right place) among the farmers would promote the judicious use of nutrient resources and optimize productivity. The Behavior Change Wheel (BCW) provides a framework for intervention development. This article describes the development of interventions, which aims to educate the farmers about the 4R Nutrient Stewardship principles.

Methods: We followed the Behavior Change Wheel guide and used the Capability, Opportunity and Motivation Behaviour (COM-B) model to educate the farmers about the 4R nutrient management. The COM-B interventions were used to educate the farmers (120) about the components of the 4R Nutrient Stewardship. Whereas, to demonstrate the first R (right source) of nutrients we undertook interventions on fields of 30 farmers by suggesting soil test based nutrient application and compared the yield with control plots.

Results: Using the COM-B model we used the behavior change interventions to educate, persuade, incentivize and enable the farmers for adopting the principles of 4R nutrient stewardship. The demonstrations on soil test based use of right source of nutrients showed an average yield advantage of 30.6 5% which was statistically significant in comparison to control plots.

Conclusion: The COM B model can be successfully used to disseminate information on optimum use of nutrients based on the nutrient stewardship principles. Interventions based on Behavior Change Wheel were undertaken on farmers' fields and the yield advantage of using principles of 4R nutrient management practices were successfully demonstrated on farmers' fields.

Key Words: smallholder farmers, INM interventions, rapid soil analysis, 4R nutrient interventions, behavior change model

INTRODUCTION

Smallholder farmers play a vital role in global food security, Smallholder farmers are essential to ensuring global food security and the health of their crops heavily relies on the condition of the soil they cultivate. However, soil degradation has been a significant challenge, leading to the loss of livelihoods and substantial economic losses among smallholder farmers. In this study the Behavior Change Wheel guide and the Capability, Opportunity and Motivation Behaviour (COM-B) model was employed to educate the farmers about the 4R nutrient management. The COM-B interventions were used to educate the farmers (120) about the four components of the 4R Nutrient Stewardship in Manchal village of the Rangareddy District of Telangana, India. Whereas, to demonstrate the first R (right source) of nutrients interventions were taken up on fields of 30 farmers by suggesting soil test based nutrient applications. The gain in yields (30.6%) after using right source of nutrients on intervention plots were found to be statistically significant when compared with control plots. Building the knowledge capital of farmers for nutrient management based on 4R practices serves manifold purposes of monetary savings on costly fertilizers, sustainable crop production and environmental protection.

Our food supply depends on the world's smallholder producers and the soils on which they farm. But soil degradation, which affects one-third of the earth's land area, threatens farmers' livelihoods and results in $40 billion per year in economic losses. The linkage between soil quality and food production is evident and the implementation of integrated nutrient management practices plays a significant role. Moreover, the present and future food security increasingly relies on the adequacy of the supply and effective utilization of nutrient resources (Johnston and Bruulsema 2014). Chemical fertilizers are integral to agricultural production, significantly boosting crop yields, ensuring food security, while also enhancing farmers' incomes (Erisman et al., 2008; Pan and Zhang, 2018). Nevertheless, their overuse can lead to adverse environmental impacts such as soil and water pollution, as well as greenhouse gas emissions (Abler, 2015; Trimpler et al., 2016; Wang et al., 2018; Yuan et al., 2021).

The efficient management of fertilizers lies at the heart of the primary conflict between food security and environmental challenges like climate change (Penuelas et al.2023). This key role necessitates the dissemination of the 4R principles (right nutrient source at the right rate, right time, and right place) among the farmers. Implementing this principle would promote the judicious use of nutrient resources and optimize productivity (Stewart and Roberts 2012).According to Dan and Ning (2018) agricultural training is essential for effective fertilizer management and the enhancement of farmers' understanding of agricultural input use. Technical assistance for efficient use of fertilizer by smallholder farmers is essential (Pan and Zhang 2018).

The probable reason for fertilizer overuse by farmers may be due to lack of adequate knowledge of fertilizer management (Guo et al., 2015; Huang et al., 2015).Moreover, farmers are lacking in three different domains of knowledge (Kaiser and Fuhrer 2003, and Redman and Redman 2014). The first is the effectiveness knowledge which implies the awareness associated with adverse effects of fertilizer overuse. Procedural knowledge, entailing the effective utilization of fertilizers, underscores farmers' belief that increased fertilizer application invariably leads to higher crop yields((Xiulu Sun et al. 2022), while reducing overall usage results in yield losses (Jia et al., 2015; Huang et al., 2015). Declarative knowledge, on the other hand, encompasses the foundational understanding of fertilizer application and its function within agricultural systems. Knowledge acquisition serves as a foundational step towards adopting eco-friendly technologies like fertilizer management systems. Understanding the effectiveness of fertilizer use can reshape farmers' perceptions regarding its environmental impact, thus influencing behavioural change. Procedural knowledge closely aligns with identifying potential barriers crucial for fostering behavioral changes in fertilizer use. Declarative knowledge mitigates farmers' uncertainty about reducing fertilizer application, thereby enabling them to curtail overuse (Ajzen et al., 2011; Kaiser and Fuhrer, 2003).

Roughly 85 percent of the farm households in India are small or marginal farmers (<2 hectares of land, with 70 percent having < 1 hectare of land). The average landholding is only 0.5 hectares per household (NSO, 2021).Small farmers contribute 51 per cent of agricultural output with 46 per cent of operated land, and a much higher share (70 per cent) in high-value crops. However, small farmers are less literate and from marginalised communities. However, small farmers often come from marginalized communities and tend to have lower literacy levels. They are generally excluded kept out from modern market arrangements such as contract farming or direct purchase. Moreover, they encounter several challenges at different stages of the value chain ranging from lack of access to quality seeds and reasonable price; dependent on local stores for seed quality, the high price of fertilizer; non-availability of fertilizers, lack of credit; limited access to credit from the formal sources; often dependent on input suppliers or intermediaries for credit, traditional, high energy consuming and inefficient equipment used for farm operations and high dependence on input dealers for choice of pesticides or insecticides.

Cost component on fertilizers for rice crop in India

Studies have shown that for the rice crop in India the cost incurred by farmers on fertilizer is substantial. It was reported that the expenditure towards fertilizers accounted for 7.84 % to 18.84 % for both small and marginal farms respectively in Nalgonda District of Telangana, India (Ramya Sai et al. 2022). The cost of fertilizers ranged from 9.6%, 9.3% and 9.4% for marginal, small and medium farmers respectively in the study areas of the state of Andhra Pradesh, India (Chaitanya and Maurya 2020).Cost of fertilizers used was 16.2% in paddy cultivation in Raichur district of Karnataka(Kumar and Patil 2019).Similarly in the study area of Uttar Pradesh the cost of fertilizer formed 13.4% of the overall cost of rice production(Mishra et al. 2020) and it was 11.19 % in Erode district of Tamilnadu (Manikandan et al 2018).The cost of fertilizer formed 9.46% in Bihar and 11.98% in Punjab(Kumar A et.al). In Nalgonda district of Telangana fertilizer cost amounted to 12.1% of the total cost of rice cultivation(Amtul et al 2020).High fertilizer prices contribute to rising global food security concerns (Hebebrand and Laborde 2022). Farmers considered fertilization to be essential to ensure good yields and were unwilling to reduce the fertilizer use (Xiulu Sun et al. 2022)

Judicious use of Fertilizers

Widespread nitrogen fertilizer overuse results in major losses, creating environmental stress and placing an economic burden on farmers and the nation's financial capital. Despite the necessary benefits, losses associated with nitrogen-based fertilizers constitute half of agriculture's contribution to global greenhouse gas emissions. In addition, the effects of nitrogen and phosphorus fertilizer overuse can be seen in the pollution of water bodies. Improved fertilizer development and dissemination will be the catalyzing factor in achieving a 60% increase in global food production by 2050, when the world's population could exceed 10 billion. Employing 4R nutrient stewardship practices will enable farmers to accrue higher yield, enhance nutrient uptake and nutrient use efficiency and thereby increase the farm income (Surekha et al 2023).

METHODOLOGY

This study attempted to test the COM-B model for behavior change of farmers to promote the 4R principles for nutrient management. The COM-B Model was developed by Michie, et. al (2011).

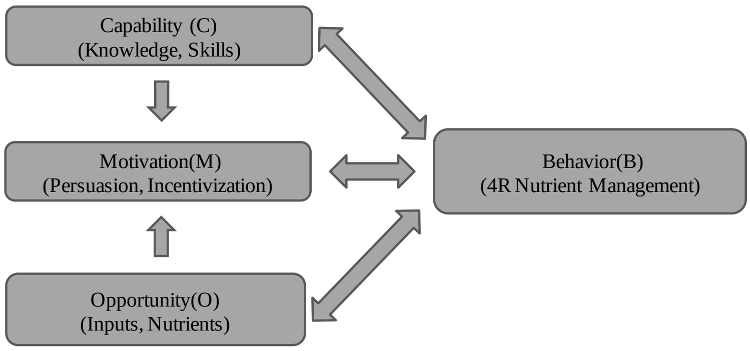
COM-B Framework for Behavior Change

The COM-B framework developed by Michie, et. al (2011 is a behavioral model comprising three core elements: the Capability (C), Opportunity (O), and Motivation (M) are defined as three key factors capable of changing behavior (B). This system serves as the central component of the Behavior Change Wheel (BCW). Surrounding the COM-B system are nine intervention functions designed to target deficiencies in any of these conditions. Additionally, seven policy categories are positioned around the wheel to facilitate the implementation of these interventions.

In this behavioral system, capability, opportunity, and motivation interact dynamically to shape behavior, as depicted in Figure 1 (the 'COM-B' system). Capability refers to an individual's psychological and physical capacity to engage in a particular activity, encompassing the requisite knowledge and skills. Motivation comprises all cognitive processes that drive and guide behavior, including habitual patterns, emotional responses, and conscious decision-making, extending beyond mere goal-setting. Opportunity encompasses external factors that enable or prompt behavior. The single-headed and double-headed arrows in Figure 1 illustrate potential influences among these components. For instance, opportunity may impact motivation, just as capability can influence it; engaging in a behavior can modify capability, motivation, and opportunity.

An intervention can impact one or multiple components within the behavior system. The interconnected causal relationships within the system can either diminish or amplify the effects of specific interventions by instigating changes elsewhere. While this model elucidates behavior, it also furnishes a foundation for crafting interventions geared towards behavior modification. When applying this framework to intervention design, the focus shifts to identifying the behavioral objective and determining which components of the behavior system require modification to attain that objective.

Figure 1. The 'COM-B' system



COM-B framework for behaviour change adapted from Michie, et. al (2011)

4R nutrient stewardship approach

Maximizing the efficiency of nutrient management is crucial for fostering environmental, economic, and social sustainability. Behaviour change interventions were designed and implemented for building knowledge capital of farmers to adhere to the principles of the 4R nutrient stewardship (IPNI 2012) selecting the appropriate source, applying the correct rate, distributing nutrients in the proper place, and timing applications appropriately.

The objective of this study is to apply the behaviour change framework and interventions to disseminate the 4R nutrient stewardship practices to smallholder farmers for rice cultivation in Rangareddy district of Telangana, State, India. The findings of this study will help in educating and demonstrating the fertilizer best management practices (BMP) among the farmers to increase productivity and profitability, while ensuring improved environmental protection.

Study Area

The study was conducted in Manchal Village of Rangareddy district of Telangana with 120 smallholder farmers during 2022.Telangana State is the 11th largest State of India, with a geographical area of over 11.2 M ha and is one of the major rice producing states with a productivity of 3327 kg/ha (SES Outlook 2022). Marginal and Small farmers in the state hold about 88.3% of the landholdings (less than 4.94 acres) accounting for 61.7% (36.83 lakh hectares) of the area operated. Three major crops grown in the state namely Paddy, Cotton and Maize constitute nearly 80% of the total produce (SES Outlook 2021). Telangana produces around 8% of the total rice produced in India. The percentage sowed area for the paddy-increased from 43.42% in 2014-15 to 63.46% in 2021-22. The total production of rice in Telangana was 134.79 lakh tonnes in 2021-22(DES 2023). The state has also recorded an increase in the consumption of major fertilisers from 28 lakh MT in 2018-19 to 37 lakh MT in 2021-22. (SES outlook 2023).The principal crops of Rangareddy district are Paddy, Jowar, Maize, Cotton, Castor, Pulses and Vegetables. Rangareddy District lies between 16° 19' and 18° 20' North latitude and 77° 30' East longitude bounded on the North by Medak on the East by

Nalgonda , on the South by Mahabubnagar and on the West by Gulbarga District of Karnataka State. Area of paddy in Rangareddy is1,46,674 acres with a yield of 2,044 kg/acres.

The farmers were selected randomly from Manchal village of Rangareddy district, Telangana State to undertake behaviour change interventions to promote the principles of the 4R nutrient stewardship. The categories of behaviour change interventions adapted from Michie et al. 2011 for transforming the fertilizer use practices as implemented by the ICAR-Indian Institute of Rice Research, Hyderabad, India have been described in Table 1.

Table 1. Categories of behaviour change interventions for dissemination of 4R Nutrient Management practices

Interventions	**Definition**	**Examples**	**Implementing agency/organization**
Education	Increasing knowledge or understanding	Providing information to promote balanced use of fertilizers	Training programs organized for using the 4R nutrient use framework and use of slow release urea formulated by ICAR-IIRR
Persuasion	Using communication to induce positive feelings or stimulate action	Using imagery to motivate increase in yields/income even with optimal use of fertilizers	Pictures of research farm, farmers fields showcasing judicious use of fertilizers
Incentivization	Creating expectation of reward	Best Farmer award, Master trainer to promote judicious use of fertilizers	Awards to practicing farmers during Farmers' Fair /Exhibitions
Coercion	Creating expectation of punishment or cost	Raising the financial cost to reduce excessive fertilizer use	Government policy, awareness programs on optimum use of fertilizers
Training	Imparting skills	Soil test based fertilizer use	Hands-on to use Rapid Soil Testing Kit developed by ICAR-IIRR and implementation of the 4R nutrient use framework
Restriction	Using rules to reduce the opportunity to engage in the target behaviour	Prohibiting sale of spurious seeds/pesticides/fertilizers	Government control on sale and availability of quality fertilizers
Environmental restructuring	Changing the physical or social context	No freebies of subsidized fertilizers	Policy suggestion to authorities for a rethink on fertilizer subsidies
Modelling	Providing an example for people to aspire to or imitate	Case studies/success stories /visit to low fertilizer use farms	Farmers' exposure visit to demonstrations on low fertilizer use farms and research fields of ICAR-

			IIRR
Enablement	Increasing means /reducing barriers to increase capability or opportunity	Behavioural support for soil test based application of nutrients/fertilizers	On-field, portable accurate, timely and cost effective soil analysis facilities /solutions for farmers. ICAR-IIRR, designed rapid soil and agronomic advice kit

Adapted from Michie et al. 2011

Dissemination of 4R nutrient management practices

In this study the dissemination of 4R nutrient management practices was undertaken to build the knowledge capital of farmers through training programs, exposure visits to demonstration farm of the ICAR-Indian Institute of Rice Research, (ICAR-IIRR) and interventions on farmers' fields for demonstrating the first R, the use of right source for problem soil management. The farmers were provided a hands-on skill building training program for the use of rapid soil testing kit developed by ICAR-IIRR, Hyderabad, India. The training on use of rapid soil testing kit was organized for all the sample farmers (120) similarly the exposure visit to the research farm of ICAR-IIRR was undertaken during the annual Farmers Fair organized at the institute. Moreover, the integrated nutrient management (INM) interventions on the use of right source of nutrients were undertaken only on the fields of 30 farmers due to financial compulsions.

ICAR-IIRR has designed a convenient and cost-effective on-site soil testing kit, designed to simplify the process of soil analysis (Brajendra and Babu 2017). This innovative kit eliminates the need for farmers to send samples to distant laboratories, saving them valuable time and effort. With its user-friendly interface and precise results, the kit offers a practical solution for farmers, enabling them to receive instant feedback on their soil's condition at a fraction of the usual cost. This initiative not only streamlines the testing process but also presents a promising entrepreneurial opportunity for young individuals. They can capitalize on this technology by offering on-field soil analysis services to farmers, providing them with immediate insights into their soil health. Additionally, the kit can be complemented with agronomy advisory services, empowering farmers to make informed decisions for effective soil management practices. Exposure visit of the farmers to the research farm of ICAR-IIRR was organized to showcase the use of controlled, slow-release nitrogen blends. ICAR-IIRR has formulated silica based slow releasing urea products containing, 38.23 to 41.03% N and these products performed better than other sources in terms of grain yield (t/ha) in three different rice varieties (unpublished data).

In order to educate and demonstrate to the farmers the importance of the first R (right source) of nutrient stewardship interventions were undertaken on use of right source of nutrients based on the soil characteristics. Therefore soil samples were collected for initial analysis from around 30 farm sites and soil analysis was done for important soil properties. Based on the severity of soil problems (high sodicity and low fertility status) these farm sites were selected and critical inputs for problem soil management were distributed to the farmers. Multi variety green manure seeds (cereals, pulses, oil seeds, spices and green manures) were procured and distributed to the selected 30 farmers. The benefits of using multi variety green manure crops were explained to the farmers. Other critical inputs like vermicompost, urea, zinc sulphate and zinc chelate were also distributed to the farmers. The green manure crop was grown for 45-60 days and was incorporated into the soil before puddling. Vermi compost was applied to the soil in the last puddle along with urea and zinc sulphate. Zinc chelate was sprayed on the crop at about one month after transplanting.

RESULTS AND DISCUSSION

The COM-B framework components and interventions employed in educating farmers about the 4Rs of nutrient management practices have been presented in table1 . The capability component (C) of the framework was implemented through physical skill development through training programs in the use of rapid soil testing kit developed by ICAR-IIRR. The psychological capability was achieved through imparting knowledge about the 4R of nutrient management practices. The physical opportunity (O) was created as enablement as listed in table 1 and also through the provision of critical inputs to the farmers to demonstrate the use of right source of nutrients (green manure, vermicompost, chelated zinc).The social opportunity was created by interventions such as Incentivization, Modeling and Environmental Restructuring as depicted in table 1. With regard to the motivation (M) component the Reflective motivation was achieved through increasing knowledge and understanding and eliciting positive feelings about behavioral target i.e., the use of right source of nutrients. Whereas, the Automatic Motivation was made possible through persuasion, Incentivization, coercion, modeling and enablement

Right Source of nutrients

The demonstrations on fields of 30 farmers to disseminate the importance of using the right source of nutrients indicated yield improvement ranging from18.3 to 43.3% and the average yield advantage recorded was 30.6% as presented in table 2. Moreover, the difference in yields of intervention and control plots was found to be statistically significant at 5% level of significance (Table 3).

Table 2 Average yield advantage of 4R nutrient interventions over farmer's practice in fertilizer use

Practice	Average yield(kg/ha)	Average Yield advantage (%)
Intervention(right source)	4555.67	30.36
Farmer's practice	3494.63	

Table 3 t statistic

Groups	M	SD	t	df	P
Intervention	4555.67	1035.55	18.1130	29	0.0001*
Farmer's practice	3494.63	811.83			

The developers of the COM-B model and BCW offer a systematic approach for transitioning from behavioral analysis to identifying potential intervention functions and policy categories capable of inducing change. This step-by-step process, from defining the problem to developing and evaluating interventions, can be applied universally across various behaviors and contexts. Table 4 displays a grid designed to aid in identifying intervention functions. Shaded squares indicate where evidence or consensus suggests a function might effectively address a specific behavioral determinant. This grid reveals that one intervention function can impact multiple determinants; for example, training can address physical capability, psychological capability, physical opportunity, and automatic motivation. However, the next step involves selecting which intervention functions are most suitable or have the greatest potential for success in fostering change within a specific context

Table 4 Links between the components of the 'COM-B' model of behaviour and the intervention functions

	Education	Persuasion	Incentivization	Coercion	Training	Restriction	Environmental restructuring	Modelling	Enablement
C-Ph									
C-Ps									
M-Re									
M-Au									
O-Ph									
O-Soc									

C-Ph*-physical capability, C-Ps-psychological capability, M-Re-Reflective motivation, M-Au-Automatic Motivation, O-Ph-Physical Opportunity, O-Soc-Social Opportunity

CONCLUSIONS

Achieving global food security requires dramatic change in current food production systems. From better technologies to improved farming practices to, inclusive markets, there is much to be done to sustainably increase food production while minimizing environmental impact. Behaviour change interventions for the dissemination of 4R nutrient management practices to smallholder farmers for judicious and balanced use of fertilizers and sustainable soil management is important. The COM-B model and its interventions can be applied successfully to educate the farmers about the 4Rs of nutrient management practices for sustainable rice production as indicated by the results in the present study on increase in yields due to adoption of right source of nutrients.

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