

Sustainable intensification and diversification options for enhancing productivity and input use efficiency in eastern IGP of India

Evaluating diversified cropping
patterns in Nalanda, Bihar, India

Research Note 49

September 2024

ABOUT THIS BRIEF

In the eastern Indo-Gangetic Plains (EIGP), agriculture faces significant challenges that directly impact farmers' productivity, profitability, and input use efficiency. The region is heavily dependent on rice and wheat cultivation, but issues such as over-reliance on traditional farming practices, inefficient use of water and fertilizers, and limited adoption of modern technologies hinder farm productivity and profit. Moreover, inconsistent irrigation systems, combined with the growing threat of water scarcity, further reduce the efficiency of input use. Climate change has also intensified the vulnerability of crops to floods, droughts, and erratic weather patterns, leading to crop failure or reduced yields. To address these complex changes, the on-farm research was set up by the Transforming Agrifood Systems in South Asia (TAFSSA) Initiative under CIMMYT with the partnership of CGIAR Institutes, JEEVIKA, and the Department of Agriculture in Nalanda district of Bihar, India.

KEY FINDINGS

1. The results of one cropping cycle, with three crops grown annually, showed that alternative diversified cropping systems produced system rice equivalent yields (REY) sometimes up to 138% higher than the most common farming practices.
2. The irrigation water productivity can be increased by 324% by diversifying the rice-wheat-fallow cropping system with the maize-mustard-mung bean.
3. Partial factor productivity of N increased by almost 263% under diversified cropping systems (maize -mustard -mung bean) compared to business as usual (farmer practice) crop rotation (rice-wheat-fallow)
4. The system equivalent rice yield was mainly harvested from diversified winter crops (potato) with intensification achieved by the inclusion of short-duration spring crops (March-June) through the diversification of monsoon rice, which also benefited water productivity and nutrient partial factor productivity.

BACKGROUND

In the eastern Indo-Gangetic Plains (EIGP), agriculture faces significant challenges that directly impact farmers' productivity, profitability, and input use efficiency. The region, which includes parts of India, Bangladesh, and Nepal, is heavily dependent on rice and wheat cultivation, but issues such as over-reliance on traditional farming practices, inefficient use of water and fertilizers, and limited adoption of modern technologies hinder productivity (Bijarniya et al., 2024). Moreover, inconsistent irrigation systems, combined with the growing threat of water scarcity, further reduce the efficiency of input use. Climate change has also intensified the vulnerability of crops to floods, droughts, and erratic weather patterns, leading to crop failure or reduced yields. Additionally, the prevalence of small and fragmented landholdings poses a significant challenge, as it limits economies of scale and reduces the ability of farmers to invest in advanced technologies or efficient cropping systems (Gathala et al., 2022). Low investment capacity, widespread poverty, and limited access to essential agricultural inputs, such as high-quality seeds, fertilizers, and machinery, exacerbate these challenges, making it difficult for farmers to improve their productivity and profit. In addition, fluctuating market prices for agricultural commodities make it difficult for farmers to secure consistent profits. Limited access to credit, inadequate agricultural extension services, and poor infrastructure further compound these issues. To improve productivity and profitability, enhancing input use efficiency, promoting climate-resilient farming techniques, addressing

land fragmentation, improving market access, and increasing investment capacity are crucial for the region's agricultural sustainability. (Gathala et al., 2021). Alternative technologies such as no-till and crop residue recycling have shown potential advantages in terms of resource use efficiency and yield stability to climate change and variability in a wide range of agro-ecologies, which could support the adaptive and productive capacity of farming systems to future climates and resource scenarios (Jat et al., 2014). To tackle these complex challenges, the futuristic potential research was codesigned in consultation with the farm communities and all relevant agriculture actors of input and output, including the service and market sectors. To assess alternative diversified cropping patterns coupled with improved and sustainable agronomic interventions, focusing on their potential to enhance production, input use efficiency (N, P, and K), and environmental impact (water productivity).

OBJECTIVES

This research aims to identify strategies that can enhance farmers' productivity and resource use efficiency while also examining the adaptation behavior of different crops and cropping systems and their interactions with improved agronomic practices (conservation agriculture). Additionally, the study seeks to demonstrate alternative options to the farmers, which will be more resilient and productive. The findings from one year of crop rotations are presented in this research brief.

DATA AND METHODS

The On-farm participatory experiments were co-designed through multi-stakeholder consultation and validated by the community. The standard protocols were developed and published in 2022. The trial followed a randomized complete block design, with five scenarios, including crop rotations and regenerative agronomic management options (Table 1), and then replicated to the individual farmer. In collaboration with field technicians and farmers as per standard protocols, the agronomic data, all above-ground biomass crop production, and all inputs, including fertilizer, amount of irrigation water, agrochemicals, and labor associated with costs, are among the data collected according to standard data protocol and procedures.

To allow yield comparison between different crops, rice equivalent yield (REY) was used (Eq. 1). The System irrigation water productivity, is calculated as harvested REY by applied water (Eq.2). System nutrient use efficiency (NUE), expressed as partial factor productivity, a measure harvested REY by applied nutrients (N, P) (Eq.3). Data have been computed for each annual crop cycle of the three cropping seasons in India (*Kharif, Rabi Summer*) and combined to represent the entire cropping system.

All the data were tested for normal distribution using the JMP 18 (SAS software) and found satisfactorily in their homogeneity. This research was conducted in RCBD; the ANOVA was constructed as fixed effect scenarios while the replication was used as a random effect. The mean of scenarios' significance differences was separated using Tukey's Honestly Significance Difference (HSD).

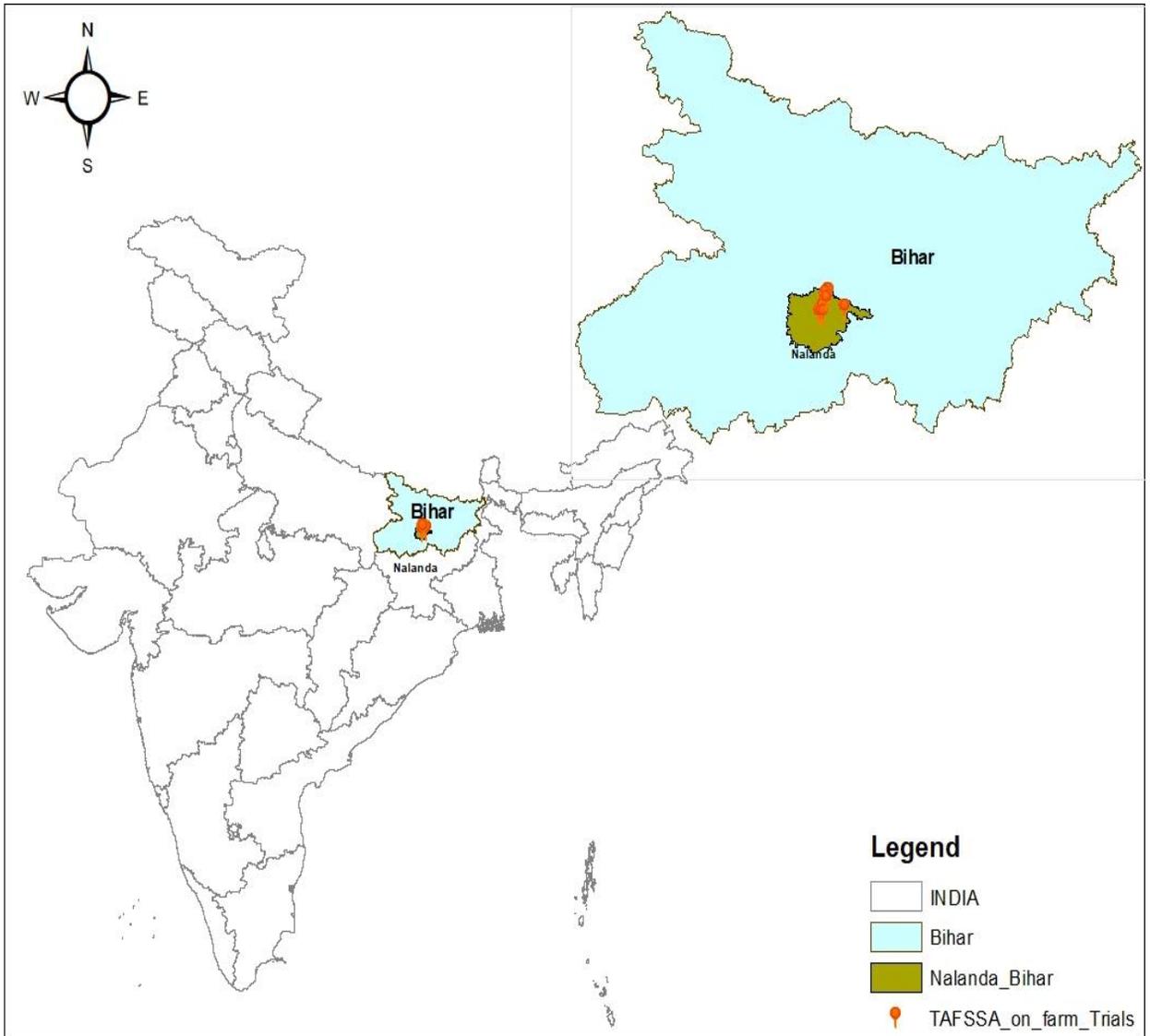
$$\text{Rice equivalent yield (t ha}^{-1}\text{)} = \frac{\text{Crop yield (t ha}^{-1}\text{)} \times \text{Market crop price (USD t}^{-1}\text{)}}{\text{Market rice price (USD t}^{-1}\text{)}} \quad (\text{Eq. 1})$$

$$\text{System irrigation water productivity (kg m}^{-3}\text{)} = \frac{\text{Crop yield (kg ha}^{-1}\text{)}}{\text{Irrigation water applied (m}^3\text{ ha}^{-1}\text{)}} \quad (\text{Eq. 2})$$

$$\text{System partial factor productivity of nutrients (kg ha}^{-1}\text{)} = \frac{\text{Crop yield (kg ha}^{-1}\text{)}}{\text{Nutrient applied (kg ha}^{-1}\text{)}} \quad (\text{Eq.3})$$



Above: Grains and pulses at a market in Nalanda, India.



Above: On-farm participatory trials located in Nalanda districts of Bihar.



Above: Crop rotation research trial at a farmer's field in Nalanda, India.; photo: KM Choudhary

Table 1: Description of the diversified cropping patterns compared

Treatments	Crop rotations	Tillage	Crop establishment method	Residue management
T1	Rice - wheat-fallow	PTR-CT	Rice: transplanting; Wheat: broadcast	All crop residue removal
T2	Rice-potato-maize	PTR-CT-CT	Rice: transplanting; Potato: drill seeding with bed planter; Maize: drill seeding -on flat beds	Incorporated rice (20-25%), maize (50%)
T3	Maize-mustard-mungbean	ZT-ZT-ZT	Maize: drill seeding; Mustard: drill seeding; Mung bean: drill seeding on flat beds	Anchored maize (50%) and mustard (50%) and mungbean (70%) residue retention
T4	Rice-chickpea-proso millet	CTDSR-ZT-ZT	Rice: drill seeding; Chickpea: drill seeding; Prosomillet: drill seeding on flat beds	Anchored rice (20-25%) chickpea (25-30%) and prosomillet (20-25%) residue retention
T5	Rice-wheat-mungbean	CTDSR-ZT-ZT	Rice: drill seeding; Wheat: drill seeding; Mungbean: drill seeding on flats	Anchored rice (20-25%) wheat (20-25%) and mungbean (70%) residue retention

Note: PTR= puddled transplanted rice, CT=conventional till, DSR=direct seeded rice, ZT=zero tillage, PR=partial residue

RESULTS

Crops and cropping systems significantly influenced seasonal crop yields and system rice equivalent yields (REY). In the monsoon season, maize's rice equivalent yield was significantly lower than rice grown under puddled wet transplanting or dry direct seeding, primarily due to maize's lower market price. Potato, however, showed high potential for producing tubers as starch, yielding 14.09 t ha⁻¹ in the winter season—2.5 times higher than other winter crops. The lowest REY was observed in farmers' traditional practice (Scenario 1). Maize following potato demonstrated higher spring yields than mung bean.

The highest system REY was achieved under the rice-potato-maize system (Scenario 2), outperforming all other cropping systems. This was attributed to the high winter yields of rabi potato, supplemented by additional summer maize yields. However, a major challenge for potato production is the lack of adequate cold storage facilities. Without proper storage, much of the potato crop is wasted due to spoilage, sprouting, or rotting. Farmers are forced to sell potatoes during peak harvest seasons when supply is high, leading to sharp price drops. Maize prices are also highly volatile, influenced by supply-demand imbalances, weather, and government policies, causing financial uncertainty for farmers.

There is limited scope to scale up the rice-potato-maize system across large areas, particularly for smallholder farmers. The second-highest system REY was achieved under the maize-mustard-mung bean system, which holds strong potential to replace the

rice-wheat system in the eastern Indo-Gangetic Plains. This diversified system, including legumes and oilseeds, helps restore soil health. The additional summer yields of mung bean further contributed to higher system productivity compared to the traditional rice-wheat cropping system.

The government of India's recent announcement of blending 20% ethanol with gasoline positions maize as a high-potential candidate, with incentives to establish ethanol factories in various states. This is expected to increase maize demand and stabilize prices, benefiting farmers adopting maize-based rotations.

Overall, the maize-mustard-mung bean system presents a sustainable alternative to the rice-wheat system, improving productivity while addressing soil health and water use concerns. In contrast, while the rice-potato-maize system offers the highest REY, challenges such as storage limitations and price volatility remain significant barriers to its broader adoption among smallholder farmers.

Although the rice-chickpea-prosomillet system offers crop diversification, farmers in the region face challenges in accessing stable markets for their produce, especially for chickpea and prosomillet. Prices for chickpea can fluctuate significantly, and prosomillet, although nutritious, often lacks market demand, poor germination crop establishment and suffers from lower price realization.

The mean data provided evidence that rice-potato-maize (scenario 2), resulted in a significant 138% increase in system yield pursued maize-mustard-mung

bean (T5) by 35%, and rice-chickpea-prosomallet (scenarios 4) by 6%, respectively), compared rice-wheat-fallow system (Table 2).

The nutrient use efficiency was expressed as partial factor productivity (PFP) of applied N and P, though varied statistically among different cropping systems. The system basis PFP of N was higher in scenario 3, followed by scenario 4, scenario 2 and scenario 5, respectively, compared to scenario 1. Under scenario 3 and scenario 4, the system PFP of N was four times greater than under scenario 1. The system PFP of P was recorded higher under scenario 2 followed by scenario 3 and scenario 5, respectively. Under scenario 2 the PFP of P was recorded 87% higher than scenario 1 (figure 1).

The irrigation water requirements of different crops vary based on their evapotranspiration demand and how

they are established. Irrigation water productivity (WPI) is influenced by irrigation water uses in different crops and crop establishment methods. During the study, the system water productivity recorded higher in scenario 3 (13.27 kg grain m⁻³) followed by scenario 4 (8.05 kg grain m⁻³), scenario 2 (7.96 kg grain m⁻³) and scenario 5 (5.37 kg grain m⁻³), respectively, compared to scenario 1 (3.13 kg grain m⁻³). The system irrigation water productivity under scenario 3 was recorded 324 % higher, followed by scenario 4 (157%), scenario 2 (154%) and scenario 5 (72%) compared to scenario 1, respectively. (figure 2). The highest irrigation water productivity in scenario 3 because of all three crops have low water requirements. The rice-wheat cropping system, which is primarily responsible for the groundwater table's decline, may be replaced by this cropping system.

Table 2: Grain yield of crops and cropping systems affected by different management practices during 2023–24.

Treatments	Rice/ maize	Wheat/potato/ mustard/ chickpea	Maize/ mungbean/ prosomallet	System** grain yield
t ha ⁻¹				
Rice-wheat-fallow (Sc1)	6.19AB	4.85C(4.66)		11.04C
Rice-potato-maize (Sc2)	6.46A	14.09A(38.40)	5.80A (6.06)	26.33A
Maize-mustard-mung bean (Sc3)	5.92B(6.19)	5.10BC(1.97)	3.88B(0.99)	14.90B
Rice-chickpea-prosomallet (Sc4)	6.33A	5.37B(2.15)		11.70C
Rice-wheat-mung bean (Sc5)	6.49A	6.03B(5.78)	2.36B(0.66)	14.88B

*Refer to Table 1 for a description of treatments. ** System grain yield was expressed as rice-equivalent yield (t ha⁻¹). Values in parenthesis represent the actual yield of respective crops. The within a column, the different uppercase letters are significantly different, at 0.05 probability based on Tukey's HSD means.

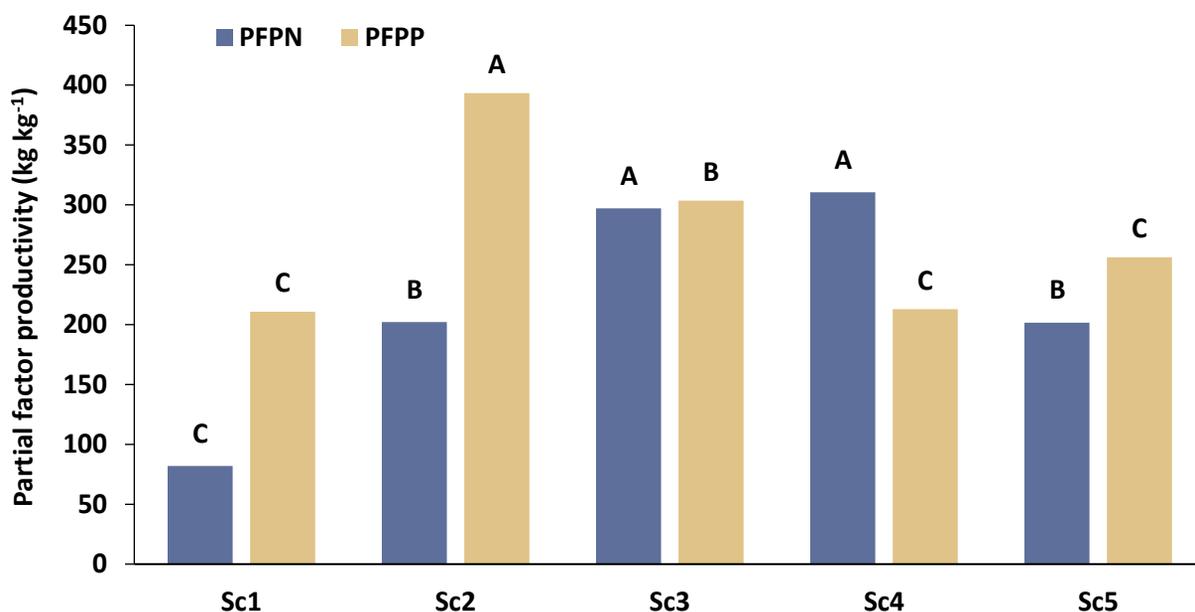


Figure 1: Nutrient use efficiency under different cropping systems presented as partial factor productivity. The bars are headed by different letters that are significantly different, based on Tukey's HSD means.

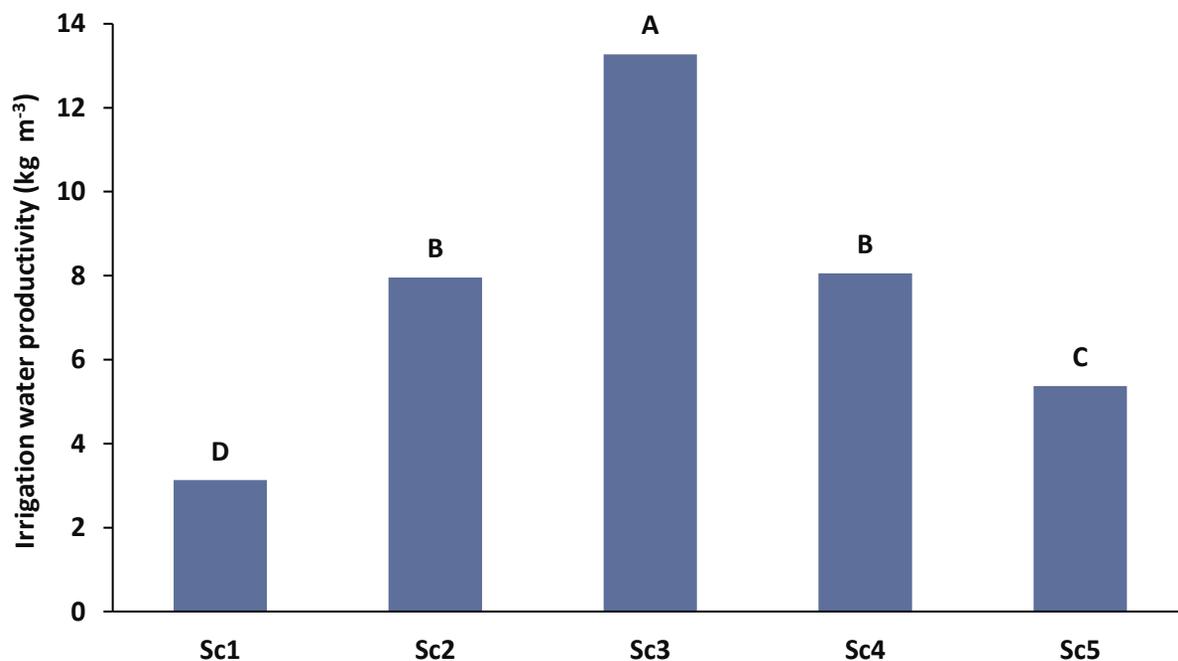


Figure 2: System irrigation water productivity by cropping pattern under various cropping systems. The bars are headed by different letters that are significantly different, based on Tukey's HSD means.

Figure notes: Yield of prosomillet not included as not able to harvest due to no germination. Sc 1=rice-wheat-fallow system + CT, Sc 2=rice-potato-maize system + CT, Sc 3=maize-mustard-mung bean system + CA, SC 4=rice-chickpea-prosomillet system +CA, Sc 5=rice-wheat-mung bean+ CA

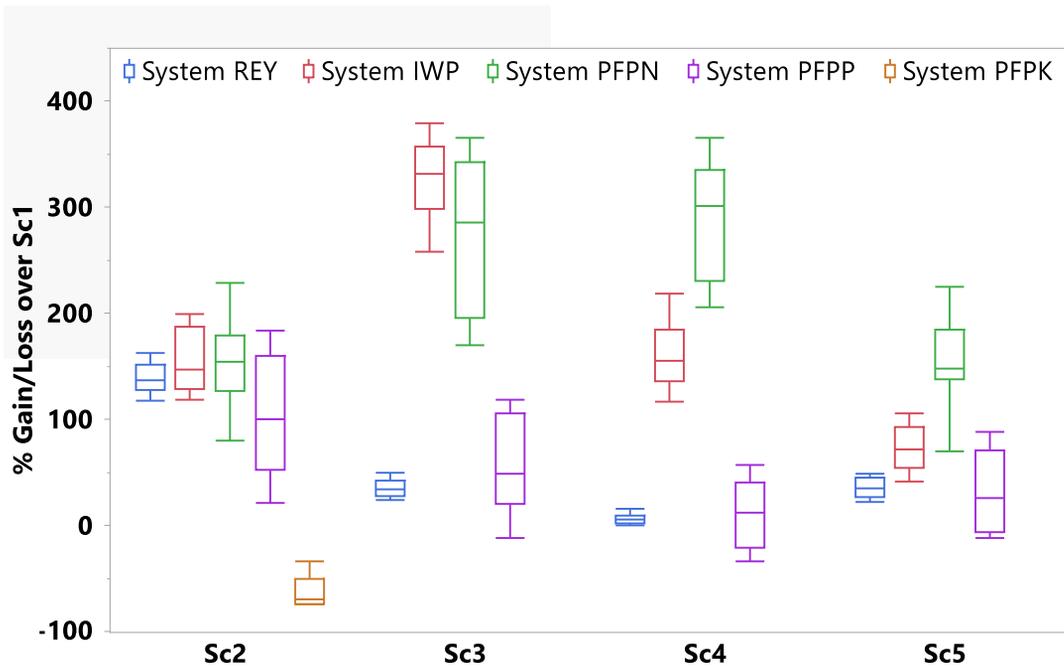


Figure 3: Effect size analysis of percent increase in grain yield of different cropping systems over T1) using dataset (2023-24)

Figure notes: Yield of prosomillet not included as not able to harvest due to no germination. Sc 1=rice-wheat-fallow system + CT, Sc 2=rice-potato-maize system + CT, Sc 3=maize-mustard-mung bean system + CA, Sc 4=rice-chickpea-prosomillet system +CA, Sc 5=rice-wheat-mungbean+ CA

CONCLUSIONS AND RECOMMENDATIONS

This study demonstrates that adopting diversified cropping systems, especially those based on maize rotations, leads to substantial improvements in both crop yields and input use efficiency when compared to the traditional rice-wheat (RW) systems. The findings emphasize that the conventional RW system in this region often results in negative environmental consequences, such as soil degradation and the decline in long-term crop productivity. These issues, which are interconnected and multifaceted, can be effectively mitigated through the adoption of diversified and intensive crop rotations, which offer better resource management and resilience against

environmental challenges. However, for farmers to make the shift to these more sustainable cropping systems, strong government policy support is essential. Policies could include financial incentives such as payments for carbon credits, which would reward farmers for adopting environmentally friendly practices, and other measures that recognize the broader societal benefits of sustainable farming. Additionally, to ensure economic viability and reduce financial risks for farmers, the government must provide guaranteed markets with minimum support prices (MSP) for crops grown in diversified systems. This would provide farmers with the security needed to transition away from traditional practices and invest in more resilient, productive, and environmentally sustainable agricultural practices.

REFERENCES

Gathala, M. K., Laing, A., Tiwari, T. P., Timsina, J., Rola-Ruzben, F., Islam, S., Maharjan, S., Brown, P. R., Das, K. K., Pradhan, K., Chowdhury, A. K., Kumar, R., Datt, R., Anwar, M., Hossain, S., Kumar, U., Adhikari, S., Magar, D. B. T., Sapkota, B. K., Shrestha, H. K., Islam, R., Rashid, M., Hossain, I., Hossain, A., Brown, B., & Gerard, B. (2021). Improving smallholder farmers' gross margins and labor-use efficiency across a range of cropping systems in the Eastern Gangetic Plains. *World Development*, 138, 105266. <https://doi.org/10.1016/j.worlddev.2020.105266>

Gathala, M. K., Mahdi, S. S., Jan, R., Wani, O. A., & Parthiban, M. (2022). Sustainable intensification in eastern Gangetic Plains of South Asia via conservation agriculture for energy, water and food security under climate smart management system. In F. A. Bahar, M. A. Bhat, & S. S. Mahdi (Eds.), *Secondary agriculture*. Cham: Springer.

Jat, R. K., Sapkota, T. B., Singh, R. G., Jat, M. L., Kumar, M., & Gupta, R. K. (2014). Seven years of conservation agriculture in a rice-wheat rotation of eastern Gangetic Plains of South Asia: Yield trends and economic profitability. *Field Crops Research*, 164, 199–210.

<https://doi.org/10.1016/j.fcr.2014.04.015>

Bijarniya, D., Groot, J. C., Jat, M. L., Toorop, R. A., Lopez-Ridaura, S., Kalvania, K. C., & others. (2024). Holistic analysis of cropping diversity and intensity implications for productive, environmental, and nutritional performance of smallholder farms in Bihar, India. *Frontiers in Sustainable Food Systems*, 8, Article 1393129. <https://doi.org/10.3389/fsufs.2024.1393129>



Above: Fresh vegetables being prepared in Nalanda, India.



INITIATIVE ON

Transforming Agrifood
Systems in South Asia

AUTHORS

KM Choudhary, Scientist, CIMMYT-India, New Delhi
Kailash C Kalvania, Data Analyst, CIMMYT-India, New Delhi

Shahid Ali, Project Manager, CIP-Bihar, India

Pooja Sinha, Livelihood Specialist-JEEViKA

Sanjeev Kumar, BAO, Noorsarai, Department of Agriculture, Government of Bihar

RK Jat, Cropping Systems Agronomist, CIMMYT-BISA

Deepak Bijarniya, Research Associate, CIMMYT-India

Timothy J Krupnik, Regional Director, Sustainable Agrifood Systems Program, Asia, CGIAR Country Convener, CIMMYT Country Representative for Bangladesh

Mahesh K Gathala, Senior Scientist, CIMMYT

SUGGESTED CITATION

Choudhary, K. M., Kalvania, K. C., Ali, S., Sinha, P., Kumar, S., Jat, R. K., Bijarniya, D., Krupnik, T. J., & Gathala, M. K. (2024). *Sustainable intensification and diversification options for enhancing productivity and input use efficiency in eastern IGP of India* (Research Note 51). Transforming Agrifood Systems in South Asia (TAFSSA).

FUNDING ACKNOWLEDGEMENTS

We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund: <https://www.cgiar.org/funders/>

To learn more about TAFSSA, please contact:
t.krupnik@cgiar.org; p.menon@cgiar.org

ABOUT TAFSSA

TAFSSA (*Transforming Agrifood Systems in South Asia*) is a CGIAR Regional Integrated Initiative to support actions that improve equitable access to sustainable healthy diets, improve farmers' livelihoods and resilience, and conserve land, air, and water resources in South Asia.

ABOUT CGIAR

CGIAR is a global research partnership for a food secure future. Visit <https://www.cgiar.org/research/cgiar-portfolio> to learn more about the initiatives in the CGIAR research portfolio

DISCLAIMER

This publication has been prepared TAFSSA Initiative and has not been peer reviewed. Any opinions stated herein are those of the author(s) and do not necessarily reflect the policies or opinions of initiatives, donor agencies, or partners

This publication is licensed for use under a Creative Commons Attribution 4.0 International License (CC BY 4.0).

Generative AI was used to improve the grammar of this document