

# Exploration of economic and environmental impacts of sustainable diversification in the eastern IGP of India

Research note 50

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## ABOUT THIS NOTE

Challenges to the agricultural systems in the Eastern Indo-Gangetic Plains (EIGP) include low crop productivity correlated with the region's increased poverty, farmers' low investment capability and aversion to risk, and increasing energy and input costs, in addition to climatic variability. The EIGP is one of the most vulnerable regions to climate change because of terminal heat in summers, frequent droughts and flood risks, and increasingly erratic monsoon rainfall behavior in recent decades. This research brief presents the findings from on-farm participatory approach research trials focused on the climate-resilient and profitable alternative crop diversification options over to the dominating existing cropping systems. These on-farm research trials were conducted by the Transforming Agrifood Systems in South Asia (TAFSSA) Initiative with the partnership of CGIAR Institutes, JEEViKA, and the Department of Agriculture in Nalanda district of Bihar, India.

## KEY STUDY FINDINGS

1. The On-farm one-year cropping cycle (three seasons) trials demonstrated alternative diversified cropping systems outperform the most common farmer practice in terms of system net return up to 280% under the rice-potato-maize system compared to the existing dominated rice-wheat system.
2. Shifting from the traditional rice-wheat system to diversified cropping systems has the potential to significantly enhance labor productivity, resulting in increases of 36% to 116%. Additionally, this transition can lead to a substantial reduction in energy utilization, decreasing by 10% to 40%.
3. The diversified cropping systems—maize-mustard-mung bean, rice-chickpea-proso millet, and rice-wheat-mung bean, combined with conservation agriculture-based management practices, contributed to reductions in Global Warming Potential (GWP) of 178.6%, 44.2%, and 15.5%, respectively, compared to traditional farming practices

## BACKGROUND

The Ingo Gangetic Plains (IGP) has a high degree of spatial variability in terms of poverty and farm size, with a clear low-to-high gradient of food insecurity from the western regions toward the eastern IGP (Erenstein and Thorpe, 2011). Challenges to the agricultural systems in the EIGP include low crop productivity correlated with the region's increased poverty, farmers' low investment capability and aversion to risk, and increasing energy and input costs, in addition to climatic variability (Gathala et al., 2022). The Eastern IGP is characterized by high population density, small farm holding size with fragmented fields, lack of access in input and output markets due to weak infrastructure, poor knowledge and access to new technologies. This region is also known for frequent climatic aberration (floods, drought, cyclones and heat) and shorter winter crop growing seasons compared to Western IGP (Jat et al., 2014). To tackle these complex challenges, there was a need to explore new innovations, including cropping systems, and

improve agronomic interventions that can increase smallholders profitability and reduce production costs and farm labor. The aim of the on-farm participatory approach is to demonstrate, create awareness, and assess diversified cropping patterns, focusing on their potential to enhance farm profit, input use efficiency (energy and labor), and environmental impact (GHG emission).

## OBJECTIVES

This study intends to identify strategies that can enhance farmers' productivity, optimize resource utilization, and increase farm profitability. It also aims to observe the adaptation behaviors of various crops and cropping systems, as well as their impact on energy use under diversified cropping systems and improve agronomic practices based on conservation agriculture management principles. Furthermore, the research addresses the reduction of greenhouse gas emissions produced by farms and agricultural environments. Findings from one year of crop rotations are detailed in this research brief.



**Above:** A farmer is inspecting her wheat field at Nalanda, Bihar; photo: CIMMYT



**Above:** A research platform trial on crop rotation taking place in Nalanda, Bihar; photo: K.M. Choudhary.

## DATA AND METHODS

The on-farm research trials were designed through community interactions and engagement of local stakeholders, including extension personnel, local dealers, and public and private development institutes. The scenarios were constructed as per the local challenges of farm profitability, production costs, labor, and market and weather through the discussion, and all scenarios were discussed with all stakeholders; finally, five scenarios (Table 1) were decided to demonstrate at volunteer champion farmers designated by the community. The trial follows a randomized complete block design, incorporating five crop rotations (Table 1), with each individual farmer considered as a replication. Data pertaining to crop management inputs—including the number of tillage operations, fuel consumption, irrigation frequency, herbicide and fertilizer usage, seed rate, labor input, pesticide application, and associated costs—were meticulously recorded for each crop using a standardized data collection format. These costs were aggregated to determine the overall production cost. The expenses related to key inputs and

outputs were analyzed economically. Gross returns were calculated based on the prevailing market prices for the commodities (grain and straw/stover) during those years. Net returns were derived by subtracting the total cultivation costs from the gross returns. Labor productivity was assessed by dividing the gross return by the total labor costs incurred throughout the crop cycle.

Mitigation options tool (MOT) were used to estimate greenhouse gas (GHGs) emissions and input energy used for each cropping system [Feliciano et al., 2015]. This tool was developed by Climate Change, Agriculture and Food Security (CCAFS) in collaboration with the University of Aberdeen. Basically, MOT estimates the performance of the production system based on the emission of GHG perspective both in terms of land-use efficiency and efficiency per unit of product from different inputs used in each crop. To estimate the GWP, all GHGs emitted from production systems are converted into CO<sub>2</sub>-equivalents (CO<sub>2</sub>-eq) using the global warming potential (over 100 years) of 34 and 298 for CH<sub>4</sub> and N<sub>2</sub>O, respectively [IPCC, 2013].



**Above:** CIMMYT Trials on Wheat, Potato, Mustard, Carrots and Peas at Karnal, Haryana, India; photo: CIMMYT

**Table 1:** Description of the diversified cropping patterns compared

Treatments	Crop rotations	Tillage	Crop establishment method	Residue management
S1	Rice -wheat-fallow	PTR-CT	Rice: Transplanting; Wheat: Broadcast -On flats	All crop residue removal
S2	Rice- potato-maize	PTR-CT-CT	Rice: Transplanting; Potato: Drill seeding with bed planter; Maize: Drill seeding - On flats	Incorporated rice (20-25%), Maize (50%)
S3	Maize-mustard-mung bean	ZT-ZT-ZT	Maize: Drill seeding; Mustard: Drill seeding; Mung bean: Drill seeding On flats	Anchored maize (50%) and mustard (50%) and mungbean (70%) residue retention
S4	Rice-chickpea-proso millet	CTDSR-ZT-ZT	Rice: Drill seeding; Chickpea: Drill seeding; Proso millet: Drill seeding - On flats	Anchored Rice (20-25%) Chickpea (25-30%) and Proso millet (20-25%) residue retention
S5	Rice-wheat-mung bean	CTDSR-ZT-ZT	Rice: Drill seeding; Wheat: Drill seeding; Mung bean: Drill seeding -On flats	Anchored Rice (20-25%) Wheat (20-25%) and mungbean (70%) residue retention

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



**Above:** CIMMYT Trials, Partial CA Rice-Wheat-Mungbean at Karnal, Haryana, India; photo: CIMMYT

## RESULTS

### ECONOMIC PROFITABILITY

The total production cost of the monsoon season ranged from 665 to 941 USD ha<sup>-1</sup>, where maize production costs under scenario 3 were significantly lower by 27% (249 USD ha<sup>-1</sup>) than the farmer's practice (Scenario 1) (Table 2). Among rice, the direct dry direct-seeded rice was also reduced by about 13% production costs, and this was contributed by avoiding the wet tillage and labor savings in direct-seeded rice over to transplanting rice. In the winter season, the maximum production costs were associated with potato cultivation (2153 USD ha<sup>-1</sup>), and the lowest was associated with mustard (433 USD ha<sup>-1</sup>). The high cost of potato cultivation was the result of high seed, labor, fertilizer, and pesticide uses. In these participatory research trials, we demonstrated the inclusion of third short-duration spring crops such as mung bean and millets to intensify the cropping systems. In the rice-potato-maize system, farmers invest more money in maize cultivation (740 USD ha<sup>-1</sup>) during the spring season, but the introduction of mung bean and proso-millet requires less money compared to the former, and these will provide alternative options to the farmers. On the system basis, the highest cost of cultivation was associated with rice-potato-maize (3834 USD ha<sup>-1</sup>), which is about two and half times more investment needed than the farmer's practice and other alternative cropping systems.

Different crops and cropping systems significantly influenced the net profit of individual seasons and systems at 0.05 probability (Table 2). In the monsoon season, about 20% higher net profit was achieved in maize and

direct-seeded rice (Scenarios 3-5) compared to conventional rice (Scenario 1-2). This resulted in a lower cost of production and slight yield improvement in rice and the replacement of rice with maize in the monsoon season (scenario 3). Potato cultivation in the winter season may provide about four times (4324 USD ha<sup>-1</sup>) higher benefits than other winter crops (1034 USD ha<sup>-1</sup>), but this also needs a similar four times investment capacity of the farmers and also has a high risk of the potato markets. In the spring season as the introduction of the third crop gave 305 to 785 USD ha<sup>-1</sup> net returns, but in the case of proso-millet, farmers faced the challenges of poor germination due to very high temperatures, and this was not successfully grown. Maize in the rice-potato-maize system provided the highest net return, followed by mung bean. This piloted on-farm participatory trial results clearly indicated that adopting the rice-potato-maize system provided the highest net return (5874 USD ha<sup>-1</sup>), which was about 186% higher than the rest of the scenarios. Though this system provided the highest net return, it also put farmers at risk to the market and required a more investment capacity, which may not align with resource-poor and marginal farmers. The maize-mustard-mung bean system demonstrated more profitability than the rice-wheat system (farmers' practice), and this system required low investment.

## LABOR PRODUCTIVITY

Different crops and cropping systems combined with agronomic interventions influence the labor demand due to their nature of cultivation, planting, seeding, level of mechanization, and crop duration, which also influences labor productivity (USD USD<sup>-1</sup> labor investment). In this study, it was clearly demonstrated that different crops and cropping systems significantly influenced labor productivity (Table 3). Maize cultivation in the monsoon season was found to have the highest labor productivity (4020 USD USD<sup>-1</sup>), followed by direct-seeded rice (Scenarios 4-5), which was lower by about 10% compared to maize cultivation. Transplanted rice (Scenarios 1-2) under wet tillage to be found labor intensive resulted in poor labor productivity. In the winter season, potato cultivation was associated with the highest labor productivity (9603 USD USD<sup>-1</sup>) because of the high potato yield and market price, even though higher labor requirements for potato cultivation than other crops (wheat, mustard, chickpea). The lowest labor productivity was associated with mustard cultivation due to lower potential yield compared to other crops. During spring cultivation, maize cultivation was observed to have the highest labor productivity. On a system basis, labor productivity was observed to be highest under rice-potato-maize (Scenario 2), followed by rice-wheat-mung bean, and lowest was with rice-wheat-fallow (Scenario 1). Specifically, rice-potato-maize increased labor productivity by 116% compared to scenario 1.

The higher labor productivity of labor in this system was associated with a

high yield potential and complimented by high net returns due to better markets. Intermediately, the rice-wheat-mung bean, maize-mustard-mung bean, and rice-chickpea-prosomal millet exhibited labor productivity levels that were 71%, 58%, and 36% higher than those recorded for scenario 1.

## ENERGY UTILIZATION

The energy consumption across various treatments was analyzed in relation to different sources and operations. The total energy inputs (MJ ha<sup>-1</sup>) during the cropping cycle were found to be significantly different at  $p \leq 0.05$  (Table 3). Maize cultivation during the monsoon season required the least energy use compared to rice cultivation, and this was three times less than the latter. Direct seeded rice (4-5) significantly reduced the energy use by about 900 MJ ha<sup>-1</sup> over to transplanted rice (Scenarios 1-2). In winter crops, potato cultivation associated with higher fertilizer and agro-chemicals, labor and tillage intensive, more inter-cultural operations, and high seed rate resulted in the highest energy use (6069 MJ ha<sup>-1</sup>), but in contrast, chickpea and mustard (Scenarios 3-4) were used about four and half less energy (1437 MJ ha<sup>-1</sup>) and this was contributed by low input use and conservational agriculture-based practices. Growing maize in the spring season required more energy than low-input and short-duration crops of mung bean and millet. Overall total system energy

used was the highest associated with rice-potato-maize (13263 MJ ha<sup>-1</sup>) because all three crops in the systems were energy intensive compared to the rest of the systems. The maize-mustard-mung bean (Scenario 3) system was recorded as the least energy use system, which was three times less than Scenario 2.

### GHG EMISSIONS PATTERN

The total emissions from different crops and cropping systems was calculated as global warming potential (GWP) (kg CO<sub>2</sub> eq. ha<sup>-1</sup> yr<sup>-1</sup>). The data of the present study indicated that divergent crop management practices influenced GWP. Among the crop management scenario 2 (rice-potato-maize) (6242 kg CO<sub>2</sub> eq. ha<sup>-1</sup> yr<sup>-1</sup>) recorded the highest GWP followed by rice-wheat fallow (4357 kg CO<sub>2</sub> eq. ha<sup>-1</sup> yr<sup>-1</sup>), rice-wheat-

mung bean (3771 kg CO<sub>2</sub> eq. ha<sup>-1</sup> yr<sup>-1</sup>), rice-chickpea-prosop millet (3022 kg CO<sub>2</sub> eq. ha<sup>-1</sup> yr<sup>-1</sup>) and the lowest was recorded under maize-mustard-mung bean (1564 kg CO<sub>2</sub> eq. ha<sup>-1</sup> yr<sup>-1</sup>) (Figure 1). The lower GWP in diversified cropping systems (Scenarios 3-5) reflects the less contributed to carbon footprints. One year mean basis, maize-mustard-mung bean, rice-chickpea-prosop millet and rice-wheat-mung bean recorded 178.6%, 44.2% and 15.5% less GWP compared to rice-wheat-fallow, respectively. Input like diesel fuel (for land preparation, seeding and irrigation water application), and fertilizers constitute the major share of the total emissions under rice-potato-maize, which was recorded 43.3% higher GWP compared to farmers practices (scenario 1) (Figure 1).



**Above:** Farmers are busy to harvest potatoes in the farm at Nalanda, Bihar, India; photo: CIMMYT

**Table 2 :** Cost of cultivation and net return (USD/ha) of crops and cropping systems affected by different management practices.

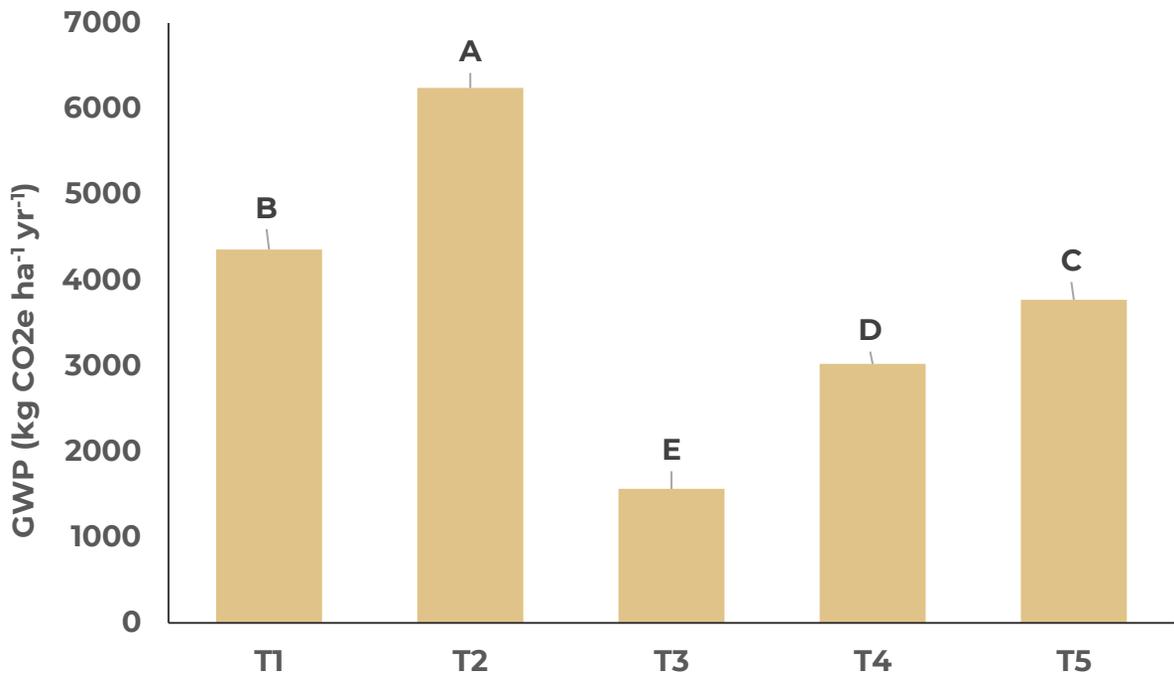
Scenarios*	Production costs (USD ha <sup>-1</sup> )				Net returns (USD ha <sup>-1</sup> )			
	Rice/maize	wheat/potato/mustard/c hickpea	Maize/mung bean/proso millet	System	Rice/maize	Wheat/potato/mustard/chickpea	Maize/mung bean/proso millet	System
Sc1	914A	638B	-	1553C	715B	829C	-	1543C
Sc2	941A	2153A	740A	3834A	758B	4324A	785A	5867A
Sc3	665C	433E	462B	1561C	892A	907BC	558B	2357B
Sc4	809B	471D	186D	1467D	856A	1070BC	-186D	1739C
Sc5	804B	563C	386C	1753B	904A	1251B	304C	2459B

\* Refer to Table 1 for a description of scenarios. \*\*conversion of INR to USD using current rates. The within a column, the different uppercase letters are significantly different, at 0.05 probability based on Tukey's HSD means.

**Table3 :** Labor productivity and energy use of crops and cropping systems affected by different management practices.

Scenarios*	Labor productivity (USD USD <sup>-1</sup> labor investment)				Total energy use (MJ ha <sup>-1</sup> )			
	Rice/maize	wheat/potato/mustard/chickpea	Maize/mung bean/proso millet	System	Rice/maize	Wheat/potato/mustard/chickpea	Maize/mung bean/proso millet	System
Sc1	2252C	5089C	-	7341E	3859AB	2414.16B		6274BC
Sc2	2260C	9603A	4025A	15888A	4124A	6069A	3070A	13263A
Sc3	4020A	4341D	3234B	11595C	1233D	1562D	1676B	4471D
Sc4	3617B	6355B	-	9972D	3362BC	1312E	1006C	5679C
Sc5	3726B	5861B	2963C	12549B	3038C	1987C	1585B	6611B

\* Refer to Table 1 for a description of scenarios. \*\*conversion of INR to USD using current rates. The within a column, the different uppercase letters are significantly different, at 0.05 probability based on Tukey's HSD means.



**Figure 1:** Total Global Warming Potential (GWP; kg CO<sub>2</sub>e ha<sup>-1</sup> yr<sup>-1</sup>) under different cropping systems. The bars are headed by different letters are significantly different, based on Tukey's HSD means.

## CONCLUSION AND RECOMMENDATION

This research demonstrates that the implementation of diversified cropping systems, especially those incorporating vegetable (potato) and maize in rotations, leads to a notable increase in farm profitability, reduced in labor use, and improved energy efficiency when compared to traditional rice-wheat (RW) systems. Given the rising greenhouse gas (GHG) emissions associated with conventional rice-wheat cropping in the eastern Indo-Gangetic Plain of India, the integration of maize into these cropping systems offers a significant opportunity to mitigate GHG emissions. The results highlight that diversified and intensive crop rotations can effectively address the multifaceted challenges posed by

escalating crop production costs, declining economic returns, labor shortages, excessive energy consumption, and increased environmental impacts linked to the traditional rice-wheat system. Additionally, this approach may involve securing guaranteed markets at minimum support prices.



**Above:** A farmer harvesting potatoes in Nalanda, Bihar, India; photo: CIMMYT

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**Above:** Watering in the maize field at Nalanda, Bihar, India; photo: CIMMYT



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