INITIATIVE ON
Transforming Agrifood Systems in South Asia

CGIAR

Exploration of economic and environmental impacts of crop diversification in the northwestern IGP of India

Research note 25
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ABOUT THIS NOTE

The energy-intensive rice-wheat system in the northwestern Indo-Gangetic Plain (NWIGP) significantly increases production costs and greenhouse gas (GHG) emissions, driven by chemical fertilizers, fossil fuels for intensive tillage, irrigation, and high labor use. A particularly harmful practice is residue burning, commonly used to clear fields after harvest, releasing large amounts of carbon dioxide and particulate matter, worsening air pollution, and posing health risks to local communities. To address these challenges, on-station research was initiated in collaboration with the ICAR-Central Soil Salinity Research Institute (CSSRI) and the Transforming Agrifood Systems in South Asia (TAFSSA) initiative under CIMMYT. The research focuses on reducing cultivation costs, improving farm profitability, decreasing energy use, and lowering GHG emissions through diversified cropping systems.

KEY FINDINGS

1. The two-year study proved that diversified cropping systems outperform reduced production costs and increased farm profits over the business–as–usual (farmers' practice). The net return in the maize-mustard-mung bean cropping system increased by 107% with 14% less production cost.
2. Labor productivity can be boosted by 24-126% by adopting diversified cropping systems (pearl millet-pea-sunflower, maize-mustard-mung bean, and soybean-wheat-sorghum) compared to farmers' practices.
3. Input energy use can be lowered by 20-55%, shifting from rice-wheat systems to diversified cropping systems.
4. The two-year data provided evidence that a significant 57%, 55%, 20%, and 16% decrease in global warming potential (GWP) under pearl millet-pea-sunflower, maize-mustard-mung bean, baby corn-carrot-cowpea, and soybean-wheat-sorghum fodder systems, respectively.

CIMMYT
IFPRI INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IRRI International Rice Research Institute
IWMI International Water Management Institute
CIP INTERNATIONAL POTATO CENTER

BACKGROUND

North-western Indo Gangetic Plains (NWIGP) is predominantly rice-based farming systems that are threatened by unsustainable natural resource degradation, low input use efficiency, and agriculturally based nonpoint source air pollution that undermines sustainability and human health (Kakraliya et al., 2022). In association with off-farm employment opportunities, these issues contribute to rural out-migration, particularly of youth, resulting in rising labor demand and increased production costs (Gathala et al., 2020). Overuse of fertilizer and intensive labor and energy use in rice-based systems in the region contribute to low farm profit and increased greenhouse gas (GHG) emissions, calling into question its sustainability (Sapkota et al., 2020). Together, these factors create a substantial carbon footprint for the region's agriculture. As climate change impacts intensify, addressing the emissions associated with this system is crucial for achieving sustainability, necessitating a shift toward more eco-friendly practices and technologies that can reduce environmental harm while maintaining farm profitability. Sustainable intensification and diversification with improved management practices increase productivity with efficient use of available resources and improve environmental quality by saving water, labor, fuel, energy, and mineral nitrogen in agriculture, and leads to a reduction in greenhouse gas emissions (Jat et al., 2020). To tackle these complex challenges, this research trial aims to assess diversified cropping patterns, focusing on their potential to enhance farm profit, input use efficiency (energy and labor), and environmental impact (GHG emission).

OBJECTIVES

The objective of this research is to develop and implement diversified cropping systems that effectively decrease production costs and enhance farm profits while improving labor productivity. This approach aims to optimize resource use efficiency, thereby reducing greenhouse gas emissions and energy utilization. By integrating sustainable agricultural practices, crop rotation, and innovative technologies, the initiative seeks to promote ecological balance and resilience in farming systems. Ultimately, the goal is to create a more sustainable and profitable agricultural framework that benefits farmers, the environment, and local communities. Results from the two-year crop rotations are described in this research brief.

Above: Intensive tillage (puddling) followed by manual transplanting in a rice-based system; photo: Deepak

Above: Alternate low input requiring no-tillage soybean-based system at Karnal, India; photo: Deepak

DATA AND METHODS

The trial follows a randomized complete block design, with seven scenarios/crop rotations replicated three times. Plot sizes are 50 m x 12.5 m. The seven scenarios were constituted by a combination of crop rotations and improved agronomic regenerative agricultural management practices. The details are presented in productivity research note 1. Sc1 has adopted a business-as-usual rice-wheat-fallow system under conventional management, Sc2 was rice-potato-pearl millet system under conventional management, Sc3 was rice-wheat-mung bean system under zero-till with residue retention as a full conservation agriculture practice, Sc4 was maize-mustard-mung bean system under permanent raise beds with residue retention, Sc5 was baby corn-carrot-cowpea (fodder) system under fresh raise bed system with no residue incorporation, Sc6 was soybean-wheat-sorghum (fodder) system under permanent raise beds with crop residue retention, and Sc7 was pear millet-garden pea-sunflower system under permanent raise bed systems with crop residue retention (Refer Table 1, research note 1 for detailed treatment descriptions).

The data on crop management inputs such as the number of tillage operations, fuel consumption, number of irrigations, herbicide, fertilizer, seed rate, labor use, pesticide application, and their costs under each treatment were recorded for each crop using a standard data recording format. All these costs were summed up to calculate the total cost of production. Gross returns were obtained as per the prevailing market prices of the commodity (grain, vegetables, fodder, and straw) over the different years. Net returns were calculated by deducting the total cost of production from the gross returns. The labor productivity was calculated as total output (USD ha-1) divided by the total labor cost (USD ha-1) involved during the crop cycle, and this is expressed as USD USD-1 labor investment.

Mitigation options tool (MOT) were used to estimate greenhouse gas (GHG) emissions and input energy used for each cropping system/ scenario [Feliciano et al., 2015]. The total energy of crops and cropping systems was calculated by using total inputs used like human labor, machinery, diesel, fertilizer, pesticides, seed, irrigation, residue recycling, soil processes, and so forth. This tool was developed by Climate Change, Agriculture, and Food Security (CCAFS) in collaboration with the University of Aberdeen. To estimate the GWP, all GHGs emitted from production systems are converted into CO2-equivalents (CO2-eq) using the global warming potential (over 100 years) of 34 and 298 for CH4 and N2O, respectively [IPCC, 2013].

Cost of production included only all variable costs; here land rent was not included.

$$\text{Net return} = \text{Gross return } (USD\ \text{ha}^{-1}) - \text{Production cost } (USD\ \text{ha}^{-1})$$

$$\text{Labor productivity (cost based)} = \frac{\text{Total agricultural output } (USD\ \text{ha}^{-1})}{\text{Total labor } cost\ (USD\ \text{ha}^{-1})}$$

$$\text{Global warming potential (GWP) } (\text{kg } CO_2\text{-eq. ha}^{-1}) = [\{CO_2\ (\text{kg ha}^{-1}) + N_2O\ (\text{kg ha}^{-1})\} \times \{298 + CH_4\ (\text{kg ha}^{-1}) \times 34\}]$$

$$Energy\ input\ (Mj\ ha^{-1}) = \sum_{i-1}^{n} (I_1 + I_2 + \cdots, In)$$

where, I_1, I_2, ..., I_n refer to the energy input involved in the application of fertilizers and pesticides, the energy used for tillage operations and irrigation, and total labor use

All input costs in *INR* converted into *USD* using the money exchange rate of 1 *USD*= 83.93 *INR*

The normality test was run to meet the homogeneity criteria, and it was found satisfactory; no transformation of data was done. This research was conducted in RCBD; the ANOVA was constructed as a fixed-effects year, and scenarios (cropping systems and improved agronomic management practices) were used, while replication was used as a random effect. The model runs as “fixed effect = year + scenarios + year by scenarios” and “random effect = replication[year] + replication[year] by scenarios.” The mean of scenarios' significance differences was separated using Tukey’s Honestly Significance Difference (HSD).

Above: Crop rotation research platform trial at ICAR-CSSRI; photo: LK Singh

RESULTS

ECONOMIC PROFITABILITY

Diversified cropping systems with improved agronomic management practices (Sc2-Sc7) proved a significant advantage in overall profitability compared to the business-as-usual of the rice-wheat system under traditional management (Sc1). The lowest cost of production was recorded under the soybean-wheat-sorghum fodder system (Sc6), followed by the maize-mustard-mung bean system (Sc4). Whereas The highest cost of production noted under the baby corn-carrot-cowpea system (Sc5) persuades the rice-potato-pearl millet system (Sc2). The maize-mustard-mung bean and soybean-wheat-sorghum fodder systems under no-tillage typically have lower production costs than the rice-wheat system. No-tillage practices eliminate the need for plowing, which saves on fuel, labor, and equipment costs. These systems with residue retention often make better use of resources, such as water and nutrients, leading to lower overall input costs. The higher cost of production in the baby corn-carrot-cowpea and rice-potato-pearl millet systems can be attributed to input costs like intensive tillage operations, as well as higher seed costs than other systems. These diverse systems also required more labor for planting, harvesting, and post-harvesting, including processing and storage, compared to the more streamlined rice-wheat system. The handling, storage, and transportation of perishable crops like carrots and potatoes can also incur higher costs, leading to an increase in production costs (Figure 1).

The highest net return was obtained under the baby corn-carrot-cow pea system (Sc5) followed by maize-mustard-mung bean (Sc4); alternatingly remaining systems proved significantly higher net return compared to business-as-usual (farmers practice).

The higher carrot yield combined with higher market prices of baby corn supplemented by additional yields from summer cowpeas as fodder contributes to achieving higher net returns under the baby corn-carrot-cowpea system despite its higher production costs. Though this system provided the highest net return, farmers will not necessarily adopt the systems because of higher investment, advanced processing facilities, and immediate supply to the market. Additionally, the baby corn and carrot market is highly volatile and more predominant in peri-urban areas. Vegetables like carrots often require cold storage and post-processing, complicating their distribution. Similarly, the demand for baby corn in local markets has been quite low, which may require a strong linkage with the suppliers of the urban market base. As a result, there is limited potential to scale this cropping system across larger areas. The maize-mustard-mung bean system shows the second-highest net return and has significant potential to replace the rice-wheat system in the NWIGP. In Sc4, the higher yields of maize during the Kharif season, the strong market prices for mustard in the rabi season,

and the additional yields of mung bean in the summer all contributed to a greater overall net return compared to Sc1. This system also has eased for the farmers as there is no need for additional investment, it is easy to store at the farm, and the local market is available. In Sc7, the higher system net return was contributed by pea yield in the rabi season and additional sunflower yield with higher prices in the summer season. This cropping system also has the potential to replace the rice-wheat system, but it might face challenges in the pea crop for high labor demand with pearl millet and sunflower market as there is not much demand for pearl millet and a lack of processing industries for sunflower.

The two years mean data provided evidence that baby corn-carrot-cowpea (Sc5), resulted in a significant 126% increase in system net return pursued maize-mustard-mung bean (Sc4) by 107%, pearl millet-pea-sunflower (Sc7) by 82%, soybean-wheat-sorghum fodder (Sc6) by 29%, rice-potato-spring pearl millet (Sc2) by 25%, and rice-wheat-mung bean (Sc3) by 17%, respectively (Figure 1).

LABOR PRODUCTIVITY

In this study, labor productivity is expressed as a return of USD per dollar of labor investment (USD USD^{-1} ha^{-1}). The lowest labor productivity was recorded under the baby corn-carrot-cowpea system (Sc5), which was statistically similar to farmers' practice (Sc1) and rice-potato-pearl millet (Sc2). In these scenarios, the lower labor productivity (USD 215 USD^{-1} labor investment) was lower than the rest of the scenarios (USD 360 USD^{-1} labor investment). Keeping labor availability as a key factor then, the soybean-wheat-sorghum (Sc5), followed by rice-wheat-mung bean (Sc3), had the highest labor productivity. The maize-mustard-mung bean and rice-wheat-mung bean systems under conservation agriculture have contributed lower labor, reflected in higher labor productivity. Even higher net returns and system yields cannot provide better labor productivity under Sc5 and Sc2 because of the labor-intensive cultivation of carrots, baby corn, and potatoes; labor requirements may be reduced by mechanized cultivation, but this will require significant investment.

GLOBAL WARMING POTENTIAL (GWP)

The total emissions from different crops and cropping systems were calculated as global warming potential (GWP) (kg CO_2 eq. ha^{-1} yr^{-1}). The two-year mean data indicated that GWP was significantly ($p \leq 0.05$) influenced by divergent crop management practices (Figure 2). The lowest GWP was recorded significantly under the pearl millet-pea-sunflower system (Sc7) and maize-mustard-mung bean (Sc4) than the other scenarios. The baby corn-carrot-cowpea (Sc5) and soybean-wheat-sorghum system (Sc6) also proved significantly lower by % GWP than the rice-based scenario (Sc1-Sc3). Within rice-based systems, the highest GWP was associated with SC2 and significantly higher than Sc1 and Sc3.

The lower GWP in diversified cropping systems (Sc4-Sc7) reflects the less contributed carbon footprints. On a two-year mean basis, SC7, SC4, Sc5, and S6 recorded 57.8%, 55.2%, 20.9%, and 16.8% less GWP compared to Sc1, respectively. Lesser inputs like diesel fuel (for land preparation, seeding, and irrigation water application) and N fertilizers used in Sc4, Sc5, Sc6, and Sc7 contribute to lesser total GHG emissions, resulting in lower GWP compared to business as usual (farmers practice).

Above: Maize crop harvested from research platform trial at ICAR-CSSRI; photo: Deepak

Table 1: Labor productivity of crops and cropping systems influenced by different management practices.

Scenarios	Labor productivity (USD USD^{-1} labor investment)			
	Rice/ maize/ soybean/ baby corn /pearl millet	Wheat/ mustard/ potato/ carrot/ pea	Pearl millet/ sunflower/ mung bean/ sorghum fodder/ cowpea	System
Rice-wheat (Sc1)	42D	184B	-	226D
Rice-potato-pearl millet (Sc2)	76C	73C	77CD	225D
Rice-wheat-mung bean (Sc3)	92B	239A	-	331B
Maize-mustard-mung bean (Sc4)	130A	75C	111C	316BC
Baby corn-carrot-cowpea (Sc5)	80BC	54D	62D	196D
Soybean-wheat-sorghum (Sc6)	139A	226A	147B	512A
Pear millet-pea-sunflower (Sc7)	52D	19E	208A	280C

Figure Note: Within a column, different uppercase letters indicate significant differences at the 0.05 probability level based on Tukey's HSD test.

Table 2: Total input energy use (MJ ha^{-1}) of crops and cropping systems influenced by different management practices.

Scenarios	Energy (MJ ha-1)			
	Rice/ maize/ soybean/ baby corn /pearl millet	Wheat/ mustard/ potato/ carrot/ pea	Pearl millet/ sunflower/ mung bean/ sorghum fodder/ cowpea	System
Rice-wheat (Sc1)	8903A	2662D	-	11565B
Rice-potato-pearl millet (Sc2)	5943B	4362A	3440A	13746A
Rice-wheat-mung bean (Sc3)	5422C	2223F	1440F	9087C
Maize-mustard-mung bean (Sc4)	1883E	2257E	1550E	5690F
Baby corn-carrot-cowpea (Sc5)	1592F	3931B	2463B	7986D
Soybean-wheat-sorghum (Sc6)	1571G	1778G	1805D	5155G
Pear millet-pea-sunflower (Sc7)	2270D	3216C	2416C	7903E

Figure Note: Within a column, different uppercase letters indicate significant differences at the 0.05 probability level based on Tukey's HSD test.

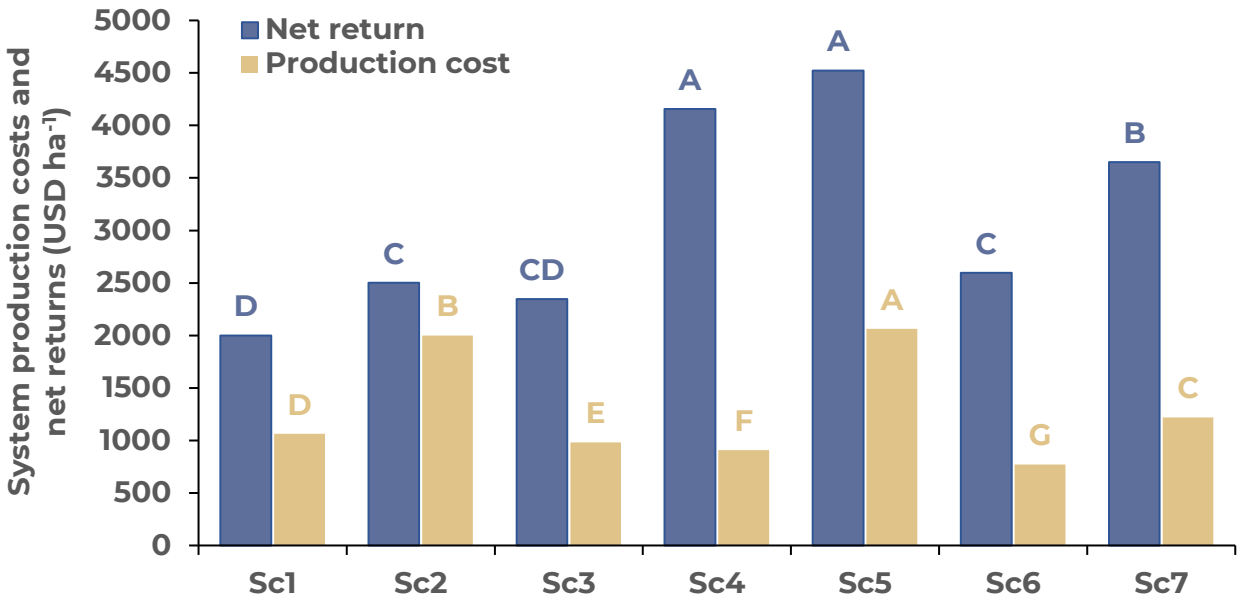

Figure 1: Cost of production and net return (USD/ha) of crops and cropping systems affected by different management practices. The bars are headed by different letters are significantly different, based on Tukey's HSD means.

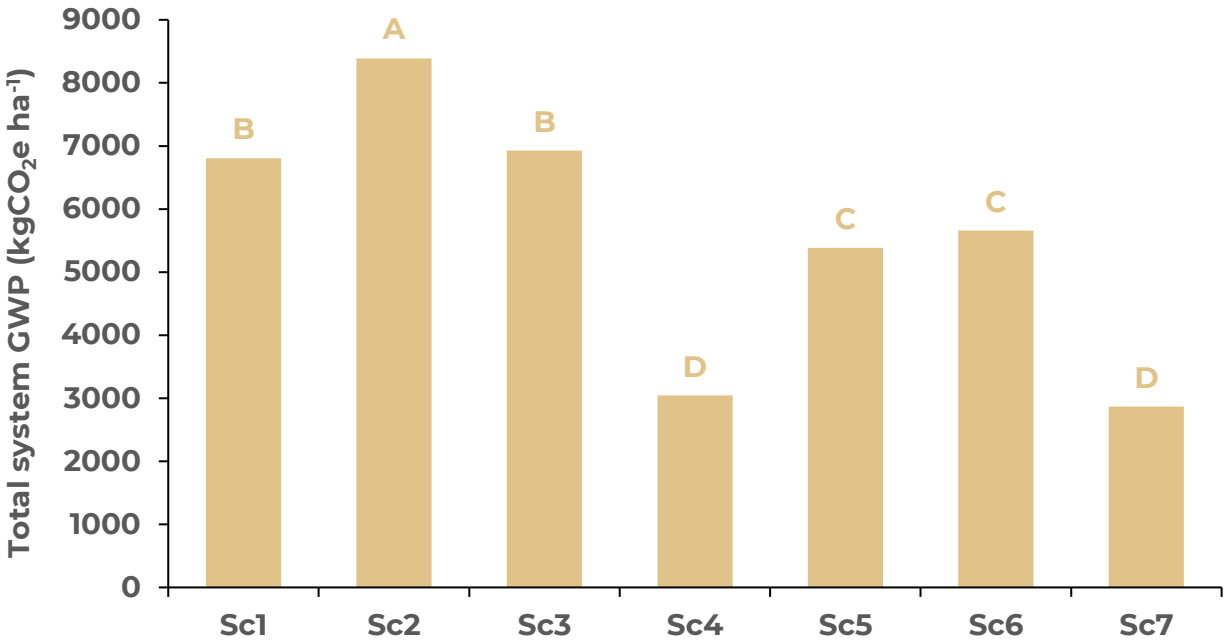

Figure 2: Total system global warming potential (kg CO_2-eq ha^{-1} yr^{-1}) under different cropping systems and agronomic management practices. The bars headed by different letters are significantly different, based on Tukey's HSD test.

CONCLUSIONS AND RECOMMENDATIONS

This study confirms that adopting diversified cropping systems, particularly non-rice crops in the systems, significantly increases farm profit, higher labor productivity, and more energy efficiency than rice-based systems. Considering the increasing GHG emissions in traditional rice-wheat cropping systems in NWIGP of India, integrating vegetables and maize into cropping rotations presents a valuable opportunity to lower global warming potential. The findings emphasize that diversified and intensive crop rotations can effectively tackle the complex challenges of increasing crop production cost and diminishing economic returns, labor scarcity, high energy use, and heightened environmental impacts associated with the conventional rice-wheat system in this region. However, adopting these diversified rotations requires government policy support, such as payments for carbon credits and other societal benefits. This could also include ensuring guaranteed markets at minimum support prices.

Above: Farmer Ashok Kumar showcasing sustainable mustard cultivation practices under the TAFSSA initiative, exemplifying efforts to enhance profitability and environmental resilience in the Indo-Gangetic Plain; photo: CIMMYT

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Above: Diversified cropping trials at ICAR-CSSRI: Showcasing sustainable practices for improved farm profitability and environmental benefits; photo: CIMMYT

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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

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