Increasing Productivity and Profitability: Evaluating Diverse Cropping Systems

A Field Study in Chapainawabganj District in Bangladesh

ABOUT THIS NOTE

The Barind Tract in Chapainawabganj, Bangladesh, covers 128,342 hectares (DAE, 2023) and faces severe agroecological challenges, including high temperatures, low soil moisture retention, and erratic rainfall. The region's poorly drained, low-organic soils are prone to drought, limiting crop productivity (Ali et al., 2018). To address these issues, a participatory research trial (2022–2023) tested diversified and climate-resilient cropping systems against traditional practices. This brief summarizes key findings on productivity and economic efficiency, offering sustainable solutions for improving agricultural outcomes in this climate-sensitive region.

KEY STUDY FINDINGS

1. The Diversified and intensified cropping systems achieved significantly higher rice equivalent yields compared to the traditional Rice-Wheat-Fallow system in Chapainawabganj, with the Rice-Maize intercropped with Red Amaranth-Sorghum system yielding 210–226% more.

2. The Rice-Maize with Red Amaranth intercrop-Sorghum system recorded the highest net profit, driven by high maize yields and market value. Its resilience to adverse weather conditions further enhances its sustainability.

3. These results highlight that diversifying and intensifying rice-based cropping systems can significantly enhance productivity and profitability for smallholder farmers, providing vital benefits to marginal farmers in Chapainawabganj and across Bangladesh.

BACKGROUND

The Chapainawabganj region of Bangladesh, particularly the Barind Tract, faces significant environmental challenges, making it one of the most vulnerable agricultural areas in the country. This ecosystem is characterized by recurring droughts, extreme temperatures, erratic rainfall, and groundwater depletion (Harun et al., 2017). These factors exacerbate water scarcity, soil degradation, and reduced crop productivity, severely limiting agricultural potential. Consequently, crop production has become increasingly difficult and unpredictable, posing challenges to the region's ability to meet food and nutritional demands (Ali et al., 2018).

Traditionally, Bangladesh's agricultural policies and research have emphasized single-crop production, particularly rice, which dominates the region's landscape. However, this approach has been insufficient in addressing the complex challenges of food security, environmental sustainability, and market demands. Moreover, limited focus has been placed on integrated, evidence-based, and multisectoral strategies that connect farms, markets, and policies to promote both economic and nutritional benefits (Ali et al., 2018).

To sustainably increase food production without further environmental degradation, intensifying and diversifying cropping systems is crucial. Diversification enables farmers to cultivate a variety of crops, enhancing resilience to climate shocks and improving household nutrition. Intensification, on the other hand, ensures higher productivity within the same land area. However, achieving these goals requires changes in farming practices, supportive policies, and market development to fully realize the potential benefits.

The weak connections between farm production, market efficiency, and economic returns pose a significant challenge to sustainable agricultural development. Farmers often select crops based on immediate factors such as input availability, crop value, market demand, and family needs. While practical, this approach may not support long-term sustainability or economic efficiency. The depletion of groundwater, which has particularly affected irrigation for Boro rice (winter rice), is compelling many farmers to shift toward less water-intensive crops. This transition presents both challenges and opportunities to promote diversified cropping systems that conserve resources while maintaining productivity and profitability (Gathala et al., 2021; Ali et al., 2018). This research addresses these challenges by examining innovative cropping systems that enhance diversification and intensification, particularly in monsoon rice-based systems that avoid the high water requirements of Boro rice during the dry winter season. Incorporating biofortified crop varieties and drought-tolerant crops offers a viable approach to increasing productivity and profitability in the region. By aligning these systems with market-based strategies, the study seeks to bridge the gap between farm-level production and broader economic outcomes.

OBJECTIVES

This research aims to identify strategies that enhance farmers' productivity and profitability while conserving resources and supporting ecological services. Specifically, the study seeks to:

1. Estimate production costs, revenue, productivity, and net returns from different cropping patterns.

2. Analyze the drivers of increased crop production.

3. Promote sustainable agricultural practices that increase farm productivity and profitability.

4. Develop resilient, diversified, and intensified cropping systems that mitigate the challenges of groundwater depletion.

DATA AND METHODS

SITE DESCRIPTION

Researcher-managed and farmer-participatory field trials were conducted in rainfed and partially irrigated environments within the Barind Tract, Chapainawabganj district, northwest Bangladesh. The trials, spanning three cropping seasons—winter 2022–23 (rabi), pre-monsoon 2023 (kharif 1), and monsoon 2023 (kharif 2)—targeted the region's challenging agroecological conditions, such as limited rainfall, high temperatures, and declining groundwater levels. The objective was to evaluate the potential of diversified and intensified cropping patterns to enhance crop productivity and resilience under these adverse environmental conditions..

TREATMENT SELECTION

The cropping patterns for the study were selected through a participatory process involving 50 farm households in each village. Prior to selecting the patterns, a discussion was held with the participating farmers to highlight the importance of local demand, profitability, nutrition, and balanced diets. Farmers ranked various cropping options, and the three highest-scoring patterns were chosen for the trials. These patterns were then compared with the region's common cropping practices. This approach ensured that the selected systems reflected farmer preferences, increasing the likelihood of adoption if the trials proved successful (Cheesman et al., 2021).

EXPERIMENTAL DESIGN

The on-farm research trials used a randomized complete block design (RCBD), with 20 farm households serving as replicates in each village. Four cropping patterns (three diversified patterns and the farmers' traditional practice) were compared. Plot sizes ranged from 150 to 300 m² per treatment. Each selected cropping system was implemented and managed across different farms, ensuring that the trials accounted for local variations in soil, water availability, and other environmental factors.

CROP MANAGEMENT

The trials covered three distinct cropping seasons:

a. ***Kharif 1 (Pre-monsoon)***: The planting of crops such as sweet corn, sorghum, and cowpea occurred between February 15 and March 1-15, 2023.
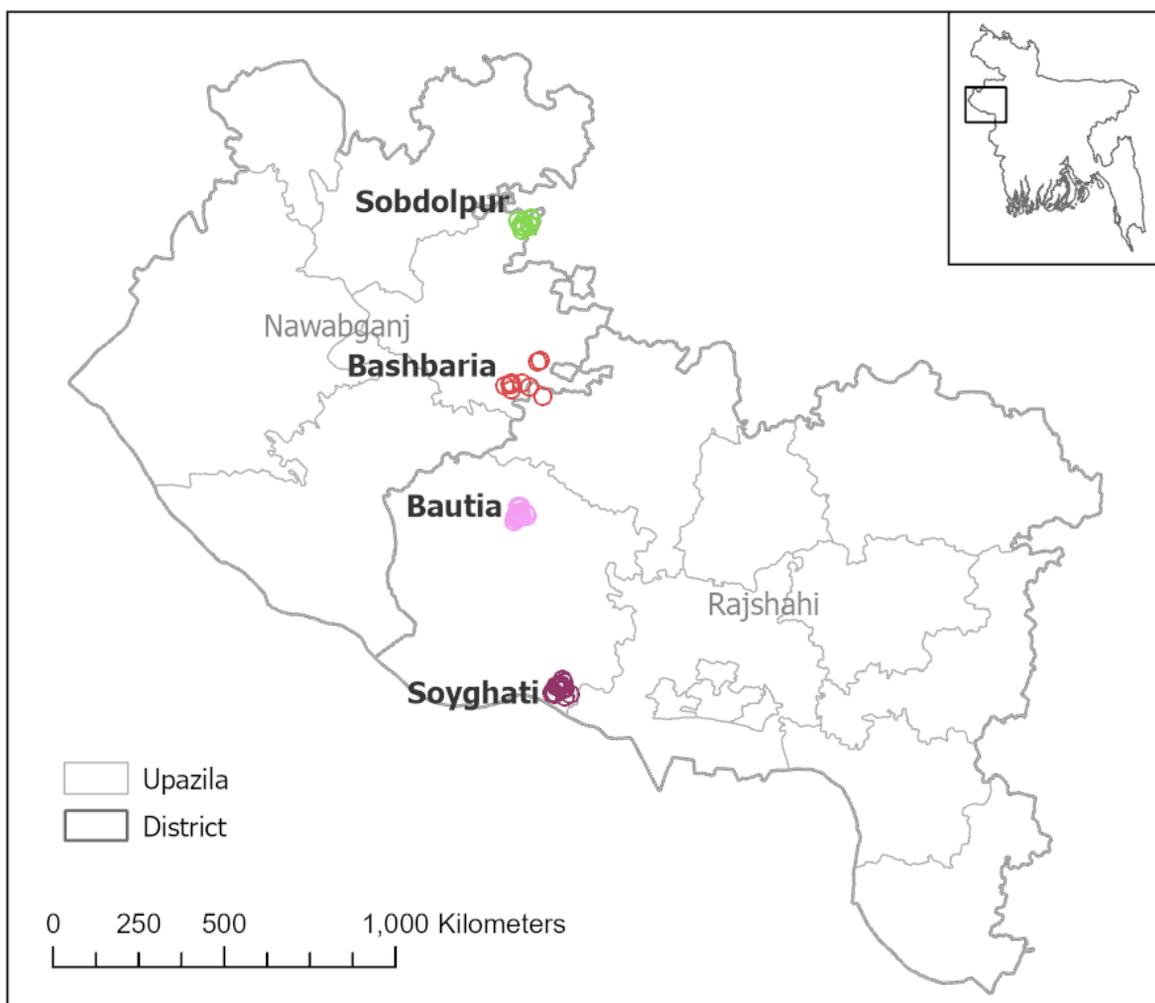
Figure 1: Small circles indicate the farmers' participatory trial fields at Bashbaria and Sobdolpur villages in Chapainawabganj district

Table 1: Treatments in Chapainawabganj district

Treatment code	Kharif-2	Rabi	Kharif-1
R-L-Sc	Rice	Lentil	Sweet corn
R-M+Ra-S	Rice	Maize+red amaranth	Sole sorghum (Fodder)
R-Cp-S+C	Rice	Chickpea	Sorghum + cowpea (Fodder)
R-W-F	Rice	Wheat	Fallow

Note: R-L-Sc: Rice-Lentil-Sweet corn; R-M+Ra-S: Rice-Maize intercrop with red amaranth-Sole Sorghum (fodder), R-Cp-S+C: Rice-Chickpea-Sorghum intercrop with cowpea (fodder), R-Wheat-F: Rice-Wheat-Fallow

b. Kharif 2 (Monsoon): Rice transplantation was carried out on August 20, 2024, using seedlings aged 20-25 days.

c. Rabi (Winter): Crops such as maize, lentil, and chickpea were sown between November 10 and November 20, 2023.

All crops were fertilized according to the Bangladesh Fertilizer Recommendation Guide (FRG 2018), and standard agronomic practices were applied for weed, pest, and irrigation management. This ensured uniform input management across all treatment plots, enabling accurate comparisons of yield and economic performance.

Input Use, Yield, Rice Equivalent Yield, and Profitability

Data on input costs and labor use were collected for each treatment plot, covering activities such as tillage, seedbed preparation, sowing, transplanting, irrigation, fertilizer and pesticide application, hand weeding, harvesting, and threshing. Key performance indicators calculated include:

1. **Yield (tons/ha)**: Total agricultural output divided by the area of land used.

2. **Rice Equivalent Yield (REY)**: Used to standardize yield comparisons across different cropping systems. Calculated as:

$$REY = \frac{\text{Crop yield (tons)} \times Market\ price\ of\ the\ crop\ (USD)}{\text{Market price of rice (USD)}}$$

3. **Production Cost (PC)**: Included all variable costs associated with crop production, excluding land rent.

4. **Gross Return (GR)**: Calculated as the production volume multiplied by the market price.

5. **Net Return (NR)**: The difference between gross return and production cost.

6. **Total Factor Productivity (TFP)**: A measure of overall farm efficiency, calculated as:

$$TFP = \frac{Total\ agricultural\ output\ (USD)}{Total\ input\ costs\ (USD)}$$

7. **Labor Productivity (LP)**: An indicator of cost efficiency based on labor input, calculated as:

$$LP = \frac{Total\ agricultural\ output\ (USD)}{Total\ labor\ cost\ (USD)}$$

All input costs and output prices were originally recorded in Bangladeshi Taka (BDT) and converted to US Dollars (USD) using the exchange rate of 1 BDT = 0.00842 USD.

STATISTICAL ANALYSIS

The data were analyzed using a randomized complete block design (RCBD), with the 20 farmer fields in each location serving as replications (random effect). Fixed effects included village, treatment (cropping pattern), and their interaction. Statistical analyses were performed using JMP14 (SAS Institute Inc., San Francisco). Means of the inputs and outputs across the cropping systems were compared using Tukey's Honestly Significant Difference (HSD) test at a significance level of P ≤ 0.05 to determine whether differences in yields and economic returns were statistically significant (Gomez, 1984).

STUDY FINDINGS

RICE EQUIVALENT YIELD

REY is a standardized measure used to compare the yields of different crops grown on the same land area, expressed in terms of rice. By converting crop yields into rice equivalents, it becomes easier for farmers, researchers, and agricultural economists to assess the productivity of various cropping systems, especially in diversified farming scenarios (Ruma et al., 2023). This method is particularly useful when dealing with multiple crops that have varying economic and nutritional values..

In the Chapainawabganj trials, the REY was calculated to assess the effectiveness of different cropping system options across two villages. The data (Figure 2 & Table 2) revealed significant variations in productivity based on the cropping systems employed.

The diversified cropping systems in the rabi season—such as maize intercropped with leafy vegetables, chickpea, and lentil—along with intensified systems incorporating sweet corn and fodder crops (sorghum and cowpea) in the kharif 1 season, demonstrated significantly higher productivity compared to the traditional Rice-Wheat-Fallow system ($p < 0.001$). The highest REY was achieved in the Rice-Maize intercrop with red amaranth, followed by the sorghum (R-M+Ra-S) system, which delivered an impressive REY of 26.5 t ha⁻¹ per year. In contrast, the traditional Rice-Wheat-Fallow (R-W-F) system recorded the lowest REY at 8.3 t ha⁻¹ per year. When comparing the performance of the cropping system options, the following trend was observed:

- R-M+Ra-S > R-L-Sc > R-Cp-S+C > R-W-F.

The superior performance of the R-M+Ra-S system can be attributed to the high yield of maize grown during the rabi season and the increasing demand for sorghum in the silage industry. This demand makes sorghum a valuable option for farmers, particularly in regions where groundwater depletion restricts irrigation during the dry season. Additionally, the ability to cultivate sorghum on previously fallow land during the pre-monsoon season further boosted the productivity of this system.

The findings from this study hold significant implications for farmers in the Barind Tract, particularly in Chapainawabganj, where environmental constraints such as drought and groundwater depletion pose challenges to traditional farming practices. The superior performance of diversified and intensified cropping systems, especially those incorporating crops like maize, sorghum, and biofortified varieties, offers a promising strategy to enhance productivity and profitability in the region.

The R-M+Ra-S system demonstrates that utilizing fallow land and adopting high-market-value crops, such as sorghum for silage, can contribute to sustainable agricultural intensification.

By adopting these diversified cropping systems, farmers can improve resilience to climate variability, increase income, and enhance household food production.

Moreover, the success of intercropping and introducing drought-resilient crops like sorghum in pre-monsoon fallow land could serve as a model for other regions facing similar agroecological challenges. Policymakers and agricultural extension services should actively promote these cropping systems through targeted programs, providing farmers with essential inputs, training, and market linkages to maximize the benefits of these innovative cropping options.
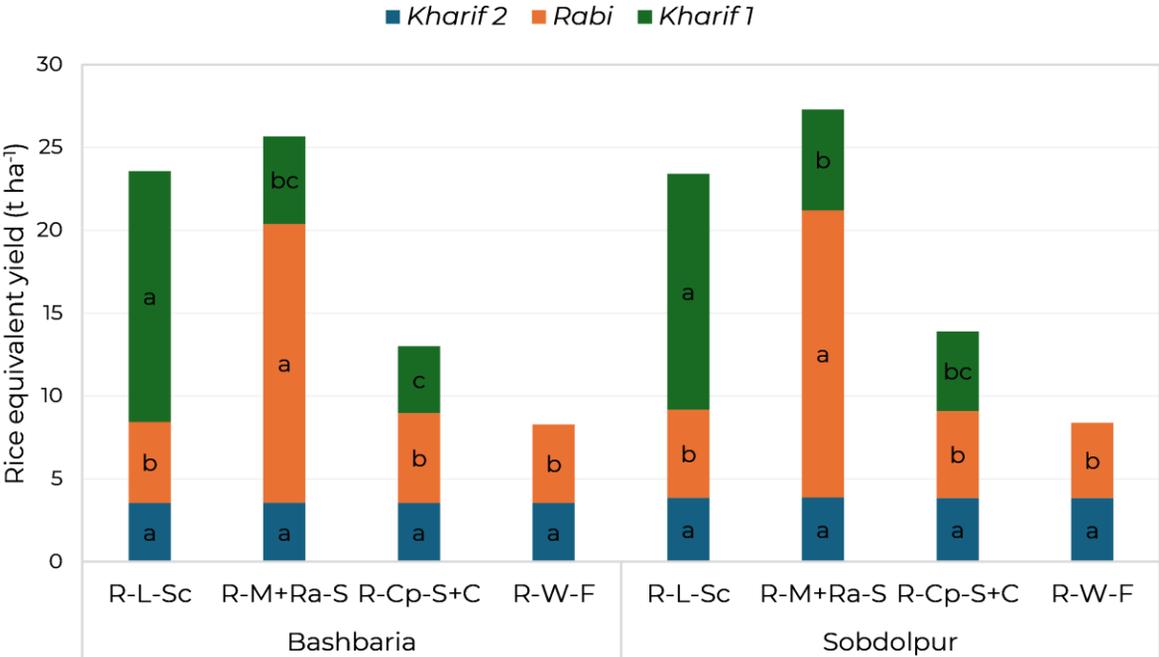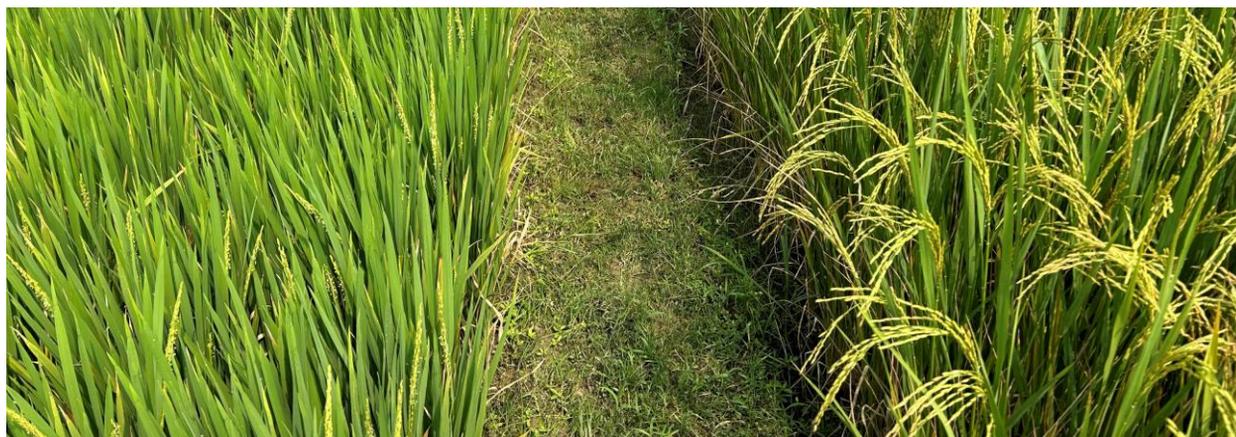

Figure 2: Rice equivalent yield by component crops and cropping systems in Bashbaria and Sobdolpur villages, Chapainawabganj, 2022-23

Note: R-L-Sc: Rice-Lentil-Sweet corn; R-M+Ra-S: Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), R-Cp-S+C: Rice-Chickpea-Sorghum intercrop with cowpea (fodder), R-W-F: Rice-Wheat-Fallow. Means of component crops of a season in cropping system options followed by the same lower-case letters in the same color bars are not significantly different (at p<0.05) according to Tukey's HSD test.

Table 2: System rice equivalent yield (REY), production cost (PC), gross return (GR), net return (NR), total factor productivity (TFP), and labor productivity (LP) by different cropping systems options in Bashbaria and Sobdolpur, Chapainawabganj, 2022-23

Source	Systems productivity and economic efficiency					
	REY	PC	GR	NP	TFP	LP
		USD ha^{-1} per year			USD/USD per yr	
Village (V)						
Bashbaria	17.6a	1566a	4881b	3314b	3.0b	9.8a
Sobdolpur	18.2a	1561a	5070a	3509a	3.2a	10.2a
Cropping system (T)						
R-L-Sc	23.5b	1835b	6018b	4183b	3.3b	13.4a
R-M+Ra-S	26.5a	2065a	7365a	5300a	3.6a	8.3c
R-Cp-S+C	13.5c	1373c	3773c	2400c	2.7c	9.0b
R-W-F	8.3d	983d	2746d	1763d	2.8c	9.3b
V × T						
Bashbaria, R-L-Sc	23.6b	1835b	5999b	4164b	3.3b	13.2a
Bashbaria, R-M+Ra-S	25.7a	2082a	7157a	5075a	3.4ab	7.9c
Bashbaria, R-Cp-S+C	13c	1360c	3665c	2305c	2.7c	9.3b
Bashbaria, R-W-F	8.3d	989d	2703d	1715d	2.7c	9.0b
Sobdolpur, R-L-Sc	23.4c	1834b	6036b	4202b	3.3b	13.6a
Sobdolpur', R-M+Ra-S	27.3a	2048a	7573a	5525a	3.7a	8.7bc
Sobdolpur, R-Cp-S+C	13.9c	1387c	3882c	2495c	2.8c	8.8bc
Sobdolpur,R-W-F	8.4d	977d	2789d	1812d	2.9c	9.6b
Probability (P) value						
V	0.057	0.633	0.029	0.023	0.023	0.269
T	<.001	<.001	<.001	<.001	<.0001	<.0001
V × T	0.131	<.001	0.277	0.216	0.248	0.031

Note: R-L-Sc: Rice-Lentil-Sweet Corn; R-M+Ra-S: Rice-Maize intercrop with re amaranth-Sole sorghum (fodder), R-Cp-S+C: Rice-Chickpea-Sorghum intercrop with cowpea (fodder), R-W-F: Rice-Wheat-Fallow**.** Means followed by the same lower-case letters in a column are not significantly different (at p<0.05) according to Tukey's HSD test.

Above: BRRI dhan 51 in left and BINA dhan 20 in right of *kharif* 2, 2023 in Sobdolpur, Chapainawabganj; photo: Maruf Hossain Shanto

COST OF PRODUCTION

The term CP refers to the total cost, including both fixed and variable expenses, associated with crop production. In this study, the costs accounted for include operational activities such as land preparation, seeding, fertilizer application, irrigation, weeding, pest control, and harvesting, as well as input costs for seeds, fertilizers, herbicides, and pesticides. However, land rent and capital interest were excluded from the analysis (Ruma et al., 2023).

The CP for the various cropping systems showed significant variations across the two study villages, with notable interactions between location and cropping system (Table 2 & Figure 3). Diversified cropping systems—such as maize intercropped with leafy vegetables, chickpeas, and lentils in the rabi season, along with sweet corn and fodder crops like sorghum and cowpea in the kharif 1 season—significantly increased CP compared to the farmers' common Rice-Wheat-Fallow system ($p < 0.001$).

The average highest CP, 2,065 USD ha^{-1} per year, was observed in the Rice-Maize+Red Amaranth-Sorghum system, while the lowest, 933 USD ha^{-1} per year, was recorded in the Rice-Wheat-Fallow system. A comparison of the CP across cropping systems followed this ranking: R-M+Ra-S > R-L-Sc > R-Cp-S+C > R-W-F. This trend was consistent in both villages. The high CP of the R-M+Ra-S system can be attributed to the extensive use of fertilizers and the high cost of hybrid maize seeds in the rabi season.

The R-M+Ra-S system, despite incurring the highest CP, is highly effective due to the well-established market for maize and sorghum. Additionally, sorghum's resilience to drought and its ability to grow on fallow land as fodder make it a favorable option for farmers. The demand for maize and sorghum in the poultry and dairy feed sectors further enhances the viability of this system.

The R-M+Ra-Sorghum system, despite having the highest cost of production, stands out as a sustainable option for farmers in Chapainawabganj due to its market feasibility and resilience to drought. The strong demand for maize in the poultry and dairy industries, along with sorghum's capacity to grow on unused fallow land, supports its long-term adoption. In contrast, the Rice-Lentil-Sweet Corn system, while profitable, faces sustainability challenges due to limited availability of high-quality sweet corn seeds and the crop's vulnerability to drought and hailstorms during the pre-monsoon season (kharif 1). Thus, the R-M+Ra-S system is a more practical and sustainable recommendation for farmers in this region.

Above: BINA dhan 20 in right of *kharif* 2, 2023 in Sobdolpur, Chapainawabganj; photo: Maruf Hossain Shanto
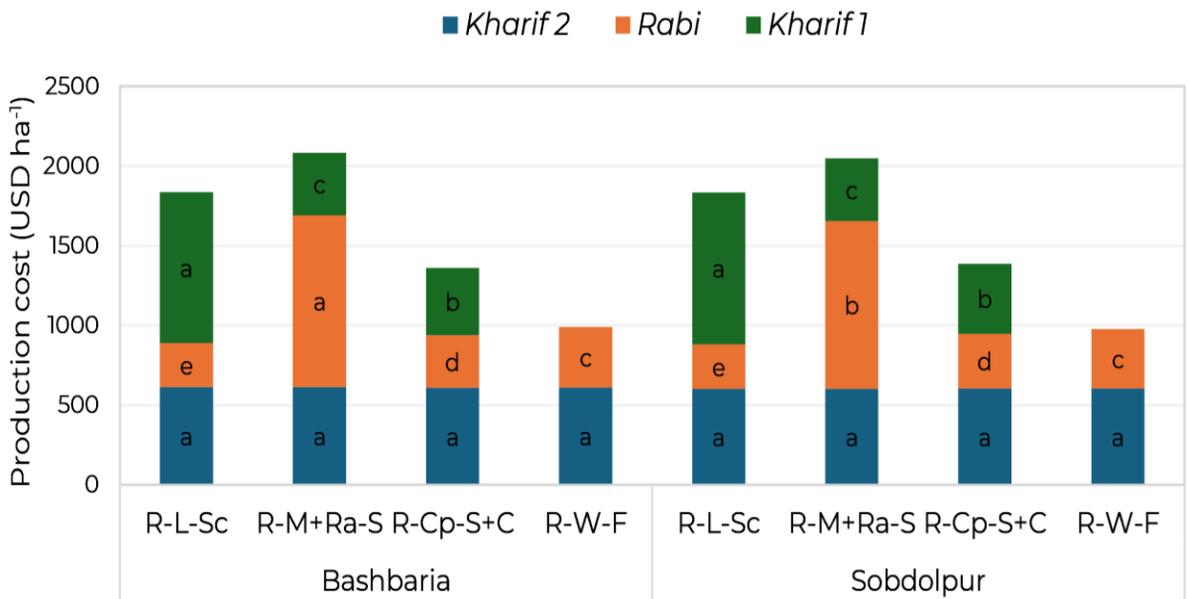
Figure 3: Production cost by component crops and cropping systems in Bashbaria and Sobdolpur villages, Chapainawabganj, 2022-23

Note: R-L-Sc: Rice-Lentil-Sweet corn; R-M+Ra-S: Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), R-Cp-S+C: Rice-Chickpea-Sorghum intercrop with cowpea (fodder), R-W-F: Rice-Wheat-Fallow. Means of component crops of a season in cropping system options followed by the same lower-case letters in the same color bars are not significantly different (at p<0.05) according to Tukey's HSD test.

GROSS RETURN

The GR, representing total income before deductions, is calculated by subtracting production costs from sales revenue (Ruma et al., 2023). The GR of various cropping system options varied significantly across the two villages; however, there were no significant interactions between locations and cropping systems (Table 2). Crop diversification during the rabi season and intensification with sweet corn and fodder crops like sorghum and cowpea during the kharif 1 season significantly increased income compared to the traditional Rice-Wheat-Fallow system (p < 0.001). The highest GR, recorded at 7,365 USD ha^{-1} per year, was achieved by the Rice-Maize intercrop with Red Amaranth-Sorghum (fodder) system. Conversely, the lowest GR of 2,746 USD ha^{-1} per year was observed in the Rice-Wheat-Fallow system. A comparative analysis ranked the systems as follows: Rice-Maize+Red Amaranth-Sorghum > Rice-Lentil-Sweet Corn > Rice-Chickpeas-Sorghum+Cowpea > Rice-Wheat-Fallow. This ranking was consistent across both villages. One notable exception was the lower income from rice (BINA dhan 20) in both villages, which was likely affected by adverse weather conditions and insect-pest attacks, owing to its early maturity compared to the longer-duration BRRI dhan 51. Despite this, the Rice-Maize+Red Amaranth-Sorghum system achieved the highest GR, primarily due to the high yield of maize, which continues to be a significant driver of profitability in this cropping system.

The Rice-Lentil-Sweet Corn system, while generating the second-highest gross income, faces several challenges. Despite the high market price of sweet corn, it is highly susceptible to drought and hailstorms during the kharif 1 season (March-April). Additionally, there is limited market demand for sweet corn in the Chapainawabganj region. During the harvest season, local farmers are primarily focused on selling seasonal fruits like mango, which reduces market attention for sweet corn.

In contrast, the Rice-Maize+Red Amaranth-Sorghum system has strong market support, driven by the sustained demand for maize in the poultry feed industry and sorghum as a fodder crop, particularly for pre-monsoon fallow land. The rising popularity of sorghum is further bolstered by the growth of the commercial silage industry in the region. This creates an opportunity to expand the adoption of the Rice-Maize+Red Amaranth-Sorghum system, which offers higher profitability and aligns with emerging market needs.

In summary, diversifying and intensifying cropping systems—particularly those incorporating maize with leafy vegetables and sorghum grown in pre-monsoon fallow land—demonstrate significant potential to enhance farmers' incomes in Chapainawabganj. Scaling up such systems could provide a sustainable pathway for improving agricultural productivity while meeting the increasing demand for fodder crops.
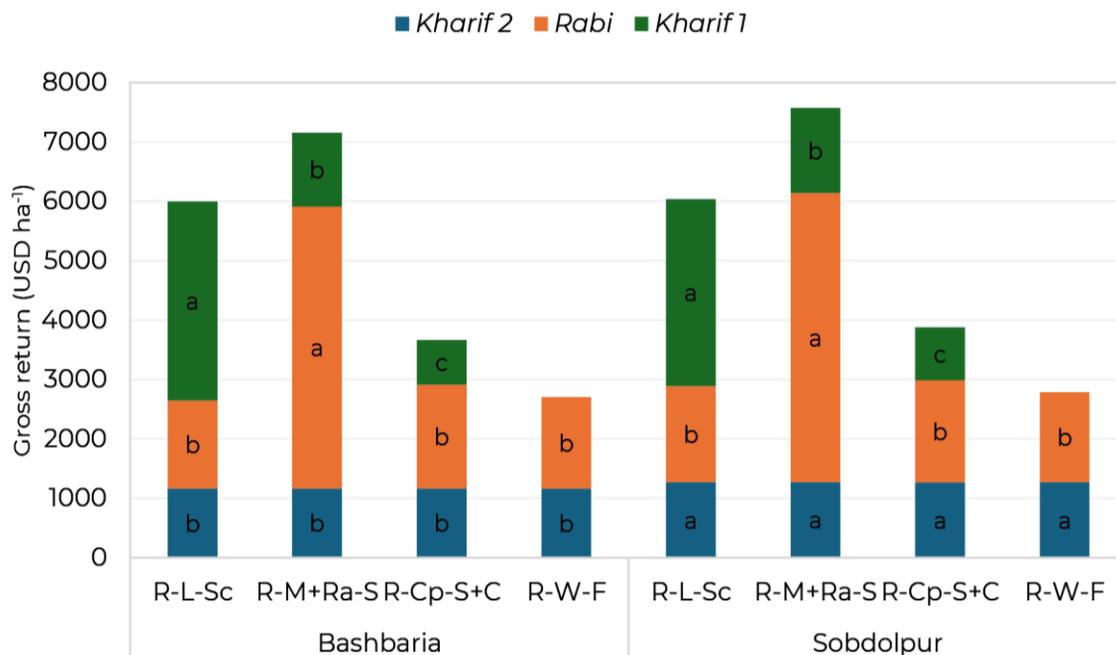

Figure 4: Gross return by component crops and cropping systems in Bashbaria and Sobdolpur villages, Chapainawabganj, 2022-23

Note: R-L-Sc: Rice-Lentil-Sweet corn; R-M+Ra-S: Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), R-Cp-S+C: Rice-Chickpea-Sorghum intercrop with cowpea (fodder), R-W-F: Rice-Wheat-Fallow**.** Means of component crops of a season in cropping system options followed by the same lower-case letters in the same color bars are not significantly different (at $p<0.05$) according to Tukey's HSD test.

NET RETURN

The NR represents the profit remaining for farmers after deducting production costs from the gross income (Ruma et al., 2023). The NR analysis across different cropping systems and villages revealed significant variations, with notable interactions between locations and cropping systems (Table 2 & Figure 5). Among the evaluated systems, the Rice-Maize with Red Amaranth intercrop-Sweet Corn (R-M+Ra-S) system achieved the highest NR, while the traditional Rice-Wheat-Fallow (R-W-F) system recorded the lowest NR.

The highest NR, 5,300 USD ha^{-1} per year, was recorded for the R-M+Ra-S system across all locations. A comparative analysis revealed a consistent ranking in NR performance, with R-M+Ra-S leading, followed by Rice-Lentil-Sweet Corn (R-L-Sc), Rice-Chickpea-Sorghum with cowpea intercrop (R-Cp-S+C), and lastly Rice-Wheat-Fallow (R-W-F). This pattern persisted across both villages, except for the unusually low NR from BINA dhan 20, which was impacted by adverse weather conditions and insect-pest attacks. These issues were likely related to the early maturity of BINA dhan 20 compared to BRRI dhan 51, which was grown in neighboring fields (Table 2 & Figure 5). The superior NR from the R-M+Ra-S system can largely be attributed to the high maize yield, which was sold at the same price as rice. Additionally, the inclusion of sorghum, grown on fallow land during the kharif 1 season, contributed extra income as high-demand livestock fodder. This makes the R-M+Ra-S system not only highly profitable but also sustainable, offering resilience to climatic challenges. It provides a promising model for expanding crop diversification in the Chapainawabganj region, balancing profitability with climate resilience. While the R-L-Sc system achieved the second-highest NR, its long-term feasibility may be limited due to environmental challenges and the restricted market demand for sweet corn. Consequently, the R-M+Ra-S system stands out as a more viable option for sustainable agricultural development.

Above: Rabi crops (wheat, lentil, and chickpeas) in trial plots, 2022-23 in Basbaria, Chapainawabganj; photo: Saiful Islam
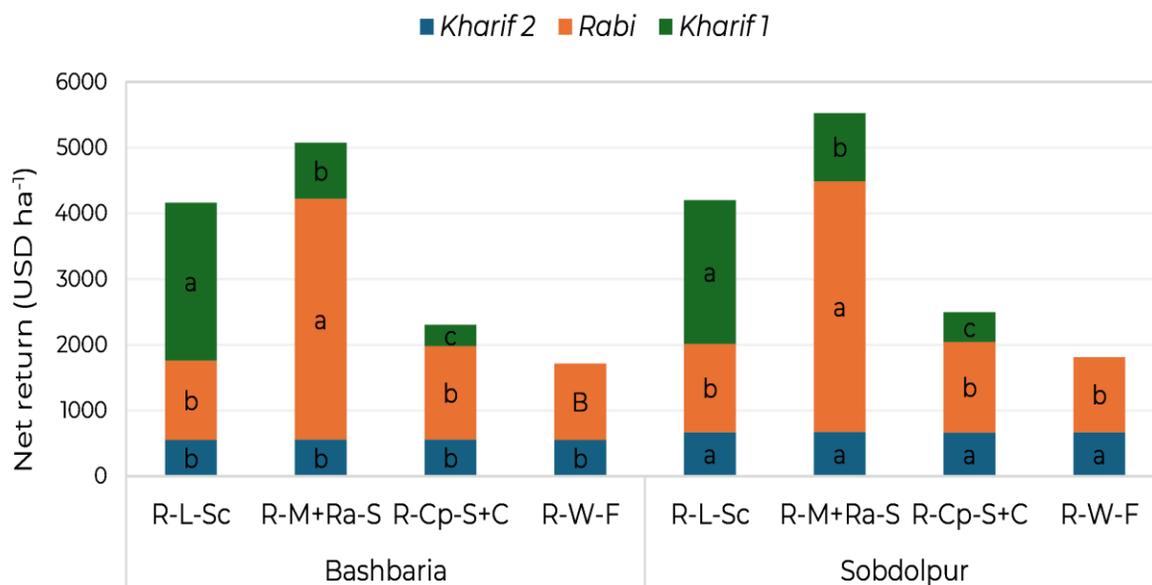
Figure 5: Net return by component crops and cropping systems in Bashbaria and Sobdolpur villages, Chapainawabganj, 2022-23

Note: R-L-Sc: Rice-Lentil-Sweet corn; R-M+Ra-S: Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), R-Cp-S+C: Rice-Chickpea-Sorghum intercrop with cowpea (fodder), R-W-F: Rice-Wheat-Fallow**.** Means of component crops of a season in cropping system options followed by the same lower-case letters in the same color bars are not significantly different (at p<0.05) according to Tukey's HSD test.

TOTAL FACTOR PRODUCTIVITY

The TFP in agriculture measures the efficiency of all inputs used to produce outputs in monetary terms. It provides a ratio of the value of agricultural outputs to the value of inputs required for production. A higher TFP indicates greater efficiency and productivity in the agricultural sector (FAO, 2007).The TFP assessment across different cropping system options showed significant variation in both villages. However, the interactions between locations and cropping systems revealed no significant differences (Table 2 & Figure 6). Diversified cropping systems during the rabi season—such as maize intercropped with leafy vegetables and pulses like lentil and chickpea—and intensification with sweet corn and fodder crops (sorghum and cowpea) in the kharif 1 season, had a significant positive impact on TFP compared to the traditional Rice-Wheat-Fallow system. The highest TFP, 3.6 USD/USD per year, was recorded in the Rice-Maize with red amaranth-Sorghum system across all locations, while the lowest TFP, 2.7 USD/USD per year, was observed in the Rice-Wheat-Fallow system in Bashbaria. Among the cropping system options, the ranking of TFP followed the order: R-M+Ra-S > R-L-Sc > R-Cp-S+C > R-W-F, and these differences were consistent across both villages.

The highest TFP in the R-M+Ra-S cropping system can be attributed to the high yield of maize grown during the rabi season and its market price, which is comparable to rice (28–30 taka per kg). Despite the R-L-Sc system having the second-highest TFP, it is less adaptable for farmers due to the susceptibility of sweet corn to drought and hailstorms during the pre-monsoon season. In contrast, the R-M+Ra-S system is more climate-resilient. Sorghum, in particular, thrives with just one irrigation on fallow land during the pre-monsoon season. Additionally, it presents an opportunity for farmers to generate extra income through the growing silage industry, making the R-M+Ra-S system a more sustainable and profitable option in the region.
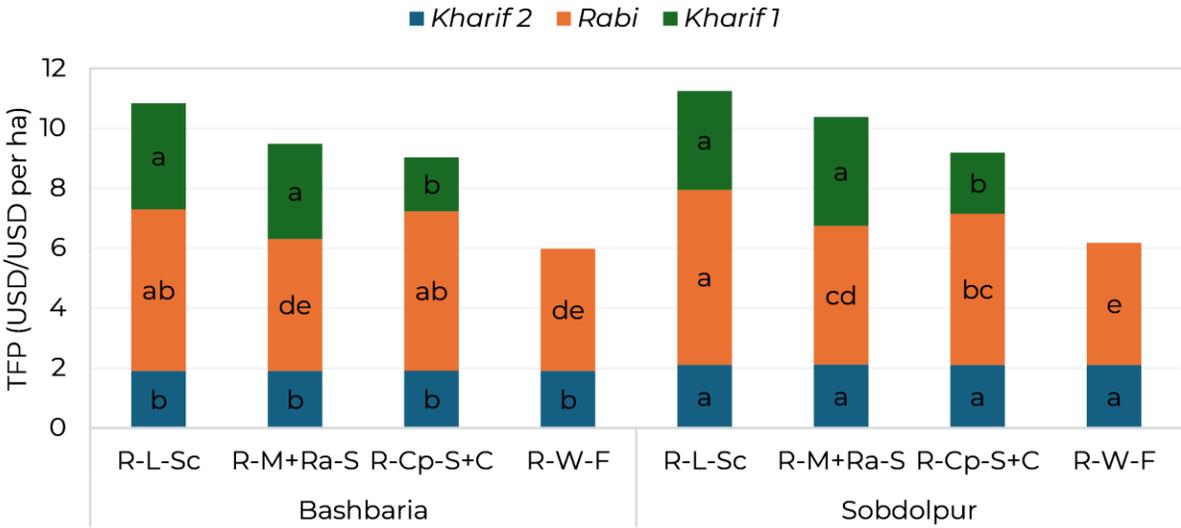

Figure 6: Total factor productivity by component crops of cropping systems in Bashbaria and Sobdolpur villages, Chapainawabganj, 2022-23

Note: R-L-Sc: Rice-Lentil-Sweet corn; R-M+Ra-S: Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), R-Cp-S+C: Rice-Chickpea-Sorghum intercrop with cowpea (fodder), R-W-F: Rice-Wheat-Fallow**. Means of component crops of a season in cropping system options followed by the same lower-case letters in the same color bars are not significantly different (at p<0.05) according to Tukey's HSD test.

LABOR PRODUCTIVITY

The LP in agriculture refers to the monetary value of the output produced by agricultural workers. It measures the total value of agricultural goods produced per unit of labor cost (Cock et al., 2022). This metric provides a ratio of the value of agricultural outputs to the labor required to produce them. Higher LP indicates more output is produced per unit of labor, reflecting improved efficiency and productivity in the agricultural sector, often driven by technological advancements (FAO, 2017).The highest LP, 13.4 USD per USD^{-1} per year, was observed in the Rice-Lentil-Sweet Corn system across all locations, while the lowest, 8.3 USD per USD^{-1} per year, was recorded in the Rice-Maize with Red Amaranth-Sorghum system.

The LP among cropping system options was ranked as R-L-Sc > R-Cp-S+C > R-W-F > R-M+Ra-S across the locations (Table 2). The highest LP in the R-L-Sc system is attributed to the high market price of sweet corn and the low labor requirements for lentil cultivation. However, sweet corn faces challenges in the area due to the lack of established market demand and difficulties in germination during the pre-monsoon season due to soil moisture scarcity. In contrast, the R-M+Ra-S system, while having lower LP, generated higher revenue and is more sustainable. Its component crop, sorghum, is highly drought-resilient and capable of germinating in low soil moisture, unlike sweet corn. Additionally, there is a growing market demand for sorghum as silage in the region. Therefore, implementing the R-M+Ra-S system in the area could positively impact farm profitability and sustainability.
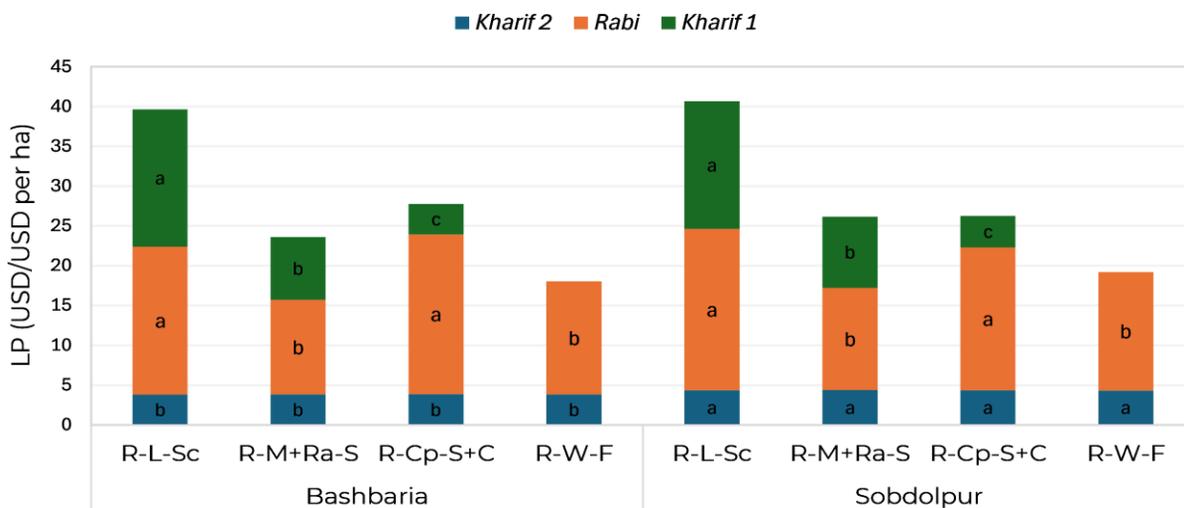

Figure 7: Labor productivity by component crops of cropping systems in Bashbaria and Sobdolpur villages, Chapainawabganj, 2022-23

Note: R-L-Sc: Rice-Lentil-Sweet corn; R-M+Ra-S: Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), R-Cp-S+C: Rice-Chickpea-Sorghum intercrop with cowpea (fodder), R-W-F: Rice-Wheat-Fallow**.** Means of component crops of a season in cropping system options followed by the same lower-case letters in the same color bars are not significantly different (at p<0.05) according to Tukey's HSD test.

Above: Rabi maize with red amaranth intercrop in trial plots, 2022-23 in Basbaria, Chapainawabganj; photo: Juyal Rana

CONCLUSIONS AND RECOMMENDATIONS

A comparative study on productivity and profitability was conducted through a participatory experiment involving farmers across various locations in the Chapainawabganj district of Bangladesh. Four different cropping systems were tested: Rice-Lentil-Sweet Corn, Rice-Maize intercropped with Red Amaranth and Sorghum as fodder, Rice-Chickpea-Sorghum intercropped with Cowpea as fodder, and Rice-Wheat-Fallow. Among these, the Rice-Wheat-Fallow system represents the common practice of local farmers, while the other three cropping systems are intensive and diversified alternatives.

The experiment was conducted on 40 farmers' fields in two villages, Basbaria and Sobdolpur, in the Chapainawabganj district. The study measured rice equivalent yield, cost of production, gross income, net profit, total factor productivity, and labor productivity of the cropping system options. It also analyzed the variance across these cropping systems and locations.

The results revealed that the rice equivalent yield of all the intensive and diversified alternative systems was significantly higher than that of the farmers' traditional Rice-Wheat-Fallow system. The Rice-Maize intercropped with red amaranth-Sorghum system demonstrated the highest rice equivalent yield among all the cropping systems, achieving yields between 210% and 226% higher than

the Rice-Wheat-Fallow system. Likewise, the net returns of the intensified and diversified systems were significantly greater, with the Rice-Maize+red amaranth-Sorghum system delivering the highest net return among all systems. However, despite its second-highest economic efficiency, the Rice-Lentil-Sweet Corn system is not feasible in this region due to the lack of market demand for sweet corn and its vulnerability to drought and hailstorms. In contrast, the Rice-Maize intercropped with red amaranth-Sorghum system appears more viable, given the high demand for maize and the ability to grow sorghum on fallow land before the monsoon season. Sorghum is in demand for silage preparation in dairy farming.

These results suggest that intensifying and diversifying rice-based cropping systems, compared to traditional systems like Rice-Wheat-Fallow, can sustainably enhance smallholder productivity and profitability in this area. However, a strong marketing strategy, especially for products like sweet corn and sorghum used in silage, is crucial for the success of these diversified cropping systems. These findings hold significant implications for marginal farmers in the region.

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