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Increasing Productivity and Profitability: Evaluating Diverse and Intensifying Cropping Systems

A Field Study in Rajshahi District in Bangladesh

Research note 46

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ABOUT THIS NOTE

The Barind Tract in the Rajshahi region of Bangladesh spans 160,000 hectares and experiences high temperatures, limited soil moisture storage, and low, erratic rainfall. The land is characterized by poor drainage, low organic matter content, and a high susceptibility to drought, leading to low crop productivity (Rashid et al., 2019). A farmers' participatory research trial was conducted on diversified, intensified, and climate-resilient cropping system options, comparing farmers' traditional cropping systems with those developed in collaboration with the Bangladesh Agricultural Research Institute and the Bangladesh Wheat and Maize Research Institute. A research brief has been prepared to summarize the results of the study, focusing on productivity and economic efficiency from 2022-23 in the Rajshahi district, Bangladesh.

KEY STUDY FINDINGS

1. The study revealed that diversified and intensified cropping systems achieved significantly higher rice-equivalent yields compared to the traditional Rice-Mustard-Fallow cropping system practiced by farmers in Rajshahi.
2. Among all cropping systems, the Rice–Lentil–Sweet Corn system performed the best, producing yields that were 260–340% higher than the Rice-Mustard-Fallow system.
3. Moreover, the net profit from the Rice–Lentil–Sweet Corn cropping system was significantly higher than other cropping systems, with the highest profitability attributed to sweet corn, a component crop with a high market value. However, the Rice-Maize + Red Amaranth-Sorghum system demonstrated resilience in adverse weather conditions, offering a potentially more sustainable option for local farmers.
4. These results suggest that intensifying and diversifying rice-based cropping systems, compared to traditional systems like Rice-Mustard-Fallow, can sustainably improve smallholder productivity and profitability. These findings are crucial for millions of marginal farmers across Bangladesh and South Asia.

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

BACKGROUND

The Rajshahi region of Bangladesh, particularly the Barind Tract, stands out from other parts of the country due to its unique environmental challenges. The Barind ecosystem is characterized by drought, extreme temperatures, erratic rainfall, and groundwater depletion (Harun et al., 2017). As a result, crop production in Rajshahi is becoming increasingly difficult. While the region has made progress in food production, particularly in rice, many people still lack access to a nutritious and diverse diet.

In Bangladesh, agricultural policies and research have traditionally focused on single-crop production and related value chains. However, there has been limited emphasis on developing evidence-based, multisectoral approaches that link farms, markets, and policies. To sustainably increase food production without harming the environment, the intensification and diversification of farming systems are essential.

The connections between farm production and economic efficiency remain underdeveloped, highlighting the need for integrated approaches that consider household food production, production costs, and market system development. Agricultural systems must be designed to generate profits and encourage farmers to grow nutritious crops while simultaneously reducing consumer prices for healthy food by addressing inefficiencies in value chains. However, farmers typically choose crops based on factors such as the availability of inputs, crop value, family needs, market demand, net returns, and government policies.

To address these issues, this research explores how intensive and diversified rice-based cropping systems, including biofortified crop varieties, can enhance crop yields, improve dietary diversity, and reduce malnutrition.

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 estimate production costs, revenue, productivity, and net returns from different cropping patterns, as well as analyze the factors driving increased crop production.

DATA AND METHODS

SITE DESCRIPTION

Researcher-managed and farmer-participatory field trials were conducted in rainfed and partially irrigated environments over three seasons: winter 2022-23 ('rabi'), pre-monsoon 2023 ('kharif 1'), and monsoon 2023 ('kharif 2') in the northwestern parts of Bangladesh, specifically in the High Barind Tract, Rajshahi (Figure 1).

TREATMENT SELECTION

The cropping patterns for the study were selected through the participation of 50 farm households in each village, who scored their preferences. The cropping patterns that ranked 1st, 2nd, and 3rd based on the farmers' scores were selected for comparison with the existing common cropping pattern (Table 1). The cropping patterns were chosen following the protocol for participatory cropping pattern selection (Cheesman et al., 2022).

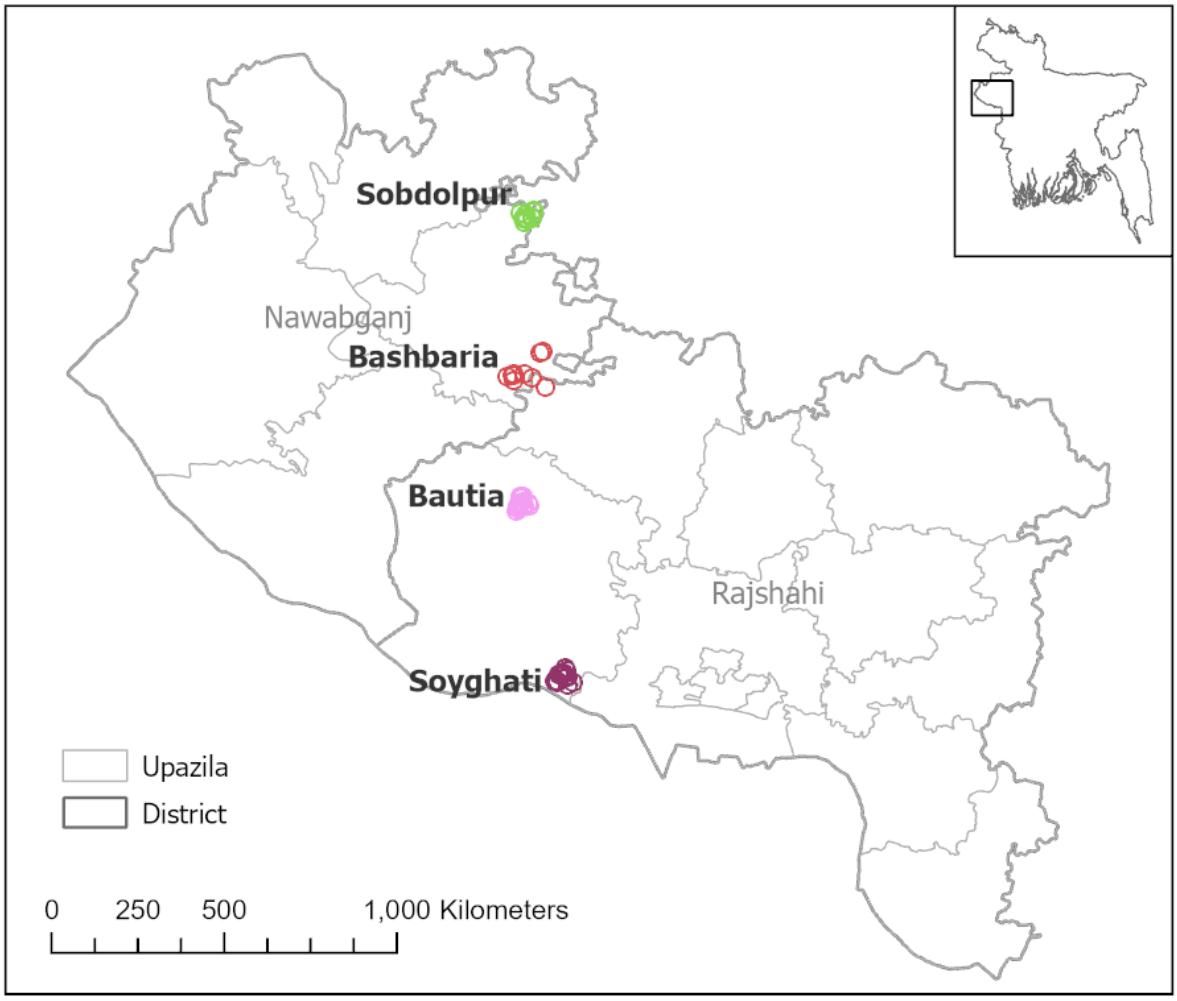

Figure 1: Small circles indicate the farmers' participatory trial fields at Bautia and Soyghati villages in Rajshahi district

Table 1: Treatments in Rajshahi 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-Mu-S+C	Rice	Mustard	Sorghum + Cowpea (Fodder)
R-Mu-F	Rice	Mustard	Fallow

Note: R-L-Sc: Rice-Lentil-Sweet Corn; R-M+Ra-S: Rice-Maize intercrop with Read Amaranth-Sole Sorghum (fodder), R-Mu-S+C: Rice-Mustard (BARI mustard 14)-Sorghum intercrop with Cow Pea (Fodder), R-Mu-F: Rice-Mustard (BARI mustard 18)-Fallow

EXPERIMENTAL DESIGN

The on-farm research trials follow a randomized complete block design (RCBD), with 20 farmer households serving as replications within a village. In each village, three diversified cropping patterns and a farmers' practice are being compared. The plot size ranges from 150 to 300 m^2 per treatment.

CROP MANAGEMENT

The planting of Kharif 1 crops (sweet corn, sorghum, and cowpea) took place between 15 and 26 February 2023. Kharif 2 rice was transplanted around 20 August 2024 using 25–30-day-old seedlings, and the Rabi crops (maize and mustard) were planted between 10 and 20 November 2024. For all three seasons, crops were fertilized according to the Bangladesh Fertilizer Recommendation Guidebook (FRG, 2018). Weed control, pest management, irrigation, and other practices were conducted following standard agronomic procedures.

INPUT USE, YIELD, RICE EQUIVALENT YIELD, AND PROFITABILITY

Input costs and labor use data (e.g., tillage, seedbed preparation, seed sowing, transplanting, irrigation, fertilizer and pesticide applications, hand weeding, harvesting, and threshing) were collected per treatment plot and calculated on a per-hectare basis. Rice equivalent yield (REY), production cost (PC), gross return (GR), net return (NR), total factor productivity (TFP), and labor productivity were calculated (Equations 1–4).

1. $Yield = \frac{Total\ agricultural\ output\ (tons)}{Total\ area\ used\ (ha)}$

2. *Rice equivalent yield (REY)* $= \frac{Crop\ yild\ (ton) \times Market\ price\ of\ the\ crop\ (USD)}{Market\ price\ rice\ (USD)}$

3. *Cost of Production(CP)* = *Production cost included only all variable cost, here, land rent was not included.*

4. *. Gross farm return (GR)* = *Production volume × Market price.*

5. *Net return (NR)* = *GR - CP*

6. *Total Factor Productivity (TFP)* $= \frac{Total\ agricultural\ output\ market\ price\ (USD)}{Total\ inputs\ in\ monetery\ term\ (USD)}$

7. $Labor\ productivity\ (LP) = \frac{Total\ agricultural\ out\ put\ (USD\ )}{Total\ \ labor\ cost\ (USD)}$

All input coat and output price of BDT converted into USD using the money exchange rate of 1 BDT= 0.00824 USD

STATISTICAL ANALYSIS

Data were analyzed using a Randomized Complete Block Design with 20 farmers' fields in each location, considering replication as a random effect. The village, treatment, and their interaction were considered fixed effects (Gomez, 1984). The analysis was performed using JMP 14 (SAS Institute Inc., San Francisco). The inputs and outputs of component crops and system means were compared using Tukey's Honest Significant Difference test at $P \leq 0.05$.

STUDY FINDINGS

RICE EQUIVALENT YIELD

Rice Equivalent Yield (REY) is a measure used to compare the yields of different crops grown on the same area of land, expressed in terms of rice. This metric helps farmers and agricultural economists assess productivity more effectively across various crops (Ruma et al., 2023).

The REY assessed under different cropping system options in both villages and the interactions between locations and cropping system options varied significantly (Table 2). Diversification of the cropping system in the rabi season (maize intercropped with leafy vegetables, traditional mustard, and canola-type mustard) and intensification with sweet corn and fodder crops (sorghum and cowpea) in the kharif 1 season significantly impacted productivity compared to the most common cropping system, T4 (Rice-Mustard-Fallow) ($p < 0.001$). The highest REY of 25.81 t ha^{-1} per year was observed in the Rice-Maize intercrop with Red Amaranth-Sweet Corn system at Soyghati, while the lowest REY of 5.31 t ha^{-1} per year was recorded in the Rice-Mustard-Fallow system at Bautia. The comparison of yield performance among cropping system options followed the order R-L-Sc>R-M+Ra-S>R-Mu-S+C>R-M-Fallow, with significant differences in both villages (Figure 2 and Table 2). The highest REY in the R-L-Sc cropping system was attributed to the high market price of sweet corn (100 BDT kg^{-1}) grown in the kharif 1 season. In contrast, the R-M+Ra-S cropping system achieved the highest grain yield due to the high productivity of rabi maize and the drought resilience of fodder crops during the kharif 1 season (March and April).The REY results followed a similar pattern in both villages in Rajshahi, except for the low yield of rice (BINA dhan 20) in Bautia. This low yield was attributed to weather constraints, insect-pest attacks, and early maturity compared to the surrounding BRRI dhan 51.

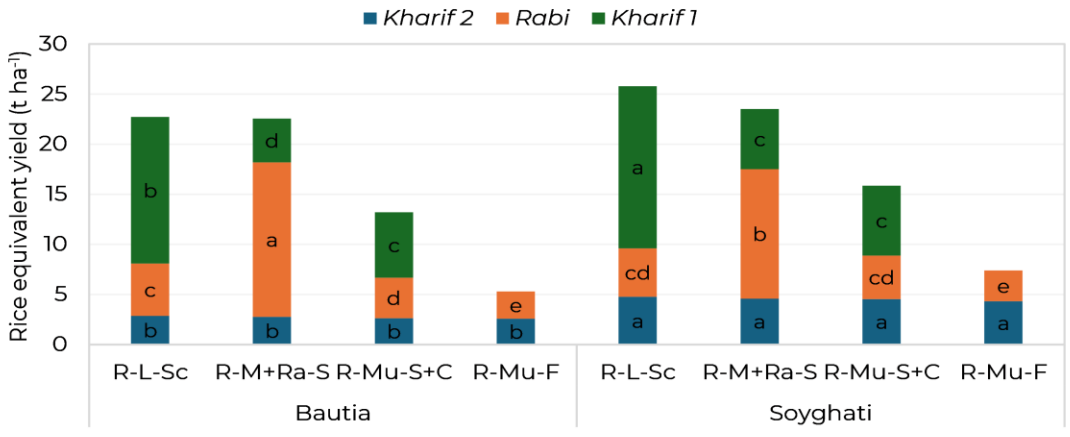

Figure 2: Rice equivalent yield (REY) by component crops and cropping systems in Bautia and Soyghati villages, Rajshahi, 2022-23

Note: R-L-Sc: Rice-Lentil-Sweet corn; R-M+Ra-S: Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), R-Mu-S+C: Rice-Mustard (BARI mustard 14)-Sorghum intercrop with cowpea (fodder), R-Mu-F: Rice-Mustard (BARI mustard 18)-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 Bautia and Soyghati, Rajshahi, 2022-23

Source	Systems productivity and economic efficiency					
	REY	PC	GR	NP	TFP	LP
		USD ha^{-1} $year^{-1}$			USD USD^{-1} $year^{-1}$	
Village (V)						
Bautia	16.0b	1487b	4278b	2791b	2.9b	8.9b
Soyghati	18.1a	1526a	4773	3247a	3.2b	10.0a
Cropping system (T)						
R-L-Sc	24.3a	1744b	6086b	4341a	3.7a	16.2a
R-M+Ra-S	23.0b	2038a	6222a	4184b	2.9b	7.1b
R-Mu-S+C	14.5c	1335c	3591c	2256c	2.9b	7.1b
R-Mu-F	6.4d	908d	2204d	1296d	2.7c	7.3b
V × T						
Bautia, R-L-Sc	22.7b	1738b	5700b	3962b	3.5b	14.8b
Bautia, R-M+Ra-S	22.6b	2026a	6092ab	4067b	2.7cd	6.6c
Bautia, R-Mu-S+C	13.2d	1291d	3387d	2095c	2.9c	7.3c
Bautia, R-Mu-F	5.3f	891e	1933f	1041e	2.5d	6.9c
Soyghati, R-L-Sc	25.8a	1750b	6471a	4721a	3.8a	17.6a
Soyghati, R-M+Ra-S	23.5b	2049a	6351a	4302b	3c	7.6c
Soyghati, R-Mu-S+C	15.9c	1378c	3795c	2416c	2.9c	6.9c
Soyghati , R-Mu-F	7.4e	926e	2475c	1550d	2.9c	7.8c
Probability (P) value						
V	<.001	<.001	<.001	<.001	<.001	<.001
T	<.001	<.001	<.001	<.001	<.001	<.001
V × T	<.001	<.001	0.039	0.023	0.005	<.001

Note: R-L-Sc: Rice-Lentil-Sweet Corn; R-M+Ra-S: Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), R-Mu-S+C: Rice-Mustard (BARI mustard 14)-Sorghum intercrop with cowpea (fodder), R-Mu-F: Rice-Mustard (BARI Mustard 18)-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: Mustard (BARI 18) on the left and mustard (BARI 14) on the right side, trial plot rabi 2022-23 in Soyghati, Rajshahi; photo: Maruf Hossain Shanto

COST OF PRODUCTION

Cost of production (CP) refers to the total of both fixed and variable costs involved in producing a crop. In this study, the costs considered include operational activities such as land preparation, seeding, fertilizer application, irrigation, weeding, pest control, harvesting, and input costs for seeds, fertilizers, herbicides, and pesticides. However, land rent and capital interest were excluded from the analysis.

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

The highest CP, 2,049 USD ha^{-1} per year, was observed in the Rice-Maize+Red Amaranth-Sorghum system in Soyghati, while the lowest, 891 USD ha^{-1} per year, was recorded in the Rice-Mustard-Fallow system in Bautia. A comparison of CP across cropping systems followed this ranking: Rice-Maize+Red Amaranth-Sorghum (R-M+Ra-S) > Rice-Lentil-Sweet Corn (R-L-Sc) > Rice-Mustard-Sorghum+Cowpea (R-Mu-S+C) > Rice-Mustard-Fallow (R-Mu-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.

While the R-M+Ra-S system incurs the highest CP, it remains a highly effective cropping system 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 strengthens the viability of this system.

Although the Rice-Maize+Red Amaranth-Sorghum system has the highest cost of production, its market feasibility and resilience to drought make it a sustainable option for farmers in Rajshahi. The established demand for maize in the poultry and dairy industries, combined with sorghum's ability to grow on otherwise unused fallow land, supports the long-term adoption of this system. On the other hand, the Rice-Lentil-Sweet Corn system, while profitable, may face sustainability challenges due to the limited availability of high-quality sweet corn seeds and the crop's susceptibility to drought and hailstorms during the pre-monsoon season (kharif 1). Therefore, the R-M+Ra-S system emerges as the more practical and sustainable recommendation for farmers in the region.

Above: Mustard (BAR14) on top, mustard (BARI 18) in middle, and maize intercropped with red amaranth of rabi 2022-23 in Soyghati, Rajshahi; photo: Maruf Hossain Shanto

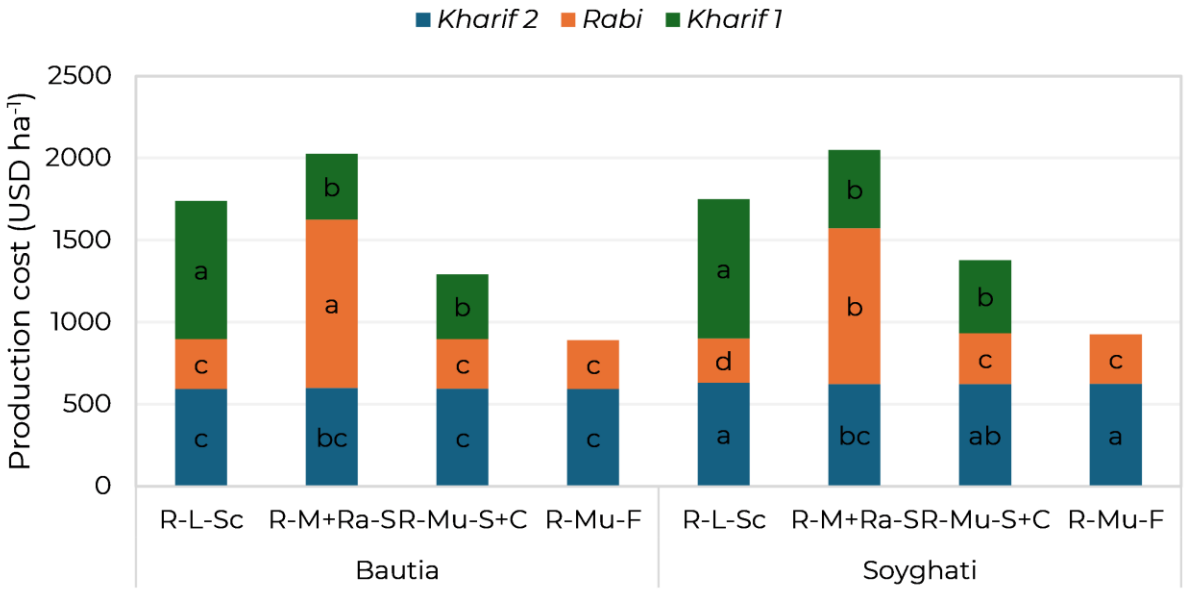

Figure 3: Production cost by component crops and cropping systems in Bautia and Soyghati villages, Rajshahi, 2022-23

Note: R-L-Sc: Rice-Lentil-Sweet corn; R-M+Ra-S: Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), R-Mu-S+C: Rice-Mustard (BARI mustard 14)-Sorghum intercrop with cowpea (fodder), R-Mu-F: Rice-Mustard (BARI mustard 18)-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

Gross Return (GR), the total income before any deductions, is calculated by subtracting production costs from sales revenue (Ruma et al., 2023). The GR of various cropping system options across the two villages, as well as the interactions between locations and cropping systems, showed significant variation (Table 2). Diversification of cropping systems during the Rabi season and intensification with sweet corn and fodder crops like sorghum and cowpea in the Kharif 1 season significantly increased income compared to the traditional Rice-Mustard-Fallow system ($p < 0.001$).

The highest GR, recorded at 6,471 USD ha^{-1} per year, was observed in the Rice-Maize intercrop with Red Amaranth-Sorghum (fodder) system in Soyghati. In contrast, the lowest GR, 1,933 USD ha^{-1} per year, was observed in the Rice-Mustard-Fallow system in Bautia. A comparative analysis of GR among the cropping systems showed a clear trend, with the systems ranked as follows: Rice-Maize+Red Amaranth-Sorghum > Rice-Lentil-Sweet Corn > Rice-Mustard-Sorghum+Cowpea > Rice-Mustard-Fallow. This pattern was consistent in both villages.

One notable exception was the lower income from rice (BINA dhan 20) in Bautia, which suffered from adverse weather conditions and an insect-pest attack, likely due to its early maturity compared to the surrounding BRRI dhan 51. Despite this, the Rice-Maize+Red Amaranth-Sorghum system achieved the highest gross income, largely due to the high yield of maize, which remains a key driver of profitability in this cropping system.

Meanwhile, the Rice-Lentil-Sweet Corn system, despite generating the second-highest gross income, faces challenges. Although sweet corn commands a high market price, it is highly susceptible to drought and hailstorms during the Kharif 1 season (March-April). Furthermore, there is limited market demand for sweet corn in the Rajshahi region. When sweet corn is harvested, local farmers are typically focused on selling seasonal fruits, such as mango, which diminishes market attention for this crop.

Given the strong market demand for maize in the poultry feed industry throughout the year and for sorghum as a fodder crop, particularly on pre-monsoon fallow land, there is considerable potential to expand the Rice-Maize+Red Amaranth-Sorghum system in the region. Additionally, sorghum is gaining popularity in the area, driven by the growing commercial silage industry. This presents an opportunity to promote and scale up these cropping systems, which are not only more profitable but also cater to an emerging market need.

In summary, the diversification and intensification of cropping systems, particularly those incorporating maize with leafy vegetables and sorghum grown on pre-monsoon fallow land, show significant promise in improving farmers' incomes in the Rajshahi district. Expanding this system could offer a sustainable pathway for enhancing agricultural productivity while meeting market demand for fodder crops.

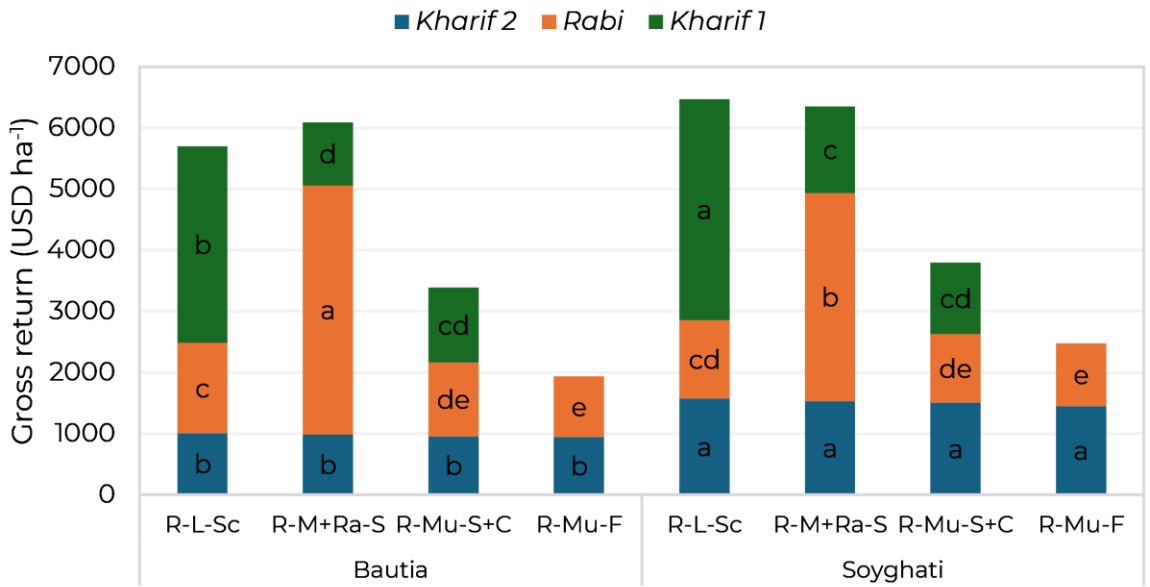

Figure 4: Gross return by component crops and cropping systems in Bautia and Soyghati villages, Rajshahi, 2022-23

Note: R-L-Sc: Rice-Lentil-Sweet corn; R-M+Ra-S: Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), R-Mu-S+C: Rice-Mustard (BARI mustard 14)-Sorghum intercrop with cowpea (fodder), R-Mu-F: Rice-Mustard (BARI mustard 18)-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

Net Return (NR) is the residual profit available to farmers after deducting production costs from the gross income (Ruma et al., 2023). The NR, assessed across various cropping systems and villages, showed significant variation, with notable interactions between the villages and the cropping systems used (Table 2 and Figure 5). Among the different cropping systems, the Rice-Lentil-Sweet Corn (R-L-Sc) system yielded the highest NR, whereas the common Rice-Mustard-Fallow (R-Mu-F) system resulted in the lowest NR.

The highest NR, 4,721 USD ha^{-1} per year, was recorded for the Rice-Lentil-Sweet Corn system in Soyghati. A comparative analysis revealed a clear ranking of NR performance across the cropping systems, with Rice-Lentil-Sweet Corn (R-L-Sc) showing the highest return, followed by Rice-Maize+Red Amaranth-Sorghum (R-M+Ra-S), Rice-Mustard-Sorghum+Cowpea (R-Mu-S+C), and finally, Rice-Mustard-Fallow (R-Mu-F). This trend was consistent across both villages, except for the notably low NR from rice (BINA dhan 20) in Bautia, which was attributed to weather constraints and an insect-pest attack, likely due to its early maturity compared to BRRI dhan 51, which was planted in surrounding fields (Table 2 and Figure 5).

The superior NR from the Rice-Lentil-Sweet Corn system can largely be attributed to the high market price of sweet corn, which was sold for 100 takas per kilogram during the Kharif 1 season. However, despite this system's high profitability, it is not necessarily the most practical option for all farmers in the region due to the susceptibility of sweet corn to drought and hailstorms, as well as the limited market demand for this crop in the Rajshahi area.

On the other hand, the Rice-Maize+Red Amaranth-Sorghum (R-M+Ra-S) system, which yielded the second-highest NR, is viewed more favorably by farmers. This preference stems from the system's drought resilience, particularly the performance of sorghum, which is grown on fallow land during the Kharif 1 season. Farmers can earn additional income by selling sorghum as fodder, which is in demand for livestock feed. As a result, the R-M+Ra-S system offers a more feasible and sustainable option for farmers in the region, providing a balance between profitability and resilience to climatic challenges.

The findings suggest that while the Rice-Lentil-Sweet Corn system offers the highest net return, its long-term feasibility may be constrained by environmental factors and limited market demand for sweet corn. In contrast, the Rice-Maize+Red Amaranth-Sorghum system, though offering a slightly lower NR, is more sustainable due to its adaptability to local climate conditions and its ability to generate additional income through fodder sales. This system could serve as a model for expanding crop diversification in the Rajshahi region, offering both economic benefits and resilience in the face of climate variability. Encouraging farmers to adopt the R-M+Ra-S system could help promote sustainable intensification while enhancing profitability, making it a more viable option for long-term agricultural development in the area.

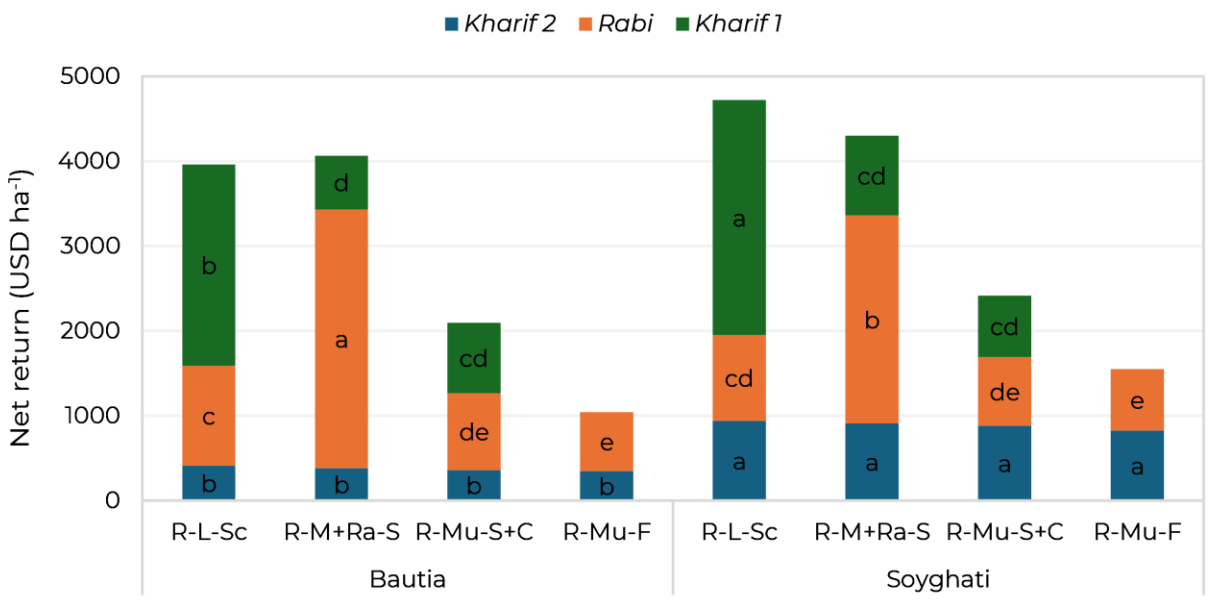

Figure 5: Net return by component crops and cropping systems in Bautia and Soyghati villages, Rajshahi, 2022-23

Note: R-L-Sc: Rice-Lentil-Sweet corn; R-M+Ra-S: Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), R-Mu-S+C: Rice-Mustard (BARI mustard 14)-Sorghum intercrop with cowpea (fodder), R-Mu-F: Rice-Mustard (BARI mustard 18)-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

Total Factor Productivity (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 to produce them. Higher TFP indicates that more output is produced per unit of input, reflecting improved efficiency and productivity in the agricultural sector (FAO, 2007).

The TFP was assessed across different cropping system options in both villages, and the interactions between locations and cropping system options varied significantly (Table 2 and Figure 6). The diversification of cropping systems in the rabi season (maize intercropped with leafy vegetables, traditional mustard, and canola-type mustard), and intensification with sweet corn and fodder crops (sorghum and cowpea) in the Kharif 1 season, significantly impacted TFP compared to the farmers' common cropping system, Rice-Mustard-Fallow. The highest TFP of 3.84 USD USD^{-1} per year was observed in the Rice-Lentil-Sweet Corn system in Soyghati, while the lowest TFP of 2.47 USD USD^{-1} per year was recorded in the Rice-Mustard-Fallow system in Bautia. A comparison of TFP among cropping system options ranked them as follows: R-L-Sc > R-M+Ra-S > R-Mu-S+C > R-Mu-F, with significant differences observed in both villages..

The highest TFP in the R-L-Sc cropping system was attributed to the high price of sweet corn (100 takas kg^{-1}) grown in the Kharif 1 season and the lower labor and fertilizer requirements for lentil crops in the rabi season. The TFP followed a similar pattern of component crops and systems in both locations in Rajshahi, except for the lower TFP in Aman rice due to the low grain yield of rice (BINA dhan 20) in Bautia. This was caused by weather constraints and insect-pest infestations, leading to early maturity compared to the surrounding BRRI dhan 51 (Table 2 and Figure 2).

Despite the highest TFP of the R-L-Sc system, it is not adaptable for farmers because sweet corn in the system is susceptible to drought and hailstorms in the pre-monsoon season. In contrast, the R-M+Ra-S system is more climate-resilient, especially since sorghum can easily grow with just one irrigation on fallow land during the pre-monsoon season. This presents an opportunity for the silage industry, enabling farmers in the area to earn additional income.

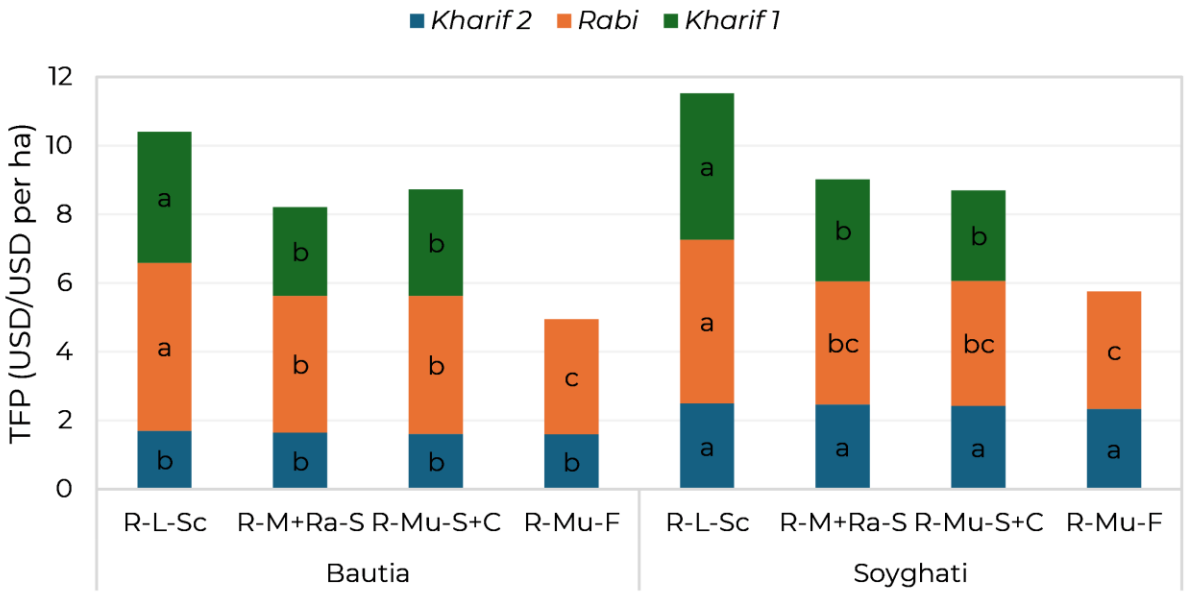

Figure 6: Total factor productivity by component crops of cropping systems in Bautia and Soyghati villages, Rajshahi, 2022-23

Note: R-L-Sc: Rice-Lentil-Sweet Corn; R-M+Ra-S: Rice-Maize intercrop with red amaranth-Sole Sorghum (fodder), R-Mu-S+C: Rice-Mustard (BARI Mustard 14)-Sorghum intercrop with cowpea (fodder), R-Mu-F: Rice-Mustard (BARI mustard 18)-Fallow**.** Means of component crops of a season in cropping system options followed by the same upper-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 output produced by agricultural workers. It measures the total value of agricultural goods produced per unit of labor cost. This provides a ratio of the value of agricultural outputs to the value of labor required to produce them. Higher LP indicates that more output is produced per unit of labor. High LP reflects improved efficiency and productivity in the agricultural sector, often due to technological advancements (FAO, 2017; Cock et al., 2022).

The highest LP of 17.57 USD USD^{-1} per year was observed in the Rice-Maize intercrop with Red Amaranth-Sweet Corn system at Soyghati, while the lowest LP of 6.92 USD USD^{-1} per year was recorded in the Rice-Mustard-Fallow system at Bautia. The LP among cropping system options was ranked as R-L-Sc > R-M+Ra-S > R-Mu-S+C > R-Mu-F in both villages (Table 2). Although the R-L-Sc system demonstrated the highest LP due to the high market price of sweet corn, market demand for sweet corn has not yet been established in this area. Moreover, sweet corn faces challenges in germination during the pre-monsoon season due to soil moisture scarcity. In contrast, the R-M+Ra-S system is more sustainable because its component crop, sorghum, is highly drought-resilient and can germinate in low-moisture soil conditions, unlike sweet corn. Additionally, there is a growing market demand for sorghum as silage in this area. Therefore, the adoption of the R-M+Ra-S system could have a positive impact on farm profitability in the region.

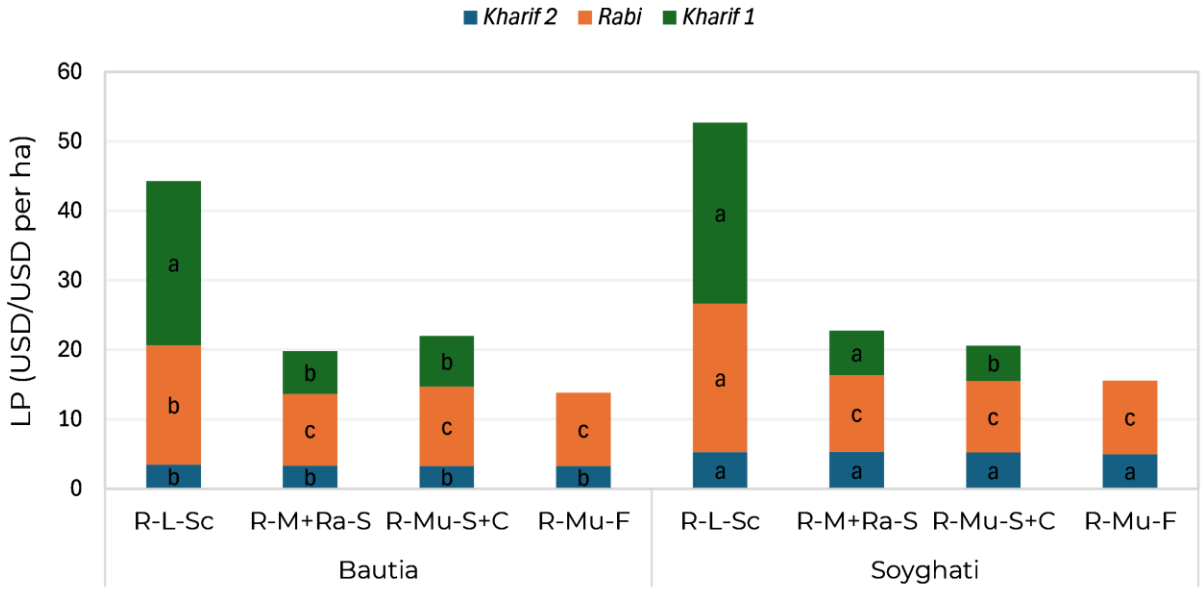

Figure 7: Labor productivity by component crops of cropping systems in Bautia and Soyghati villages, Rajshahi, 2022-23

Note: R-L-Sc: Rice-Lentil-Sweet corn; R-M+Ra-S: Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), R-Mu-S+C: Rice-Mustard (BARI mustard 14)-Sorghum intercrop with cowpea (fodder), R-Mu-F: Rice-Mustard (BARI mustard 18)-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.

CONCLUSION AND RECOMMENDATION

A comparative study of productivity and profitability was conducted through a participatory experiment involving farmers across various locations in the Rajshahi district of Bangladesh. Four different cropping systems were tested: Rice-Lentil-Sweet Corn, Rice-Maize intercropped with Red Amaranth and Sorghum as fodder, Rice-Mustard intercropped with Sorghum and Cowpea as fodder, and Rice-Mustard-Fallow. Among these, the Rice-Mustard-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, Bautia and Soyghati, within the Rajshahi district. The study measured several factors, including rice equivalent yield, cost of production, gross income, net profit, total factor productivity, and labor productivity, while analyzing the variance across these cropping systems.

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-Mustard-Fallow system. Among all the cropping systems, the Rice-Lentil-Sweet Corn system demonstrated the highest rice equivalent yield, achieving yields between 189% and 210% higher than the Rice-Mustard-Fallow system. Similarly, the net returns of the intensified and diversified systems were significantly greater, with the Rice-Lentil-Sweet Corn system delivering the highest net return among all systems.

However, despite its high economic efficiency, the Rice-Lentil-Sweet Corn system is not feasible in this region due to the lack of market demand for sweet corn. In contrast, the Rice-Maize intercropped with Red Amaranth-Sorghum system appears to be more viable, given the high demand for maize and the ability to grow sorghum on fallow land before the monsoon season. Sorghum, in particular, is in demand for silage production in dairy farming.

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

Above: Mustard field; photo: CIMMYT

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Above: Mustard Grains; Photo: CIMMYT

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Transforming Agrifood Systems in South Asia

AUTHORS

Saiful Islam, Research Coordinator, CIMMYT
Stephanie Cheesman, former Post-Doctoral Fellow Cropping Systems Agronomist, CIMMYT
Maruf Hossen Shanto, Agriculture Development Officer, CIMMYT
Md. Shakhawat Hossain, Senior Scientific Officer, OFRD, BARI
Md. Arifur Rahaman, Research Associate, CIMMYT
Khaled Hossain, Research Associate, CIMMYT
Mahesh Kumar Gathala, Senior Scientist and Cropping System Agronomist, CIMMYT
Timothy J. Krupnik, Regional Director, Sustainable Agrifood Systems Program, Asia, CIMMYT Country Representative for Bangladesh

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To learn more, please contact: ms.islam@ciar.org

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

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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.

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