INITIATIVE ON
Transforming Agrifood Systems in South Asia

CGIAR

Enhancing crop productivity, profitability and input use efficiency through efficient crop diversification in Bangladesh

Comparing diversified cropping patterns in Dinajpur, Bangladesh

Research Note 32

October 2024

ABOUT THIS NOTE

In recent times, the sustainability of rice-rice cropping systems has been threatened by yield plateaus, high input costs, declining water and labor availability, and increasing food demand. Hence, rice-based cropping systems require more attention to ensure future food security. This research note summarizes the impact of crop diversification on crop and water productivity, yield, and profitability based on data from an agronomic research platform trial conducted over one complete cropping cycle. The trial was established at the Bangladesh Wheat and Maize Research Institute (BWMRI) in Dinajpur, Bangladesh, in August 2022.

KEY STUDY FINDINGS

1. After completing the one-year cropping cycle (three seasons within one year), we observed that all diversified cropping systems treatments (T3–T9) performed better compared to the most common farmer practice treatments (T1 and T2) in terms of rice equivalent yields (REY), net profit, labor, and water use efficiency.
2. An REY increase of up to 30% was recorded, for example, by adding the leafy vegetable napa shak between two rice crops (T4 vs. T1) or by intercropping the same vegetable with maize (T5 vs. T2).
3. The maize intercropped with leafy vegetables, sorghum, and aman rice cropping pattern (T5) emerged as the best-performing cropping pattern in terms of rice equivalent yield, economic benefits, and input use efficiency.
4. Treatment T9, which replaces rice with soybean during the monsoon, demonstrated superior water use efficiency compared to other diversified cropping patterns.
5. Total crop duration and land utilization were found to be highest for treatment T5, followed by treatments T6 and T9.

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

BACKGROUND

Bangladesh is a highly populated country that is self-sufficient in rice but not in other crops. It is also one of the most vulnerable countries to climate change. Ensuring overall food security remains a significant challenge, compounded by the prevalence of malnutrition. The increasing scarcity of resources (water, labor, and energy) and rising production costs make the rice-based cropping system less sustainable and less profitable (Alam et al., 2014).Challenges in crop production include stagnating crop yields, overuse of resources, and environmental degradation affecting water, soil, and greenhouse gas (GHG) emissions. In Bangladesh, the average cropping intensity is 200%, with five out of 316 identified cropping patterns based solely on rice, accounting for 51% of the net cropping area (Nasim et al., 2018). While this helps ensure food security for the country's staple crop, it does not address malnutrition. Crop diversification represents a promising pathway toward a sustainable farming system (Wang et al., 2024). Diversifying cropping systems could potentially resolve the unsustainability of current crop productivity and water use while ensuring sustainable food security in Bangladesh. Rice, wheat, and maize are the major cereal crops, often grown in rotation with non-cereal crops such as potato, mustard, and legumes (Balasubramanian et al., 2012). Major non-rice crops in these cropping systems include wheat, potato, maize, pulses, oilseeds, and jute. The diversification of crop rotations should be a key consideration in national policymaking related to food, agriculture, water, and health (Tao et al., 2020). This agronomic research trial has multiple objectives, including the efficient use of land, water, and labor to produce higher yields and nutrients for human consumption, improving climate resilience, and increasing farmers' incomes. This research highlights an approach to examining trade-offs and interactions among these objectives for different cropping patterns, aiming to identify the best options for cereal-based cropping systems in Bangladesh.

Above: Diversified agronomic research platform trial at BWMRI, Dinajpur; photo: Washiq Faisal

OBJECTIVES

The Regional One CGIAR Initiative: Transforming Agrifood Systems in South Asia (TAFSSA) focuses on farm- and landscape-level research to promote resource conservation and ecological services. This study aims to ensure food and economic security while maintaining sustainability by diversifying and intensifying the rice-–rice system with high-value crops.

Crop diversification increases productivity, stabilizes farm income, and enhances sustainability. The study provides empirical evidence on how diversified cropping patterns can balance food production, sustainable groundwater use, and farmer profitability.

Above: Maize field in on station trial at BWMRI, Dinajpur; photo: CIMMYT

DATA AND METHODS

The experiment used a Randomized Complete Block Design (RCBD) with nine treatments and three replications. Treatments included nine cropping systems with varying levels of intensification and integration of non-rice crops (cereals, legumes, oilseeds, fiber, fodder, and leafy vegetables) during winter and spring, aimed at evaluating yield and profitability.

The design had 27 plots, each measuring 17 m × 11.5 m (195.5 m^2). 70 cm-wide bunds, lined with polythene, separated plots to prevent seepage. The research site was the Bangladesh Wheat and Maize Research Institute (BWMRI), Dinajpur (GPS: 25.742715, 88.672334).

Treatments 4 and 5 included split plots for leafy vegetables like spinach, red amaranth (*lal shak*), coriander, and napa shak. Details of all treatments are in Table 1, with additional setup information in Cheesman et al. (2022).

Popular high-yielding crop varieties were used, with recommended fertilizer doses applied. Annual soil tests were done after each cropping cycle. Agronomic data, including crop phenology, costs (input/output), and irrigation volume, were recorded.

Rice Equivalent Yield (REY) was calculated (Eq. 1) for yield comparisons. Profitability was assessed via net profit (Eq. 2), and Water Use Efficiency (WUE) via total water used (Eq. 3).

Results covered the three main cropping seasons in Bangladesh—Rabi, Kharif-1, and Kharif-2—from Nov. 2022 to Oct. 2023 and were combined for pattern comparisons.

$$REY\ (t/ha) = Y\ (t/ha) \times \frac{mktpr\ (US\$/t)}{mktpr_{rice}\ (US\$/t)} \qquad \textit{(eq. 1)}$$

$$Net\ income\ (US\$/ha) = Y(t/ha) \times mpr\ (US\$/t) - \sum prod\ cost\ (US\$/ha) \qquad \textit{(eq. 2)}$$

$$Water\ Use\ Efficency\ (WUE)\ (kg/m3) = \frac{Yield\ (Kg/ha)}{Amount\ of\ water\ applied\ (m3/ha)} \qquad \textit{(eq. 3)}$$

where: REY = rice equivalent yield; Y = yield; mktpr = market price; WUE = Water Use Efficiency; prod cost = production costs.

N.B.: production cost includes costs for seed, fertilizer, irrigation, pesticides / insecticides / herbicides used and labor for all operations; not included is land rent, which however for farmers can be substantial.

STATISTICAL ANALYSIS

Statistical analyses were performed using packages in R 4.4.1 (R Core Team,2024). The data were analyzed using a Randomized Complete Block Design with nine treatments and three replications to evaluate the effects of various treatments. All output data were compared using Tukey's HSD significant difference test from the agricolae R package at $P < 0.001$.

Table 1: Diversified agronomic research platform trial at BWMR, Dinajpur

Transforming Agrifood Systems in South Asia

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TAFSSA research platform trial at BWMRI, Dinajpur

Objectives:

Transforming Agrifood Systems in South Asia (TAFSSA), is a One CGIAR regional integrated initiative; this trial emphasizes farm- and landscape-level interdisciplinary research to identify strategies to increase farmers' profits and nutritional yields, conserve resources, and maintain or enhance ecological services, while also mitigating greenhouse gas (GHG) emissions from farms and agricultural landscapes. The pathway to impact for this work includes deployment of recommendations from research through public and private extension networks, and through policy design and reform support.

Treatment	Diversification options	Kharif-2	Rabi	Kharif-1
T1	Business as usual - 1	*Aman* rice	Fallow	*Boro* rice (BF)
T2	Business as usual - 2	*Aman* rice	Maize	Fallow
T3	Profitability & improved nutrition	*Aman* rice (BF)	Potato	Sweet corn
T4	Increased production & improved nutrition	*Aman* rice (BF)	Leafy vegetables	*Boro* rice (BF)
T5	Increased production & improved nutrition	*Aman* rice (BF)	Maize+leafy vegetables	Sorghum (fodder)
T6	Diversified production	*Aman* rice (BF)	Mustard	Groundnut
T7	Diversified production & improved nutrition	*Aman* rice (BF)	Carrot	Maize (early)
T8	Profitability & soil health	*Aman* rice (BF)	Wheat	Jute
T9	Diversified production & soil health	Soybean	Mustard	Maize

Leafy vegetables: spinach, red amaranth, coriander, napa shak; BF = biofortified

Design:	RCBD with three replications	Date of initiation:	05 December 2022

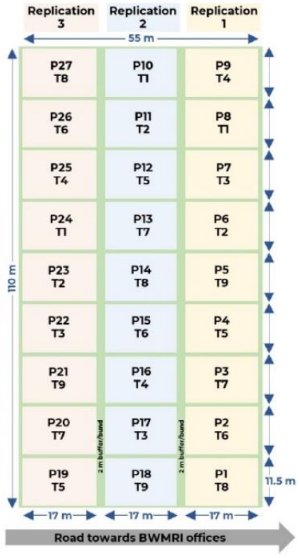


Table 2: Summary of results from the agronomic research platform trial after one complete cropping cycle

Treatment	REY (t/ha)	Production cost (US$/ha)	Net profit (US$/ha)	Labor cost (US$/ha)	Irrigation cost (US$/ha)	Water applied (m3/ha)	Water use efficiency (kg/m3)
T1	14.88 cde	2849.84 c	1436.40 d	1782.54 c	508.13 a	11588.41 a	1.28 e
T2	13.44 e	2141.72 f	1710.46 d	1057.15 h	253.64 bc	6776.20 c	1.98 de
T3	20.41 b	2789.03 d	3224.72 ab	1510.15 d	259.53 bc	6670.71 c	3.06 bc
T4	26.18 a	4792.23 a	2554.90 c	1861.61 b	515.14 a	11609.00 a	2.25 cde
T5	25.67 a	3965.31 b	3628.23 a	2036.36 a	273.54 b	7289.93 b	3.52 b
T6	14.85 cde	1866.73 h	2455.82 c	1016.51 i	225.56 c	6327.66 d	2.34 cd
T7	17.09 c	2217.40 e	2793.55 bc	1166.90 f	228.42 c	6325.94 d	2.70 bcd
T8	14.78 de	1883.51 h	2416.36 c	1144.57 g	236.83 bc	6618.57 cd	2.23 cde
T9	16.27 cd	2065.18 g	2628.19 bc	1189.81 e	54.31 d	1283.02 e	12.68 a
P-Values	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

RESULTS

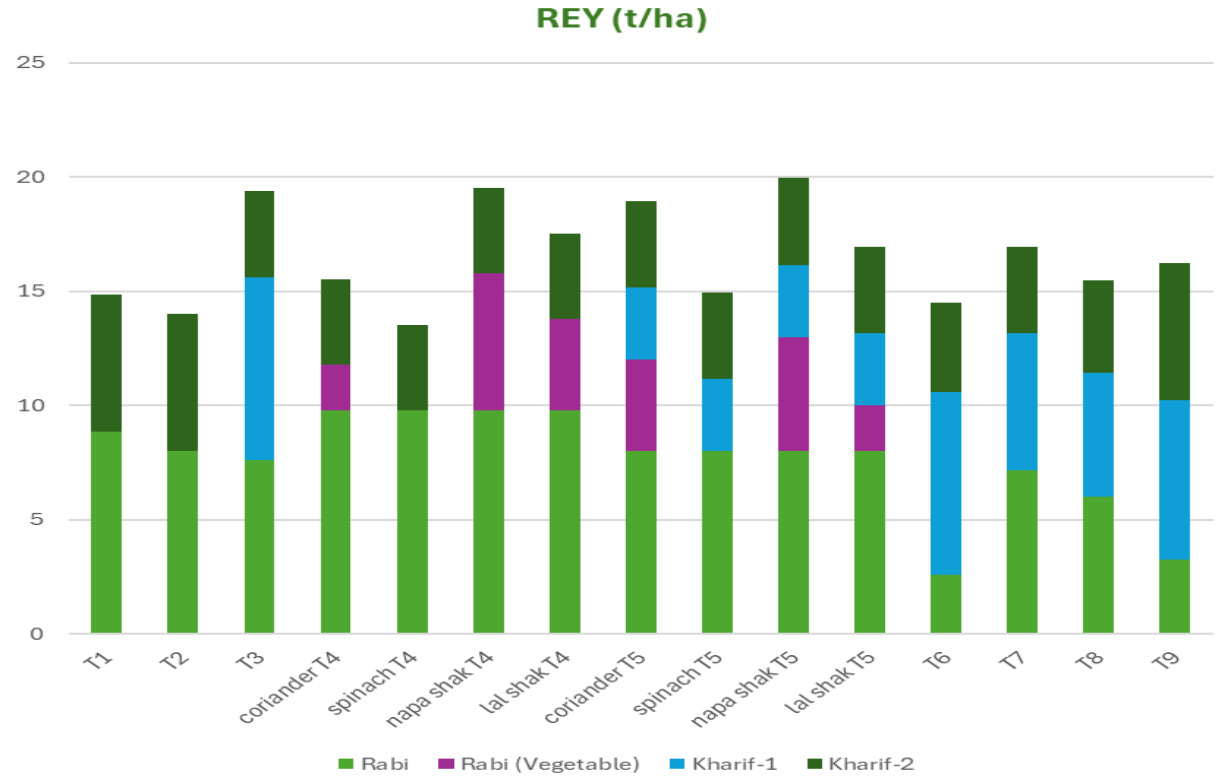
Results from the complete one-year cropping cycle showed that all diversified treatments (T3-T9) achieved higher rice equivalent yield (REY). The REY was significantly highest in both Treatment (T4) vegetables–Boro rice–Aman rice (26.18 t/ha) and Treatment (T5) maize + vegetables–sorghum–Aman rice (25.67 t/ha), attributed to the high market price of vegetables (Table 2). Maximum net profit (3628.23 USD/ha) was observed in Treatment (T5) maize + vegetables–sorghum–Aman rice due to higher production and market prices of vegetables. Treatment (T3) potato– sweetcorn–Aman rice recorded the second-highest net profit (3224.72 USD/ha) due to the high market price of sweetcorn (Figure 1). The lowest net profit was recorded from the traditional Treatment (T1) Rice–Rice system, which was 2.5 times lower than Treatment (T5) maize + vegetables–sorghum–Aman rice. During Kharif-1, growing sweetcorn (T3) or groundnut (T6) instead of maize (T7 or T9) increased REY (Figure 1). Water use was notably high whenever traditional Boro rice was grown, as seen in Treatments T1 and T4 (Table 2). Among other treatments, T5 (maize + vegetables–sorghum–Aman rice) required extra water for maize intercropped during Rabi season but resulted in higher net profit, albeit with increased labor use over the full cropping cycle (Table 2). Using leafy vegetables instead of fallow in Treatment (T4) vegetables–Boro rice–Aman rice increased profitability but also required additional labor. Treatments (T6-T9) increased profitability without requiring significant additional labor. The highest water use efficiency was recorded in Treatment (T9) mustard–maize–soybean sequence (Table 2).

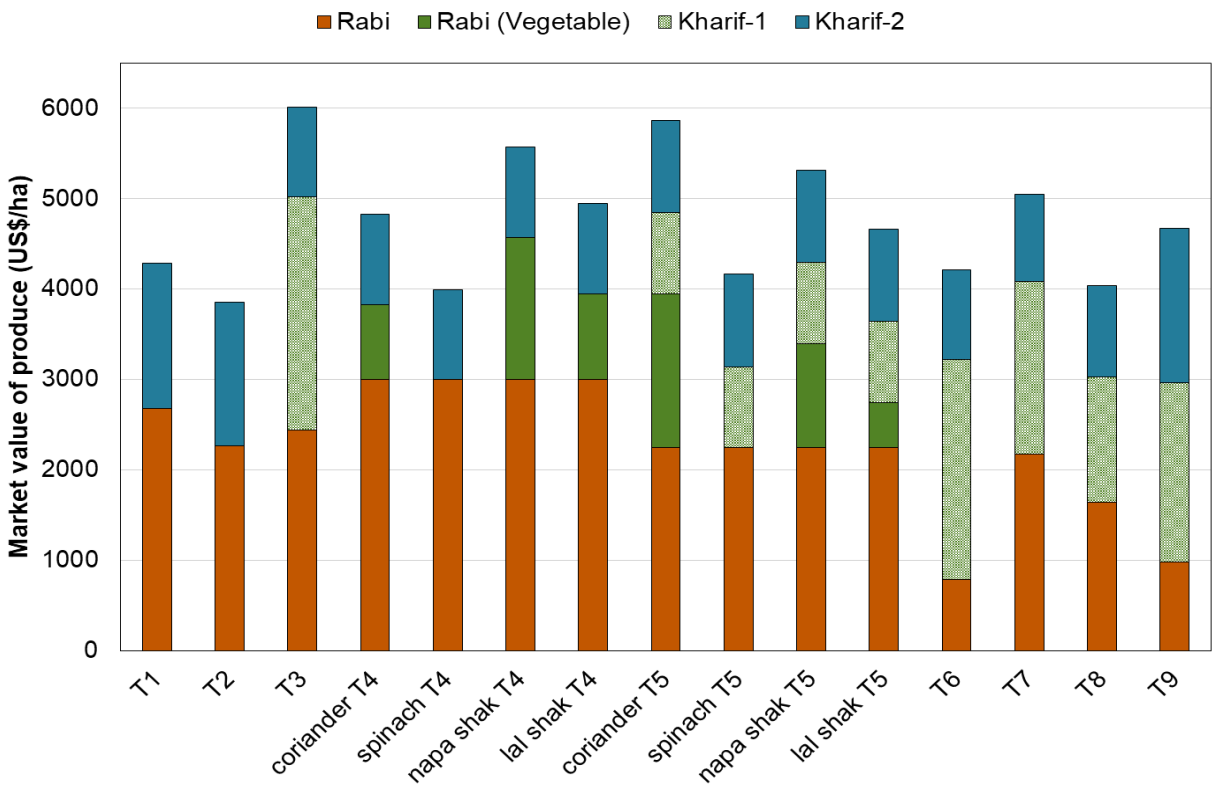
In terms of labor costs, Treatment (T5) maize + vegetables–sorghum–Aman rice required more labor than the other cropping patterns (Table 2). However, farmers' feedback highlighted the need to address local marketing challenges for these crops. The development of a robust local market system has been emphasized by farmers as essential for better profitability. Net profit was calculated using fixed local market prices. However, the prices of vegetables and other crops are highly variable, even within cropping seasons. This variability needs to be accounted for to provide more accurate profitability assessments.

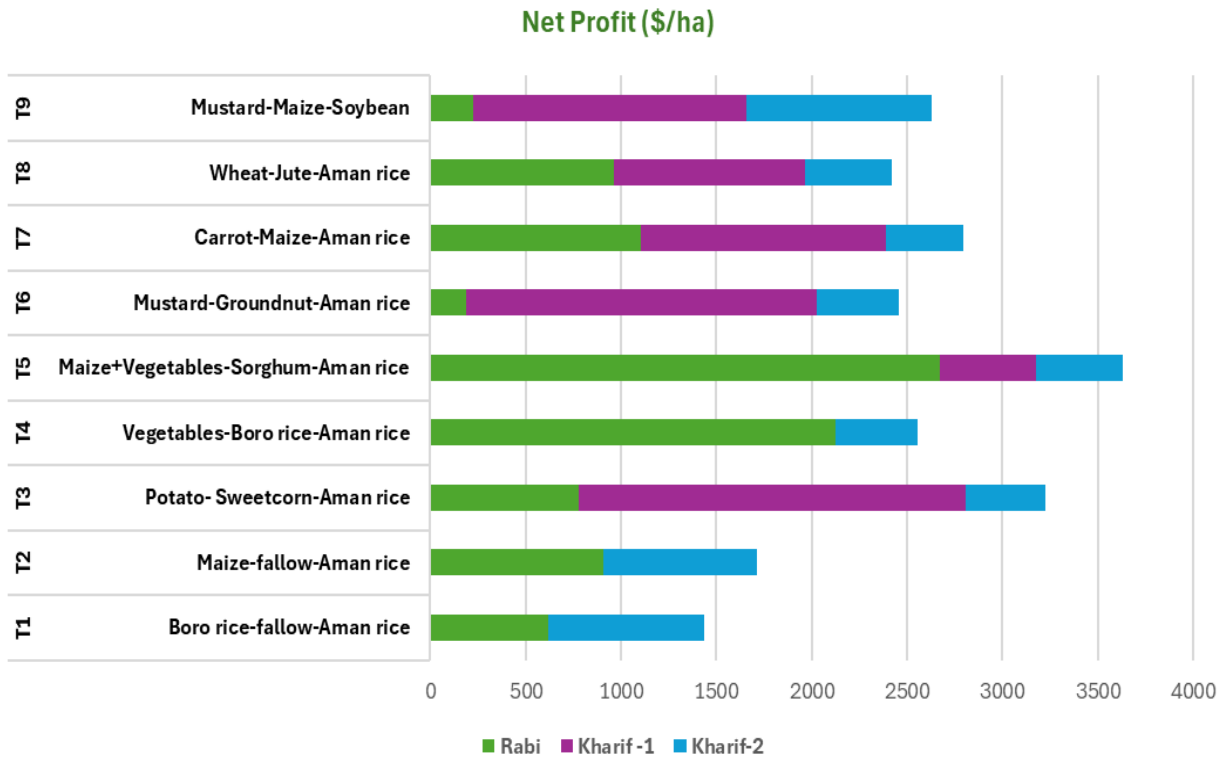
Above: Maize intercrop with vegetables (Rabi crop); photo: Washiq Faisal

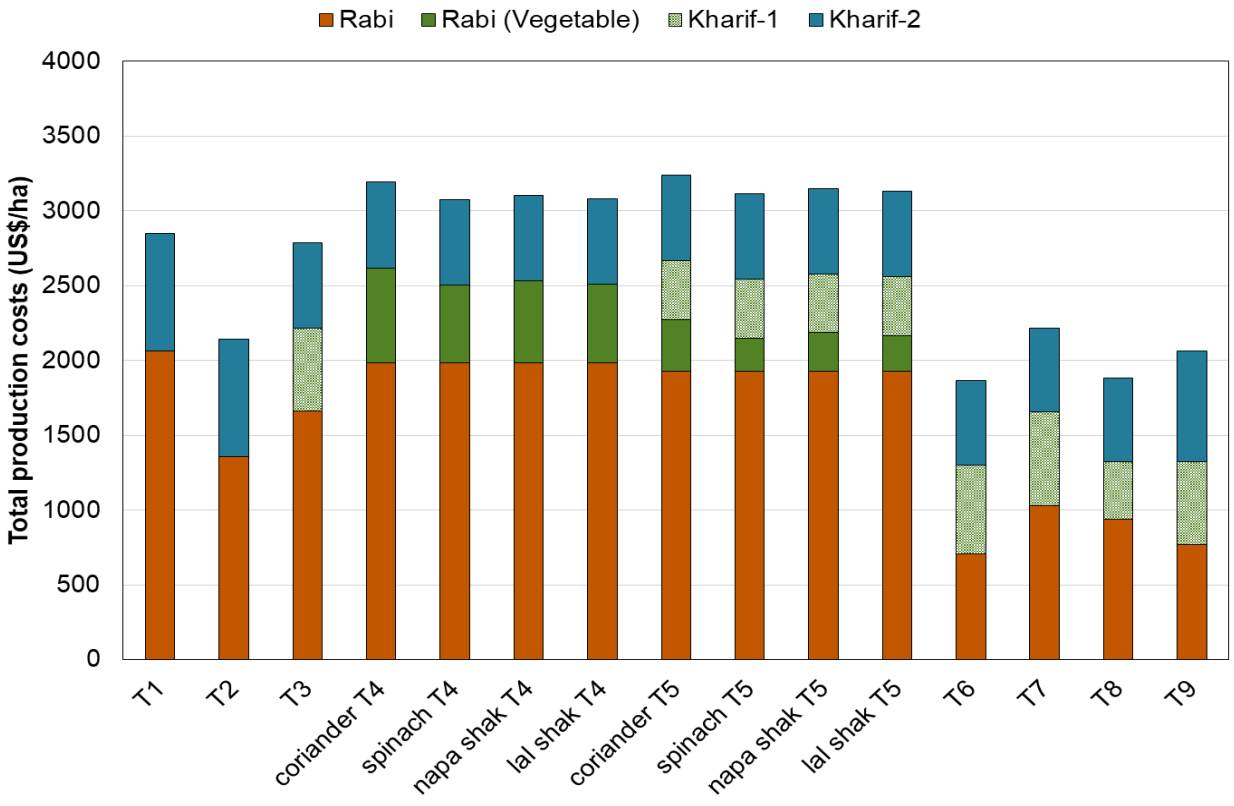
The highest land utilization (fallow: 29 days) was recorded in T5 (maize + vegetables–sorghum–Aman rice), followed by T6 (mustard–groundnut–Aman rice) and T9 (mustard–maize–soybean) with 33 fallow days. The lowest utilization (fallow: 70 days) was in T3 (potato–sweetcorn–Aman rice) (Figure 1).

Figure 1: Results from the diversified cropping pattern (rey, net profit, production cost, market value, irrigation as well as total crop duration in the field.

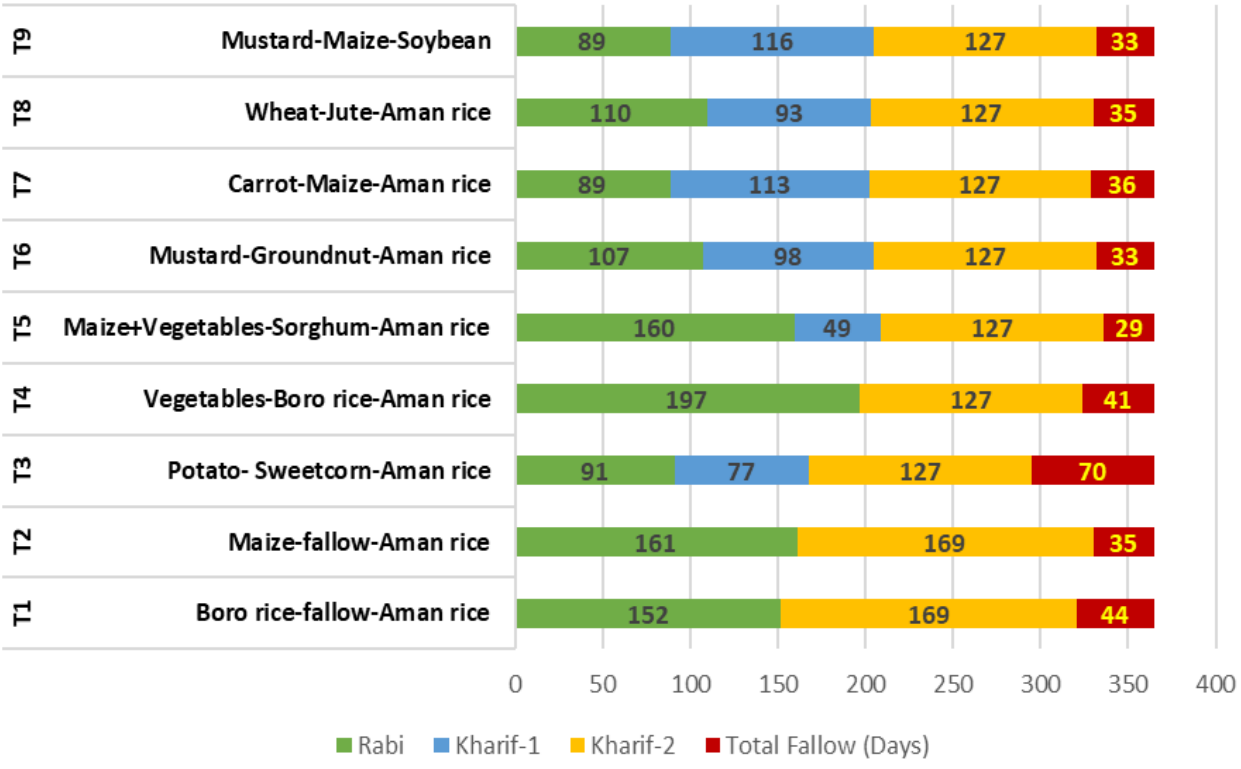


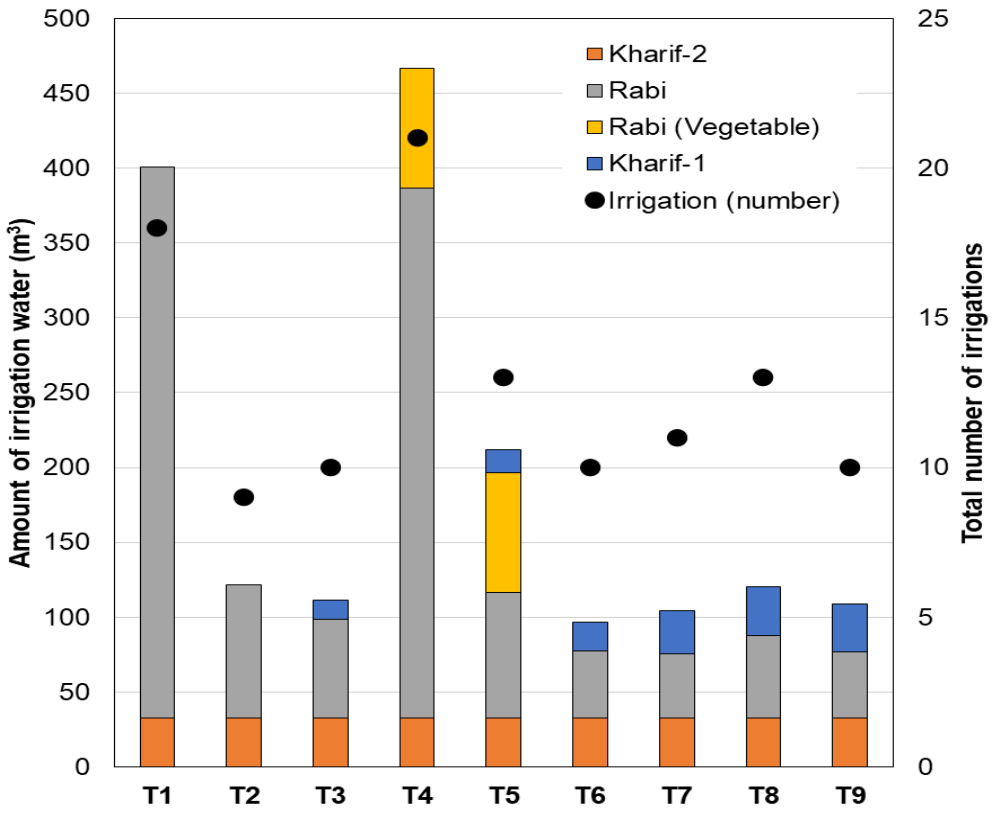



Net Profit ($/ha)
T9
Mustard-Maize-Soybean
T8
Wheat-Jute-Aman rice
T7
Carrot-Maize-Aman rice
T6
Mustard-Groundnut-Aman rice
T5
Maize+Vegetables-Sorghum-Aman rice
T4
Vegetables-Boro rice-Aman rice
T3
Potato- Sweetcorn-Aman rice
T2
Maize-fallow-Aman rice
T1
Boro rice-fallow-Aman rice
0
500
1000
1500
2000
2500
3000
3500
4000
Rabi
Kharif -1
Kharif-2


Rabi
Rabi (Vegetable)
Kharif-1
Kharif-2
Total production costs (US$/ha)
4000
3500
3000
2500
2000
1500
1000
500
0
T1
T2
T3
coriander T4
spinach T4
napa shak T4
lal shak T4
coriander T5
spinach T5
napa shak T5
lal shak T5
T6
T7
T8
T9

Crop duration (days)





CONCLUSIONS AND RECOMMENDATIONS

The findings indicate notable variations in productivity and profitability among different cropping patterns after one full cropping cycle. The research concludes that Treatment (T5) maize + vegetables–sorghum–Aman Rice cropping sequence resulted in higher rice grain equivalent yield, economic efficiency, production efficiency, and net returns. Land use efficiency was also highest in the same treatment (maize + vegetables–sorghum –Aman Rice), as this pattern utilized the land for the maximum period. In line with the economic yield, the market value of the produce was higher for the diversified cropping patterns than for the most common rice-based ones. However, the prices of vegetable crops, in particular, can fluctuate significantly within and across seasons, and this variability needs to be considered in future assessments.

Adding a leafy vegetable as an intercrop to maize or as a sole crop between two rice crops is not a significant investment in terms of additional production costs. However, doing so increases the net profit (calculated as the market value of produce minus total production costs) from approximately $1,436/ha (T1) to $2,468/ha by adding the leafy vegetable napa shak between two rice crops (T4) and from approximately $1,710/ha (T2) to $2,442/ha by intercropping the same vegetable with maize and adding a fodder crop (T5) instead of leaving the land fallow during the Kharif-1 season (Table 2).On the other hand, net income may decrease if the wrong leafy vegetable is chosen, as competition can negatively affect maize performance. Without proper establishment of the leafy vegetable, the loss cannot be compensated. Labor needs differ only slightly between T1 and T4, indicating that leafy vegetables grown as sole crops are not very labor-intensive.

Overall, vegetable-based systems are superior in nearly all aspects compared to traditional rice–rice or rice–maize systems. Therefore, it is advisable for farmers to substitute cereal-based systems with diversified crops and incorporate high-value crops into conventional cropping systems. This approach provides additional revenue sources, enhances farming resilience, promotes a diverse ecosystem for long-term farm viability, supports sustainable production, and improves resource use efficiency.

However, the conclusions remain premature, as further data from multiple cropping years is necessary. Additionally, an analysis of the environmental footprint of each cropping system is essential for recommending optimal practices in sustainable agriculture.

Above: Transplanting Boro rice in Bangladesh; photo: Washiq Faisal

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Above: Crop sowing at research platform, BWMRI, Dinajpur (Rabi crop-2023); photo: Washiq Faisal

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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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