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IMPROVEMENT OF CROPPING PATTERN BY INCORPORATING SESAME IN THE FALLOW LAND BEFORE MUSTARD– B. AMAN RICE IN CUMILLA DISTRICT

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Abstract

An on-farm study at Kesobpur, Titas, Cumilla (AEZ-19) during 2022–23 and 2023–24 evaluated an improved cropping pattern—Mustard (BARI Sarisha-18)–Sesame (BARI Til-4)–B. *Aman* rice (BRRI dhan91)—against the farmers' existing Mustard (Tori-7)–Fallow–B. Aman rice (Furchun). The improved system, tested in an RCBD with five replications, significantly ($P < 0.05$) increased yields of all component crops. Mean rice equivalent yield (REY) was 15.32 ± 0.33 t ha^{-1}, 151% higher than the existing pattern. Production efficiency, land-use efficiency, harvest index, gross return (Tk. 329,757 ± 7,000 ha^{-1}), and gross margin (Tk. 209,860 ± 6,250 ha^{-1}) were also significantly higher. The marginal benefit–cost ratio (4.39) confirmed economic superiority. The Mustard–Sesame–B. *Aman* rice pattern is statistically and agronomically superior and recommended for wider adoption in AEZ-19 and similar agro-ecological zones of Bangladesh.

Keywords: Mustard–Sesame–B.*Aman* rice, Cropping pattern, Rice equivalent yield, Production Efficiency, Land-use efficiency and Profitability.

Introduction

Bangladesh agriculture faces the pressing challenge of ensuring food and income security for a rapidly growing population amid severe constraints on the horizontal expansion of arable land. Consequently, future increases in agricultural production must rely largely on vertical intensification including enhanced yield per unit area, increased cropping intensity, and efficient utilization of fallow periods by improving crop sequencing and varietal replacement (FAO, 2021; BBS, 2022). In this context, optimization of existing cropping patterns is a key strategy for improving land-use efficiency and farm profitability. A cropping pattern represents the annual sequence and temporal arrangement of crops within a given land area, shaped by climatic conditions, soil properties, rainfall, irrigation facilities, crop varieties, input availability, market access, and technological advancement (Hossain *et al*., 2018). Previous studies have shown that rational modification of cropping patterns, particularly by including short-duration crops in fallow periods,

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can substantially enhance system productivity and farmers' income without exerting additional pressure on limited land resources (Islam *et a*l., 2020). Cropping system intensification and diversification are recognized globally as key strategies for enhancing productivity and sustainability in smallholder agriculture (Cassman, 1999; Tilman *et al*., 2002.

Rice-based cropping systems dominate Bangladeshi agriculture. For irrigated ecosystems, the Bangladesh Rice Research Institute (BRRI) recommended the transplanted *Aman*–mustard–Boro cropping pattern using short-duration mustard varieties such as Tori-7 (70-75 days) during the transition between T. *Aman* and Boro rice (Khan *et al*., 2004). However, traditional local mustard variety produce low yield and return limited economic value due to poor genetic potential and susceptibility to pests and diseases, thereby constraining overall system productivity (Ali *et al*., 2019).

To overcome these limitations, the Bangladesh Agricultural Research Institute (BARI) has developed high-yielding yellow-seeded mustard varieties, including BARI Sarisha-18, which possess higher yield potential and improved oil quality compared to Tori-7 (BARI, 2021). These varieties, with a growth duration of about 92-94 days, offer opportunities for diversifying rice-based cropping systems. In addition, sesame (*Sesamum indicum* L.), a short-duration and drought-tolerant oilseed crop, has proven suitable for cultivation during fallow periods, contributing to increased cropping intensity, income diversification, and reduced production risk (Rahman *et al*., 2020).

In Cumilla district, particularly in the Kasobpur area of Titas Upazila, the mustard–fallow–B. *Aman* rice cropping pattern is widely practiced, covering about 10.76% of the cultivated land (DAE, 2020). Despite its dominance, this system remains characterized by inefficient use of the fallow period and low land productivity. Studies elsewhere in Bangladesh have demonstrated that replacing fallow periods with oilseed crops such as sesame can significantly enhance system productivity and profitability, while mustard residues contribute to improved soil fertility and performance of succeeding rice crops (Singh and Ghosh, 1999; Islam *et al*., 2017. However, location-specific on-farm evidence on the agronomic and economic feasibility of replacing the existing mustard–fallow–B. *Aman* system with an intensified mustard–sesame–B. *Aman* rice cropping pattern using high-yielding varieties remains limited in the Cumilla district. Therefore, the present study was conducted to evaluate the productivity and profitability of an improved mustard–sesame–B. *Aman* rice cropping pattern through varietal replacement and crop inclusion under farmers' field conditions to provide practical insights for the sustainable intensification of rice-based cropping systems in AEZ-19 and similar agro-ecological regions of Bangladesh.

Materials and Methods

Experimental site and agro-ecological conditions

The on-farm trial was conducted during two consecutive cropping cycles (2022–23 and 2023–24) to increase crop productivity through varietal replacement of mustard and transplanted *Aman* (B. *Aman*) rice in the existing cropping system Mustard (Tori-7)–Fallow–B. *Aman* (*Furchun*). The experiment was carried out at farmers' fields in Cumilla district, which falls under the Old Meghna Floodplain Agro-Ecological Zone (AEZ-19). The experimental area is located between 24°16′ N latitude and 90°89′ E longitude. The land was classified as lowland with good drainage. The soil was sandy loam in texture, belonging predominantly to Dark Grey Floodplain soils. Soil reaction ranged from slightly acidic to nearly neutral (pH 5.3–5.4). Organic matter content was low, and the overall fertility status of the soil was poor, with low levels of nitrogen (N), phosphorus (P), potassium (K), and Boron (B). Topsoil was acidic to neutral, while subsoil was neutral in reaction.

The climate of the study area is subtropical monsoon. The majority of annual rainfall occurred from April to September, while the crops grown during the *Rabi* and pre-*kharif* seasons received about 140.5 mm of rainfall from October to March. During the study period, the monthly mean maximum and minimum temperatures were 31.9°C and 19.3°C, respectively, with an annual rainfall of approximately 2024 mm and a mean relative humidity of 82.7%. The highest temperature (33.9°C) was recorded in August, whereas the lowest (10.1°C) occurred in December. Relative humidity ranged from 75.2% in March to 84.5% in August **(**Bangladesh Meteorological Department, 2024).

Experimental design and treatments

The experiment was laid out in a randomized complete block design (RCBD) with five dispersed replications. Two cropping patterns were evaluated as treatment variables: (i) Improved cropping pattern**:** Mustard (BARI Sarisha-18) – Sesame – B. *Aman* rice (BRRI Dhan91), and (ii) Farmers' existing pattern: Mustard (Tori-7) – Fallow – B. *Aman* rice (*Furchun*). Each unit plot measured 400 m^2.

Crop management practices

Mustard: Mustard was grown during the *rabi* season as the first crop in the sequence. In the improved pattern, BARI Sarisha-18 was sown using the broadcast method at a seed rate of 7 kg ha^{-1}**.** Sowing was done during 4-5 November 2022 and 10-12 November 2023, while harvesting took place during 6–8 March 2023 and 11–25 February 2024, respectively. Fertilizers were applied following the Fertilizer Recommendation Guide (FRG, 2018)**.** Intercultural operations, including weeding and pest management, were performed as required.

Sesame: Sesame was cultivated as the second crop in the improved cropping sequence. Seeds were broadcast at a rate of 7-8 kg ha^{-1}**.** The crop was sown during 15-18 March 2023 and 10-25 March 2024**,** and harvested during 15-18 June 2023 and 5-10 June 2024, respectively. Recommended fertilizer doses and intercultural operations were followed to ensure optimum crop growth.

B. Aman rice: B. Aman rice was the third crop in both cropping patterns. In the improved pattern, BRRI Dhan91 was used, while farmers' local variety *Furchun* was maintained in the existing pattern. Seeds were broadcast at a rate of 30 kg ha^{-1} during 20–25 June in both years. Fertilizer application and crop management practices were followed according to BRRI (2013) guidelines. Rice was harvested on 20 November 2023 and 8 November 2024 in the respective seasons. Plants were harvested, leaving approximately 15 cm stubble height, and the remaining residues were incorporated into the soil.

Crop establishment and calendar: Mustard was sown during late October to early November (Rabi season) and harvested in January. Sesame was sown immediately after mustard harvest in late January to early February and harvested in April. B. Aman rice was established in July under rainfed conditions using broadcast seeding and harvested in November. These planting windows correspond to the prevailing cropping calendar of AEZ-19 in Cumilla.

Data collection and analysis: Agronomic performance of the cropping patterns was evaluated using parameters such as field duration, rice equivalent yield (REY), production efficiency, and land utilization index (LUI). Standard procedures were followed for calculating these indices to compare the productivity and efficiency of the improved and existing cropping systems.

Rice Equivalent Yield (REY): For comparison between crop sequences, the yield of every crop was converted into rice equivalent yield on the basis of the prevailing market price of the individual crop (Verma and Modgal, 1983). REY was calculated to compare productivity of different crops on a common basis using prevailing market prices:

REY (t ha^{-1}) = Σ (Yield of crop × Price of crop) / Price of rice

Production Efficiency: Production efficiency value in terms of kgha^{-1}day^{-1} was calculated the total main product in a cropping pattern divided by the total duration of crops in that pattern (Tomar and Tiwari, 1990). Production efficiency was computed as:

PE (kg ha^{-1} day^{-1}) = REY / Twhere T is the total duration of the cropping system (days).

Land utilization index (LUI): It was worked out by taking the total duration of crops in an individual cropping pattern divided by 365 days (Rahman *et al.,* 1989). It was calculated by the following formula-

UE (%) = (Σ d_i / 365) × 100

where d_i is the duration (days) of the i-th crop

Harvest Index (HI) is a measure of a crop's efficiency in converting total biological yield

(biomass) into economic yield (the usable harvested portion such as grain, seed, or tuber). It indicates how effectively a plant partitions dry matter to the harvested product. It was calculated by the following formula:

HI = Economic yield / Biological yield or expressed as percentage:

HI (%) = (Economic yield / Biological yield) × 100

Profitability Analysis

Economic performance was assessed using gross return, gross margin, and marginal benefit–cost ratio (MBCR). Marginal Benefit–Cost Ratio (MBCR) is an economic indicator used to evaluate the additional return obtained from an improved technology or treatment compared with an existing practice, relative to the additional cost incurred. It shows how much extra benefit is gained for each additional unit of cost invested. The Marginal of prevalent pattern (F) and any potential replacement (E), which was computed as (CIMMYT, 1988).

MBCR = (Gross $return_1$ − Gross $return_0$) / ($Cost_1$ − $Cost_0$) Where, Gross $return_1$ = Gross return from improved technology/patter, Gross $return_0$ = Gross return from existing (control) practic, $Cost_1$ = Cost of improved technology/patter and $Cost_0$ = Cost of existing practice

Statistical Analysis

Data were analyzed using analysis of variance (ANOVA) appropriate for RCBD. Year effects were tested, and data were pooled over years after confirming homogeneity of variance. Treatment means were compared using the least significant difference (LSD) test at the 5% level of probability. Standard errors were calculated to indicate variability among replications. The experiment was laid out in a randomized complete block design (RCBD) with five replications and two cropping patterns over two years. The data were subjected to analysis of variance (ANOVA) using the following model:

Yijk=μ+Ti+Yj+(TY)ij+Rk(Yj)+εijk

Where, Yijk = observed response, μ = overall mean, Ti = treatment effect, Yj = year effect, (TY)ij = treatment × year interaction, Rk(Yj) = replication effect within year, εijk = error term.

Homogeneity of variance across years was tested; non-significant treatment × year interactions allowed pooling of data over years. Mean comparisons were performed using least significant difference (LSD, 0.05) and standard errors (SE) were reported. Significant differences are denoted by different letters in tables ($P \leq 0.05$).

Results and Discussion

Crop management and field duration

Crop management practices, including sowing/transplanting dates, harvesting time, fertilizer application, intercultural operations, and plant protection measures for both the improved and farmers' existing cropping patterns, are presented in **Table 1**. Variation in crop duration among the component crops was primarily influenced by varietal characteristics and cropping sequence.

Under the improved cropping pattern**-** Mustard (*BARI Sarisha-18*)–Sesame (*BARI Til-4*)–B. Aman rice (*BRRI dhan91*)- the mean field duration of mustard ranged from 90 to 95 days, while sesame occupied the field for 85 to 90 days. The field duration of B. Aman rice varied from 139 to 141 days. In contrast, under the farmers' existing cropping pattern-Mustard (*Tori-7*)-Fallow–B. Aman rice (local variety *Furchun*)- the field duration of mustard was considerably shorter **(**60–68 days), whereas B. Aman rice required a longer duration (144–147 days).

As a result, the **total field duration** of the improved cropping pattern was markedly higher (**319–328 days**) compared with the existing pattern (**210-215 days**), reflecting the successful utilization of the fallow period through inclusion of sesame. Similar increases in total cropping duration and cropping intensity through the incorporation of short-duration oilseed crops have been reported by Sultana *et al*. (2021).

The longer duration of B. *Aman* rice in the existing cropping pattern was attributed to the use of a long-duration local variety (*Furchun*), whereas the improved pattern employed BRRI dhan91, which, despite being a high-yielding variety, matured slightly earlier **(**139–141 days). Early harvesting of BRRI Dhan91 during 8–20 November in both study years facilitated the timely sowing of mustard within the optimum planting window. Timely establishment of *Rabi* crops following *Aman* rice harvest is critical for achieving higher yields and better system productivity (Mondal *et al*., 2014; Rahman *et al*., 2020).

The turnaround time, the interval between harvest of one crop and sowing of the next, was substantially reduced in the improved cropping pattern **(**37-47 days**)** compared with the existing pattern **(**150–155 days). Reduction in turnaround time is a key indicator of improved land-use efficiency and has been identified as a major contributor to enhanced cropping intensity and profitability in rice-based systems (Hossain *et al*., 2018;

Grain/seed and by-product yield

Grain/seed and by-product yield of the component crops under the improved and farmers' existing cropping patterns are presented in Table 2. Yield performance varied markedly between cropping patterns and years, largely due to varietal replacement and improved crop management practices.

Under the improved cropping pattern**,** seed yield of mustard (*BARI Sarisha-18*) was 1.62 and 1.88 t ha^{-1} during the first and second years, respectively, with corresponding stover yields of 1.50 and 1.32 t ha^{-1}. The mean seed yield of *BARI Sarisha-18* **(**1.75 t ha^{-1}**) was** more than 84% higher than that of the local variety *Tori-7* grown in the farmers' existing pattern. The higher yield of *BARI Sarisha-18* may be attributed to its superior genetic potential and better response to recommended management practices, as also reported by Nazrul *et al*. (2013)

Sesame grown in the improved cropping pattern produced grain yields of 1.34 t ha^{-1} in the first year and 1.27 t ha^{-1} in the second year, with a mean yield of 1.31 t ha^{-1}. The corresponding mean stover yield was 2.31 t ha^{-1}. These yields are comparable with earlier findings for *BARI Til-4*, a short-duration and high-yielding sesame variety well suited for inclusion between mustard and B. *Aman* rice (Mondal *et al*., 2015).

Grain yield of B. *Aman* rice (*BRRI dhan91*) under the improved pattern was 3.25 and 3.55 t ha^{-1} in the first and second years, respectively. The mean grain yield (3.40 t ha^{-1}) and straw yield (3.44 t ha^{-1}) were 30% and 57% higher, respectively, than those obtained from the farmers' existing pattern, where the local variety *Furchun* was used. The yield advantage of *BRRI Dhan91* can be attributed to varietal superiority and the application of improved production technologies, which have been shown to significantly enhance rice yield in the *Aman* season (Nazrul *et al*., 2013).

In contrast, lower yields of both grain and by-products under the farmers' existing pattern were mainly due to the use of low-yielding local varieties, imbalanced fertilizer application, and suboptimal crop management practices. Overall, all component crops under the Mustard–Sesame–B. *Aman* rice sequence produced consistently higher grain/seed and by-product yields in both years compared with the farmers' existing cropping pattern. Similar yield improvements through varietal replacement and improved management in diversified rice-based systems have also been reported by Nazrul *et al*. (2013).

Field duration

The field duration of a cropping pattern is primarily governed by the growth duration of its component crops. In the farmers' existing cropping pattern (Mustard–Fallow–B. *Aman*), mustard variety *Tori-7* and local B. *Aman* variety *Furchun* were used. In contrast, the improved cropping pattern consisted of mustard (*BARI Sarisha-18*), sesame (*BARI Til-4*), and B. *Aman* rice (*BRRI Dhan91*).

BARI Sarisha-18 required approximately 26–27 days longer to reach maturity than *Tori-7*, whereas *BRRI Dhan91* matured in nearly the same duration as *Furchun*. The additional time required for mustard in the improved pattern was effectively compensated by the inclusion of sesame and better synchronization of crop sequences. As a result, production efficiency was higher in the improved cropping pattern than in the farmers' existing pattern (Table 1). Similar observations on improved production efficiency through crop diversification and varietal substitution in rice-based systems have been reported by Mondal *et al*. (2014).

Crop Yields and Field Duration

Grain/seed yields of mustard, sesame, and B. Aman rice were significantly higher ($P \leq 0.05$**)** in the improved cropping pattern than the farmers' existing system (Table 2). Mustard yield increased by 84% and B. Aman rice by 30%, while sesame yielded 1.31 t ha^{-1}. The improved system utilized the previously fallow period, increasing total cropping duration and reducing turnaround time.

Rice equivalent yield (REY): The overall productivity of the cropping systems was assessed using rice equivalent yield (REY), which integrates the yield performance of all component crops into a single comparable unit based on prevailing market prices. Table 3 showed that the improved cropping pattern recorded a substantially higher mean REY (15.32 tha^{-1}) than the farmers' existing cropping pattern. The improved pattern produced approximately 151% higher REY than the existing system, mainly due to the inclusion of sesame as an additional crop, adoption of high-yielding varieties of mustard and B. *Aman* rice, and improved crop management practices. In contrast, the farmers' pattern resulted in lower REY because of prolonged fallow periods, use of low-yielding local varieties (*Tori-7* and *Furchun*), and traditional management practices. Mean REY of the improved system was 15.32 ± 0.33 t ha^{-1}, significantly higher than the existing pattern (6.10 t ha^{-1}, $P \leq 0.05$) (Table 3). Inclusion of sesame and high-yielding varieties contributed to this increase. Similar improvements in REY following cropping system intensification and oilseed inclusion in rice-based systems have been reported by Khatun *et al*. (2016) and Nazrul *et al*. (2017).

Table 1. Agronomic parameters of improved pattern and farmers' existing pattern at MLT site Chandina under Titas, Cumilla, during 2022-23 and 2023-24

Parameters	Year	Improved Pattern (IP)			Farmers' Practice (FP)		
Crop	2022-23	Mustard	Sesame	B.*Aman*	Mustard	Fallow	B.*Aman*
	2023-24	Mustard	Sesame	B.*Aman*	Mustard	Fallow	B.*Aman*
Variety	2022-23	BARI Sarisha-18	BARI Til-4	BRRI dhan91	Tori-7	--	Farchun
	2023-24	BARI Sarisha-18	BARI Til-4	BRRI dhan91	Tori-7	-	Farchun
Sowing/ planting time	2022-23	4-5 Dec	15-18 March	25 June	10 Nov	-	15 June
	2023-24	07-12 Nov.	08-16Feb.	21-25 Jul.	25 Nov.	-	26 June
Spacing (cm)	2022-23	Broadcast	Broadcast	Broadcast	Broadcast	-	Broadcast
	2023-24	Broadcast	Broadcast	Broadcast	Broadcast	-	Broadcast
Fert. dose (N-P-K-S-Zn-B kg ha^{-1})	2022-23	115-34-42.5-27.3-1.8-1.7	57.6-30-25-20-1.8-1.7	89.4-12-52-12.4-5.4-2.04	56.9-39.6-62.5-		56.9-16.5-16.5
	2023-24	115-34-42.5-27.3-1.8-1.7	57.6-30-25-20-1.8-1.7	89.4-12-52-12.4-5.4-2.04	56.9-39.6-62.5-		56.9-16.5-16.5
Harvesting time	2022-23	06-08 March	15-18 Jun	20 Nov.	15 Jan.	-	6 Nov.
	2023-24	11-25 Feb.	05-10 Jun	08 Nov.	31 Jan	-	20 Nov.
Field duration (days)	2022-23	92	90	146	66	-	144
	2023-24	95	85	139	68	-	147
TAT (days)	2022-23	15	10	12	4	-	151
	2023-24	7	25	14	5	-	145

Note: IP= Improved Pattern and FP=Farmers' Pattern.

Table 2. Seed/grain yield and by-product of Mustard-Sesame-B.*Aman* rice cropping patterns under improved and existing patterns at Kesobpur, Titas in Cumilla during 2022-23 and 2023-24

Year	Pattern	Grain/Seed yield (t\ha)			By-product yield (t\ha)		
		Mustard	Sesame	B.*Aman*	Mustard	Sesame	B.*Aman*
2022-23	IP	1.620	1.34	3.25	1.50	2.16	2.53
	FP	0.998	Fallow	2.50	1.45	Fallow	3.50
2023-24	IP	1.880	1.27	3.55	1.32	2.45	2.58
	FP	0.902	Fallow	2.25	1.30	Fallow	3.44
Mean	IP	1.750	1.31	3.40	1.41	2.31	2.52
	FP	0.950	Fallow	2.38	1.43	Fallow	3.47
LSD (0.05)		0.08	0.05	0.10	-	-	-
SE		0.04	-	0.05	-	-	-

Table 3. REY, production efficiency, land utilization index, and harvest index of improved pattern and existing patterns at Kesobpur, Titas in Cumilla during 2022-23 and 2023-24

Year	Pattern	REY (tha-[1])	Production efficiency	Land utilization index (%)	Harvest index (%)
2022-2023	IP	13.638	18.93	89.5	50.0
	FP	6.09	16.62	61.5	41.41
2023-2024	IP	16.99	21.00	89.9	51.34
	FP	6.1	15.49	58.6	39.94
Mean	IP	15.32	19.97	89.6	50.67
	FP	6.095	16.06	60.6	40.68
LSD (0.05)		0.65	1.20	2.1	1.5
SE		0.33	0.60	1.05	0.75

Table 4. Cost and return analysis of improved cropping pattern and existing cropping pattern at Kesobpur, Titas in Cumilla during 2022-23 and 2023-24

Year	Pattern	Gross returns (Tkha-1)	Total variable cost (Tkha-1)	Gross margin (Tkha-1)	MBCR
2022-2023	IP	340950	128890	212060	4.27
	FP	152320	84722	67598	
2023-2024	IP	318563	110903	207660	4.51
	FP	114375	65640	48735	
Mean	IP	329757	119897	209860	4.39
	FP	133347	75181	58166	
LSD (0.05)		14000	-	12500	-
SE		7000	-	6250	

Note: Different letters indicate significant differences at $P < 0.05$.

Production efficiency: Production efficiency, expressed as kgha^{-1} day^{-1}, varied significantly between the two cropping patterns (Table 3). The mean production efficiency of the improved cropping pattern was 19.97 kgha^{-1}day^{-1}, which was about 24% higher than that of the farmers' existing pattern. In the improved system, production efficiency ranged from 18.93 to 21.00 kgha^{-1}day^{-1} over the two study years, whereas the corresponding values for the farmers' pattern ranged from 15.49 to 16.62 kgha^{-1}day^{-1}. The higher production efficiency in the improved pattern was attributed to greater total system yield, efficient utilization of growing days, and superior performance of improved varieties. Similar findings have been documented by Nazrul *et al.* (2013), who reported higher production efficiency in diversified rice-based cropping systems with short-duration oilseed crops. Lower production efficiency in the farmers' pattern resulted from longer crop duration combined with lower yield output, leading to reduced productivity per unit time.

Land-use efficiency: Land-use efficiency indicates the proportion of the year during which land remains occupied by crops. The results revealed that the improved cropping pattern utilized land for 89.6% of the year, whereas the farmers' existing pattern used land for only about 60% (Table 3). The significantly higher land-use efficiency in the improved pattern was primarily due to the replacement of fallow periods with sesame cultivation, thereby minimizing idle land time. Similar increases in land-use efficiency through reduction of fallow periods and inclusion of short-duration crops have been reported by Islam *et al.* (2017) and Sultana *et al*. (2021).

Harvest index: The system-level harvest index was higher under the improved cropping pattern (50.67%) compared with the farmers' existing pattern. The higher harvest index reflects a greater proportion of economic yield relative to total biological yield, resulting from varietal replacement and improved crop management. The inclusion of sesame and the use of high-yielding mustard (*BARI Sarisha-18)* and B. *Aman* rice (*BRRI dhan91*) varieties contributed to higher grain and seed yields without a disproportionate increase in biomass. Similar improvements in harvest index through varietal substitution have been reported in diversified cropping systems (Nazrul *et al.,* 2013; Mondal *et al*., 2014).

Production efficiency in the improved pattern (19.97 ± 0.60 kg ha^{-1} day^{-1}) was significantly higher than the existing pattern (16.06 ± 0.60). Land-use efficiency increased from 60.6% to 89.6% and harvest index from 40.68% to 50.67% (all $P \leq 0.05$, Table 3).

Profitability analysis: Profitability analysis based on prevailing market prices indicated a clear economic advantage of the improved cropping pattern over the farmers' existing system (Table 4). The mean gross return from the improved pattern was Tk. 329,757 ha^{-1}, compared with Tk. 133,347 ha^{-1} from the farmers' pattern, representing a 147% increase. The mean total variable cost was higher in the improved cropping pattern (Tk. 119,897 ha^{-1}) than in the farmers' pattern (Tk. 75,181 ha^{-1}), mainly due to the additional cost of sesame cultivation and improved inputs. However, the gross margin of the improved pattern was substantially higher, being approximately 2.6 times greater than that of the farmers' existing system. The marginal benefit–cost ratio (MBCR) of 4.39 further confirmed the economic superiority and financial feasibility of the improved cropping pattern. Gross return, gross margin, and MBCR were significantly higher in the improved system (Table 4). Mean gross return increased by 147% and gross margin by 2.6 times relative to the farmers' pattern, confirming economic superiority ($P \leq 0.05$. Similar profitability gains from diversified and intensified rice-based systems have been reported by Khatun *et al*. (2016) and Rahman *et al*. (2020).

Study limitation and interpretation

A limitation of the present study is that the improved pattern differed from the farmers' practice in multiple components simultaneously, including varietal replacement (BARI Sarisha-18 vs. Tori-7; BRRI dhan91 vs. Furchun), inclusion of sesame during the fallow period, and improved crop management. Consequently, the observed improvements in productivity and profitability represent the combined effect of the integrated cropping system, and the individual contributions of sesame inclusion, varietal change, or management practices cannot be separated. Therefore, the results should be interpreted as system-level benefits rather than causal effects of any single intervention. Future studies employing factorial experimental designs (e.g., variety × crop inclusion × management) would allow partitioning of these effects and provide clearer attribution of yield gains.

Conclusions and Recommendations

The Mustard (BARI Sarisha-18)–Sesame (BARI Til-4)–B. Aman rice (BRRI dhan91) pattern produced higher system productivity, resource-use efficiency, and economic returns than the farmers' existing Mustard–Fallow–B. Aman rice system in AEZ-19. These improvements reflect the combined effects of varietal replacement, crop intensification through sesame inclusion, and improved management rather than any single factor. The pattern shows strong potential as a practical option for sustainable intensification of rice-based systems in medium and medium-low lands of AEZ-19 and similar environments. However, further multi-location and factorial studies are needed to confirm its broader applicability and to quantify the contributions of individual components. Wider demonstration through collaborative efforts of the Department of Agricultural Extension and Bangladesh Agricultural Research Institute may facilitate validation and adoption.

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