Article

Crop Diversification in Rice—Based Cropping Systems Improves the System Productivity, Profitability and Sustainability

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Abstract: Cropping systems in the Level Barind Tract (LBT) of Bangladesh are highly diverse, as Transplanted (T.) Aman and Boro (T. Boro) rice are a common practice in the area. Although, T. Aman is generally cultivated in the rainy (monsoon) season, but the T. Boro rice is the intensive irrigation-based winter rice with high establishment costs as a result of exhaustive tillage and high labours for transplanting of seedlings. Furthermore, pumping of a large amount of irrigation during T. Boro cultivation declines the level of groundwater, which is not environmentally friendly nor cost-effective. Therefore, the replacement of the T. Boro rice from the cropping pattern in the LBT area is the major concern of policymakers. In this context, a replicated three to four crop-based cropping systems (CS) field trial was conducted in LBT of Gaibandha, Bangladesh for consecutive three years (2018–2020) to evaluate productivity, profitability and sustainability of the multiple crop-based cropping systems. Among these CS, existing three crops based CS, CS1: T. Aman–Potato–T. Boro (introduction of the local potato in the existing cropping system) were compared with four crops based CS2: T. Aman–Potato–Cucumber–T. Aus (Introduction of high yielding potato, cucumber and T. Aus as an improved cropping system). After two years of observations, significantly higher system productivity (rice equivalent yield; REY) was found in the improved CS2 than that of existing CS1 in both years (two years' average 49% or 11.1 t ha^{−1}). As a result of the introduction of the high yielding potato, cucumber and T. Aus rice instead of the T. Boro rice. The CS2 was also found profitable as compared to the CS1 in terms of higher gross margin (by 74%), net return (double) and benefit-cost ratio (BCR) (1.69 vs. 1.44) due to higher gross return with slightly higher (by 28%) production cost. It is due to farmers received higher prices for potato, cucumber and two rice crops in the improved CS2 than the existing CS1. On the other hand, protein and energy output was lower (by 17% and 9%, respectively) in the CS2 than the existing CS1, due to the less content of protein and energy value in the vegetable cucumber. The results of the study revealed that crops diversification in the existing T. Boro based CS with high yielding potato, cucumber, and T. Aus rice, improved the system productivity, profitability and sustainability; which lead to improve the food security of the increasing population and also reduce the adverse effect on the environment.

Keywords: crop; cropping system; intensification; productivity; profitability

1. Introduction

Bangladesh is a small country of 0.148 million km² but surprisingly it has to feed 144 million people [1]. Rice is the staple food for most of the people in Bangladesh which occupy about 75% of the total cropped area [2] and contributes about 95% of the total food grain [1]. Currently, Bangladesh is now 4th largest rice-producing country in the world after China, India and Indonesia [3]. There are three rice-growing seasons in Bangladesh: Aus (June to August), Aman (August to October) and Boro (February to May) rice. The transplanted Boro (T. Boro) are now the major contributors to total rice production (18.9 Mt) in the country, despite Aman coverage an area of 17% more than Boro [2]. Currently, about 36.4 million-ton (Mt) of rice is being produced from an area of 11.5 million hectares (Mha) of land with an average of 3.16 t ha^{−1} [1]. Although rice production increased more than three folds in the last few decades, the country still could not attain sustainable self-sufficiency in food. Moreover, frequent occurrence of devastating floods, droughts, cyclones, etc., result in disruption to the overall supply of food grains. The average predicted population of Bangladesh will be 182 and 192 million in 2025 and 2030, respectively, and the average rice requirement predicted to be 36.4–37.7 and 40.1–41.0 Mt [4]. Besides, T. Boro rice production is cost-intensive due to more labours and irrigation [5], farmers do not want to sacrifice the Boro rice for their food security. Potato is an important tuber crop and main vegetable in Bangladesh, and considering the area and production, it ranks 2nd position after rice. Currently, about 9.65 Mt of potato were produced from an area of 0.47 Mha with an average yield of 20.6 t ha^{−1} [1]. Farmers for this reason usually cultivate local potato cultivar (cv. Lalpakri) that are less yielded. On the other hand, cucumber is another important vegetable produced in the specific area of Bangladesh, with small coverage and produced 0.12 Mt from 0.02 Mha of land with an average of 7.75 t ha^{−1} [3], but are highly profitable due to more market price with higher crop yield and popularly grown among the farmers of this region. Farmers of Level Barind Tract of Bangladesh usually cultivate local and long-duration T. Aman varieties (Gutiswarna, duration 150 days), delayed the timely sown of the next crop. The late rice harvest of T. Aman varieties [6] reduces the chance of there being sufficient soil moisture after T. Aman harvest with which too late sown of the succeeding rabi crops. The late harvest of T. Aman rice and increased T. Boro rice cultivation (32% from 2008 to 2015) under the rice-based cropping system causes the decline of rabi crop yield [7,8]. So, there have an opportunity to introduce the short-duration high yielding T. Aman variety (BRRI dhan57) instead of the long duration Gutiswarna (local) rice cultivar, which can help to intensify the existing cropping system. The population of Bangladesh is increasing at 1.37% p.a. [1], with the decreasing of cultivable land by 1% p.a. (0.08 Mha) due to rapid urbanization as well as industrialization especially by garments industries [9], and a competitive world market, the challenge of ensuring future food security is daunting. Therefore, there is a need to increase the productivity, profitability and sustainability of rice-based cropping systems by system intensification.

The cropping system of Bangladesh is usually rice-based as well as diversified, includes tuber crops, pulses, oilseed, vegetables, and other winter cereals like maize and wheat. In the level Barind tract of Bangladesh, T. Boro-T. Aman-potato (dry season rice, locally called boro rice, and rainy season rice, called Aman rice) is one of the major cropping systems. Currently, about 0.18 Mha of land (2.11% of the net cropped area) under this cropping system in Bangladesh [10]. The productivity and sustainability of rice-based systems are threatened because of inefficient use of inputs (seed, fertilizer, scarcity of resources (water and labour), climate change, energy crisis and rising fuel prices, the rising cost of cultivation and emerging socioeconomic changes such as urbanization, migration of labour, preference of nonagricultural work as well as declining soil fertility [5,11,12]. Besides, farmers' withdrawal of huge groundwater during the T. Boro rice cultivation, caused the lowering of water tables [13]. Hence the irrigation cost is increasing day by day as well as the need to install more expensive pumps (deep tube-wells, DTW). Moreover, the more uplift of groundwater has led to the accumulation of heavy metals especially arsenic (As) and lead (Pb) in the groundwater [14–18]. As a result, irrigated (T. Boro) rice

caused to bring a lot of arsenic into the food chain [19–21]. Thus the T. Aman-Potato-T. Boro cropping systems as currently practised are not sustainable. Therefore, an alternative cropping system is needed that will reduce the production cost, increase crop productivity, reduce adverse effects on the environment as well as sustainable food production. One potential way of achieving this is to switch short duration T. Aman (BRRI dhan57) in place of long duration T. Aman (Gutiswarna) variety, include high yielding potato cultivar, discard the T. Boro rice (cost-intensive) in the existing cropping system and introduce the profitable vegetable crop cucumber and T. Aus; the improved T. Aman-Potato-Cucumber-T. Aus cropping system will increase the total system productivity, profitability and sustainability of the rice-based cropping system as well as help food security (by two rice crops T. Aus and T. Aman) for the ever-growing population of Bangladesh. Given the above, a two-year cropping system experiment was conducted to evaluate (a) the effects of cropping system intensification from T. Aman-Potato-T. Boro to T. Aman-Potato-Cucumber-T. Aus; (b) the introduction of the short duration T. Aman and high yielding potato variety in the improved cropping system and also (c) the system REY performance, protein and energy output in both cropping systems. This research also tried to find out the outcomes of system performance in terms of crop yield, system productivity, profitability and sustainability of the improved cropping system in the Level Barind Tract of Bangladesh.

2. Materials and Methods

2.1. Site Description, Edaphic and Climatic Condition

The experiment was conducted over two years (2018 to 2020) in the farmer's field of Dhaperhat, Sadullahpur, Gaibandha, Bangladesh (25°36' N, 89°35' E and 25 m ASL) under the supervision of On-Farm Research Division (OFRD), Bangladesh Agricultural Research Institute, Gaibandha. The land at the experimental site was flood-free high land, deep grey terrace soil under the agro-ecological zone (AEZ-25) of level Barind tract [22]. The soil was silty clay loam with low water holding capacity. The topsoil (0–15 cm) was slightly acidic (pH 6.2), low organic matter content (0.93%) and most of the nutrients are low to medium (Table 1). Before setup, the experiment this site had a history of growing upland crops like rice, potato, sweet gourd, and others. The climate of this region is subtropical monsoon with an average annual rainfall of 907 mm, about 95% of which usually occurred from May to October (Figure 1a) and the monthly average maximum temperature ranges from 26 to 36 °C, while the monthly average minimum temperature ranged from 12 to 26.4 °C (Figure 1b).

Table 1. Initial soil properties of the experimental site.

Soil Depth (0–15 cm)	pH	OM (%)	Total N (%)	P	K	S	Zn	B
				µg/g Soil				
Value	6.20	0.93	0.03	13.8	0.25	20.2	0.88	0.26
Interpretation	Slightly acidic	VL	VL	L	M	M	L	L

VL = very low, L = low, M = medium.

2.2. Experimental Design

The experiment was laid out in a randomized complete block design (RCBD) with seven dispersed replications. The existing two crops based CS were compared with three crops based CS1: T. Aman-Potato-T. Boro (existing cropping system) and four crops based CS2: T. Aman-Potato-Cucumber-T. Aus (improved cropping system). The unit plot size was 600–2600 m². The experiment commenced with the transplanting of T. Aman crops in July 2018.

Figure 1. (a): Monthly mean maximum and minimum temperature and (b): monthly mean rainfall (mm) during the two years in comparison to the long term (1985 to 2015).

2.3. Crop Management

There are three rice-growing seasons in Bangladesh: Aus (June to August), Aman (August to October) and Boro (February to May) rice. However, potato and cucumber crops were used in the research to replace Boro rice. Details for all crops used in the present research are discussed in the following sub-headings:

2.3.1. Transplanted Aman Rice (Monsoon Rice)

Sprouted seeds of BRRI dhan57 (duration 105 days), used in the improved cropping system were broadcast between 28–31 July and Gutiswarna (duration 150 days), used in the existing or farmers cropping system between 5–10 June each year at 35 kg seed ha⁻¹. Seven days before transplanting the field was puddled by ploughing (four passes) using a 2-WT, followed by 2–3 times laddering. Twenty-five-day-old seedlings were uprooted carefully from the seedbed and transplanted on 1–7 July (for Gutiswarna) and 23–26 August (for BRRI dhan57) in both the year, with 2–3 seedlings hill⁻¹ maintaining 20 cm × 20 cm hill spacing. Total fertilizer application was 55 kg N ha⁻¹ as urea, 16 kg P ha⁻¹ as triple superphosphate, 35 kg K ha⁻¹ as muriate of potash, 10 kg S ha⁻¹ as gypsum. All P, K, S were broadcast just before transplanting. Urea was applied into three equal splits at 10 DAT, 30 DAT (4–5 tiller

stage) and 50 DAT (7 days before panicle initiation). As this is a rainy season, so the crop received only two supplement irrigations during the whole crop growing period. Weeds were well controlled by two hands weeding at 15 and 35 DAT. The Aman rice was infested by stem borer and rice bug, which was well-controlled by applying Imidacloprid (Emitaf[®], Auto Crop Care Limited, Bangladesh.) at 25 g a.i. ha⁻¹ and carbofuran (Furadan 5G[®], Padma Oil Company Limited, Strand Road, Chittagong, Bangladesh) at 500 g a.i. ha⁻¹. Rice blast was controlled by spraying Tebukonajol + Triphoxystrobin (Nativo 75WG[®], Bayer Crop Science, Bangladesh) at 300 g ha⁻¹. The crops were harvested on 5–10 November (Gutiswarna) and 14–20 November (BRRI dhan57) in both crops' year. The rice was cut 25 cm above the ground and rice straw retained in the succeeding crop.

2.3.2. Potato

Land preparation was done by 4–6 ploughing by a 2-Wheel tractor (2-WT) followed by laddering. Two different varieties were used such as the local (Lalpakri) variety (duration 90 days) in the existing/ farmers cropping system and BARI Alu-25 (duration 90–95 d) in the improved cropping system. Potato seeds were sown on 10–15 November (for Lalpakri) and 20–23 November (for BARI Alu-25) each year in both the cropping system at optimum soil moisture level, at 1500 kg seed ha⁻¹, maintaining 60 cm × 25 cm spacing and 3–5 cm sowing depth. Potato tubers were treated by carbendazim (0.1%) before plantation into the main field to control fungal (*Rhizoctonia*) infection. Total fertilizer application was 150 kg N ha⁻¹ as urea, 64 kg P ha⁻¹ as triple superphosphate, 125 kg K ha⁻¹ as muriate of potash, 20 kg S ha⁻¹ as gypsum, 2 kg Zn ha⁻¹ as zinc sulphate and 1.5 kg B ha⁻¹ as boric acid along with 10 t ha⁻¹ well-decomposed cow-dung. Cowdung was applied during the final land preparation. Half of the N and all the P, K, S, Zn and B fertilizers were broadcasted just before plantation, and the rest of N was top-dressed at 30–35 days after plantation (DAP) as well as the earthing up also done the same time. The crops were irrigated four times in both the years at 8–10 days after planting (DAP), 30–35 DAP, 45–50 DAP and 60–65 DAP maintaining 2/3rd depth of the furrow. Two hand weeding was done at 30–35 DAP and 60–65 DAP by spading in between the ridges and cover the ridges with loose soil, just before 2nd and 3rd irrigation. Carbofuran (Furadan 5G[®], Padma Oil Company Limited, Bangladesh) at 500 g a.i. ha⁻¹ was used as basal during final land preparation to control Cutworm infestation and Imidacloprid (Admire 20 SL[®], Bayer Crop Science Limited Bangladesh Masum Plaza (5th to 7th Floor), Plot # 13, Road # 15, Rabindra Sarani, Sector #3 Uttara, Bangladesh) at 25 g a.i. ha⁻¹ was sprayed in two instalments at 45 and 60 DAP to control Aphid infestation. The crops were also sprayed alternatively with Mancozeb (Dithane-M 45[®], Bayer Crop Science Limited, Dhaka, Bangladesh) at 1.76 kg a.i. ha⁻¹ and Fenamidin at 494 g a.i. ha⁻¹ (Secure[®], Bayer Crop Science Limited, Dhaka, Bangladesh) at 15 d intervals to protect from the Late Blight infection. The crop was harvested on 4–10 February in the existing cropping system and 18–21 February in the improved cropping system at full bulking of the tubers.

2.3.3. Cucumber

Cucumber (local variety, duration 85–90 d) was sown in the pit at 20–25 February each of the years at optimum soil moisture level at 6 kg seed ha⁻¹ with a sowing depth of 3–5 cm and spacing of 1.5 m × 1.5 m. Total fertilizer application was 58 kg N ha⁻¹ as urea, 44 kg P ha⁻¹ as triple superphosphate, 100 kg K ha⁻¹ as muriate of potash, 22 kg S ha⁻¹ as gypsum, 3 kg Zn ha⁻¹ as zinc sulphate and 1.7 kg B ha⁻¹ as boric acid. Half of the N and all the P, K, S, Zn and B fertilizers were applied in the pit one week before plantation, and the rest of N was applied at 10–15 DAP and 25–30 DAP as well as weeding at the same time. The cucumber received four post-sowing irrigation at 10–20 DAP, 20–30, 30–40, 60–70 DAP in both the year. There have some fruit fly and aphid infestations in cucumber. Fruit fly controlled by spraying Diafenthiuron (Pegasus 50 SC[®], Syngenta Bangladesh Limited 755 Satmasjid Road, Dhaka 1205, Bangladesh) at 500 g a.i. ha⁻¹ and Aphid controlled by spraying of Abamectin (Sunmectin 1.8 EC[®], Auto Crop Care Limited, Bangladesh) at

18 g a.i. ha⁻¹. The crop was harvested from 01 May and continued up to 20 May in each of the years.

2.3.4. Transplanted Aus Rice

Sprouted seeds of BRRI dhan48 (duration 110 d) were broadcast at 35 kg seed ha⁻¹ on the seedbed between 28–30 April in each of the years. The main field was puddled by cultivating four passes using a 2-WT, followed by 2–3 laddering. Twenty-five-day-old seedlings were uprooted carefully from the seedbed and transplanted on 23–26 May each of the years with 2–3 seedlings hill⁻¹ and 20 cm × 20 cm hill spacing. Total fertilizer application was 83 kg N ha⁻¹ as urea, 32 kg P ha⁻¹ as triple superphosphate, 75 kg K ha⁻¹ as muriate of potash, 14 kg S ha⁻¹ as gypsum. All the P, K, and S fertilizers were broadcast before transplanting. Urea was broadcast in three equal splits at 10 d after transplanting (DAT), 30 DAT (4–5 tillering stage) and 50 DAT (one week before panicle initiation). Six to seven irrigation was applied in the whole crop growing period. Two hand weeding performed at 25–30 DAT and 45–50 DAT in both the crop growing year, respectively. In both years, the rice was infested by stem borer and rice blast. These infestations were well-controlled by applying Imidacloprid (Emitaf[®], Auto Crop Care Limited, Bangladesh.) at 25 g a.i. ha⁻¹, carbofuran (Furadan 5G[®], Padma Oil Company, Bangladesh) at 500 g a.i. ha⁻¹, tebukonajol + triphoxystrobin (Nativo 75WG[®], Bayer Crop Science, Bangladesh) at 300 g ha⁻¹. The crops were harvested between 20–25 August over the years. The T. Aus rice was also cut 25 cm above the ground and retained rice residue similar to T. Aman crop.

2.3.5. T. Boro

Sprouted seeds of BRRI dhan28 (duration 140 d) were broadcast at 40 kg seed ha⁻¹ on the seedbed between 25–31 December in each year. The main field was puddled by similar practices like T. Aus and T. Aman. Forty-day old seedlings were uprooted carefully from the seedbed and transplanted on 7–15 February in both the year, with 2–3 seedlings hill⁻¹ maintaining 20 cm × 20 cm hill spacing. Total fertilizer application to the main plots was 92 kg N ha⁻¹ as urea, 36 kg P ha⁻¹ as triple superphosphate, 80 kg K ha⁻¹ as muriate of potash, 22 kg S ha⁻¹ as gypsum and 3.6 kg Zn ha⁻¹ as zinc sulphate and 1.7 kg B ha⁻¹ as boric acid. All P, K, S Zn and B were applied before transplantation of rice seedling into the main field. Urea was broadcast into three equal splits at 10 days after transplanting (DAT), 40 DAT (4–5 tiller stage) and 55 DAT (7 days before panicle initiation). The crop received eighteen irrigations during the whole crop growing period. Weeds were well-controlled by 2 hand weedings at 30 DAT and 60 DAT. There were some stem borer infestations, and rice bug at the grain filling stage. Good control of stem borer was achieved by applying fipronil 3G (Regent 3G[®], BASF Bangladesh Limited, HR Bhaban (4th Floor), 26/1, Kakrail Road, Bir Uttam Samsul Alam Rd, Dhaka 1000, Bangladesh) at 300 g a.i. ha⁻¹ and Flubendiamide (Belt 24WG[®], Bayer Crop Science, Bangladesh) at 48 g a.i. ha⁻¹. Rice bug (*Leptocoris oratorius* L.) was well controlled by the application of Malathion (Hilthion[®] The Limit Agro products Limited, House No. 322 (Flat 6A, Rd No 22, Dhaka 1206, Bangladesh) at 570 g a.i. ha⁻¹ and Imidacloprid (Emifaf[®] Auto Crop Care Limited, CWS (B) 74, Rd 25, Dhaka 1212, Bangladesh) at 25 g a.i. ha⁻¹. The crop was harvested on 25–31 May in both years. Rice straw management was the same as other rice crops.

2.4. Observations

2.4.1. Crop Yield

Grain yield was determined by harvesting from an area of 9 m² (3 m × 3 m) area for rice and 4 m² (2 m × 2 m) for potato and 5 pits for cucumber in each plot. The rice was manually threshed, and fresh grain and straw weights were determined. The moisture content of rice grain was determined from an average of 3 subsamples using a grain moisture meter (Model: GMK-303RS). Grain yield (t ha⁻¹) was measured at 12% moisture content (rice).

2.4.2. System Rice Equivalent Yield

Rice equivalent yield (REY) of potato and cucumber was calculated from the grain/tuber/fruit yield and price of each crop using the formula:

$$\text{REY (of crop}_x\text{)} = Y_x (P_x/P_r) \quad (1)$$

where, Y_x is the yield of crop 'x' (t ha^{-1}), P_x is the price of crop 'x' ($\text{US\$ t}^{-1}$) and P_r is the price of rice [23]. The price of rice, potato and cucumber used were US\$ 240, 180 and 144 t^{-1} , respectively. These values were calculated from the farmgate price in Bangladeshi taka (BDT), which were converted in US\$ using 1 US\$ = 84.84 BDT (the exchange rate in March 2020). System REY was determined as the sum of the REY of each crop in both the cropping system.

2.4.3. System Protein Output

System protein output was determined from the sum of the protein output in the grain of each crop in the following cropping system using the following formula:

$$\text{Protein output (kg ha}^{-1}\text{)} = \text{Protein\%} \times \text{dry grain yield (t ha}^{-1}\text{)} \times 1000/100 \quad (2)$$

The protein content used for rice, potato and cucumber were 8.8, 1.9, and 0.7% respectively [24,25].

2.4.4. System Energy Output

Total system energy output was determined by the sum of energy (the main product of rice, potato and cucumber) and the by-product of rice crop. The energy content used for rice grain, rice straw, potato tuber and cucumber fruit were 14.7, 15.6, 4.06 and 0.8 MJ kg^{-1} , respectively [26,27].

2.5. Sustainable Yield Index (SYI)

The sustainable yield index (SYI) of the cropping system was calculated by using the following formula:

$$\text{SYI} = (\text{Ymean} - \text{SD})/\text{Ymax} \quad (3)$$

where, Ymean is the mean yield, SD is the standard deviation and Ymax is the maximum yield.

2.6. System Economic Performance

The amount of total cost was calculated as the sum of total variable and fixed costs. The price of all inputs and outputs were determined in BDT based on the local market price, which was converted to US\$ using an exchange rate of 1 US\$ = 84.84 BDT. The variable costs used in the analysis were land preparation, seed, uprooting and transplanting of the rice seedlings, transplantation, fertilizer, insecticide, fungicide, harvesting, threshing, etc. (Tables 2 and 3), and the information provided by the local farmers of that area. The land preparation and irrigation were based on the charges of the local service providers. Fixed costs (land rental value interest on operating cost) are those costs that do not change with the change in the volume and type of production.

Table 2. Cost of potato and cucumber production used in the economic analysis.

Parameters	Potato			Cucumber		
	Quantity (ha ⁻¹)	Unit Price (US\$)	Total (US\$)	Quantity (ha ⁻¹)	Unit Price (US\$)	Total (US\$)
Variable Cost						
Seed (Kg)	2000	0.6	1200	6	24	144
Land preparation	1	102	102	1	102	102
Human labour (Man day ⁻¹)						
Pit preparation	-	-	-	12	3.6	43
Seeding	-	-	-	10	3.6	36
Fertiliser	2	4.8	10	2	3.6	7
Irrigation	15	4.8	72	7	3.6	25
Weeding/Earthing up	16	4.8	77	7	3.6	25
Fungicide/Insecticide	12	4.8	58	7	3.6	25
Macha preparation	-	-	-	30	4.8	144
Harvesting and cleaning	45	4.8	216	28	4.2	118
Total labour	90	-	432	103	-	424
Fertiliser						
Cowdung (t)	10	12	120	-	-	-
Urea (kg)	300	0.19	58	125	0.192	24
TSP (kg)	220	0.3	66	220	0.3	66
MoP (kg)	250	0.19	48	200	0.192	38
Gypsum (kg)	120	0.12	14	120	0.12	14
Zinc (kg)	10	4.8	48	10	4.8	48
Boron (kg)	10	3.6	36	10	3.6	36
Irrigation	2	36	72	4	36	144
Fungicide (kg)	10	4.8	48	-	-	-
Insecticide (L)	5	14.4	72	5	14.4	72
String (Kg)	-	-	-	70	3	210
Bamboo (no.)	-	-	-	70	1.8	126
Total variable cost	-	-	2316	-	-	1448
Fixed Cost						
Interest on OC (%)	0.09	-	12	0.09	-	12
Land rental value	1	540	135	1	540	135
Total fixed cost	-	-	147	-	-	147
Total cost	-	-	2463	-	-	1596

Table 3. Costs of rice production used in the economic analysis.

Parameters	T. Aus			T. Aman			T. Boro		
	Quantity ha ⁻¹	Unit Price (US\$)	Total (US\$)	Quantity ha ⁻¹	Unit Price (US\$)	Total (US\$)	Quantity ha ⁻¹	Unit Price (US\$)	Total (US\$)
Variable Costs									
Seed (Kg)	35	0.6	21	35	0.48	17	40	0.6	24
Land preparation	1	102	102	1	102	102	1	102	102
Human Labour (Man Day ⁻¹)									
Seedling uprooting	7	4.2	29	7	3.6	25	10	4.8	48
Transplanting	22	4.2	92	20	4.8	96	21	4.8	101
Fertiliser	2	4.2	8	2	3.6	7	3	4.8	14
Irrigation	7	4.2	29	4	3.6	14	8	4.8	38
Weeding	7	4.2	29	7	4.8	34	10	4.8	48
Fungicide/Insecticide spray	7	4.2	29	2	4.8	10	4	4.8	19
Harvesting and cleaning	28	4.8	134	20	4.8	96	27	4.8	130
Total labour	80		353	62		282	81		398
Fertiliser									
Cowdung (t)									
Urea (kg)	180	0.192	35	120	0.192	23	200	0.192	38
TSP (kg)	160	0.3	48	80	0.3	24	180	0.3	54
MoP (kg)	150	0.192	29	70	0.192	13	160	0.192	31
Gypsum (kg)	80	0.12	10	60	0.12	7	120	0.12	14
Zinc (kg)							10	4.8	48
Boron (kg)							10	3.6	36
Irrigation	7	9.6	67	2	9.6	19	18	7.8	140
Fungicide (kg)									
Insecticide (L)	3	14.4	43	2	14.4	29	2	14.4	29
Total variable cost			707			516			915
Fixed Cost									
Interest on OC (%)	0.09		12	0.09		15	0.09		18
Land rental value	1	540	135	1	540	169	1	540	203
Total fixed cost			147			184			221
Total Cost			854			700			1136

Land rental cost was the rental value for one year considering the local rental price. Rental values were assigned to each crop based on the duration of the crop; for T. Aman-Potato-T. Boro cropping system durations of 3, 4.5 and 4.5 months, respectively, whereas in T. Aman-potato-cucumber-T. Aus cropping system durations of 3 months of each crop. Interest on operating capital (IOC) was calculated using the following equation:

$$\text{IOC} = \text{TVC} \times i \times t / (100 \times 12) \quad (4)$$

where, TVC = total variable cost, i = annual interest rate (9%, current bank interest rate in Bangladesh), t = length of the crop production period in months (as above).

The gross return for each crop was calculated from the amount of harvested product t ha^{-1} (grain and straw) and their farmgate prices. The prices of the rice grain, rice straw, potato, and cucumber were 240, 12,144 and 180 US\$ t^{-1} , respectively. The gross margin for each crop was determined as the difference between the gross (total) return and total variable cost. Net return was calculated as the difference between gross return and total cost. The benefit-cost ratio (BCR) was calculated from the gross return divided by the total cost. Annual cropping system economic performance was calculated from the sum of the returns and the sum of the costs for each crop in each one-year cycle.

2.7. Weather Data

Daily maximum and minimum temperature and rainfall data during the experiment period (2018 to 2020) were collected from the weather station of the Department of Agricultural Extension, Gaibandha. Long term weather data (1985 to 2015) also acquired from the website (https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/gaibandha_bangladesh_7921384) (accessed on 9 May 2021).

2.8. Statistical Analysis

Data were analysed by t-test using Microsoft excel program and the means were separated using p -value at the 5% level of significance ($p < 0.05$).

3. Results and Discussion

3.1. Weather Variables (Air Temperature and Rainfall)

3.1.1. Transplanted Aman Rice

In the 2018–19 crop season, the maximum and the minimum air temperature were ranged from 21.8 to 34.0 °C and 13.1 to 27.3 °C. Again, in the 2019–20 crop season, the maximum and the minimum air temperature were ranged from 20.8 to 33.9 °C and 12.5 to 27.0 °C. Compared to long-term air temperature data, the average maximum air temperature increased by 1.4 °C in the 2018–19 crop season and 2.6 °C in the 2019–20 crop season, respectively. Again, the average minimum air temperature decreased by 1.4 °C in the 2018–19 crop season and 1 °C in the 2019–20 crop season, respectively. Changes in the rainfall pattern were also observed, in the 2018–19 crop season 20.5 mm less rainfall was recorded and 406.1 mm more rainfall was recorded in the 2019–20 crop season compare to the long-term average rainfall data.

The monthly maximum temperature was higher (1.6 to 2.4 °C) during transplanting of T. Aman (Gutiswarna, used in the existing cropping system) transplantation (July) compared to the long-term average but in the case of BRRI dhan57 (used in the improved cropping system), it was similar. Later on, the temperature was similar to the long term in both the crop growing period with some exception at the maturity stage (end of October) with a deviation of 2.5 to 3.0 °C (Figure 1a). Conversely, the monthly mean minimum temperature was much higher (up to 4.5 °C) compared to the long-term data during the total crop period (July to the first week of November) (Figure 1a). The crop received 460 mm rainfall in 2018–19, comparatively lower than the long term (512 mm), but occurred reverse in 2019–20 (822 mm), which was much higher than the long-term average. Between the two years, the second year received more rainfall (>362 mm) than that of the first crop year (Figure 1b).

3.1.2. Potato

During the crop growth, the maximum monthly average temperature was ranged from 21.8 to 26.5 °C in the 2018–19 crop season and in the 2019–20 crop season it was from 20.8 to 26.0 °C. Meanwhile, the minimum monthly average temperature was ranged from 13.1 to 17.5 °C in the 2018–19 crop season and 12.5 to 17.2 °C. The monthly mean maximum temperature during each potato crop (November to February) was usually lower compared to the long-term average with a deviation of 2.5 to 5.4 °C across the two years. On the contrary, the monthly mean minimum temperature was slightly higher (0.5 to 2.8 °C) than the long-term average during the whole potato growing period. The second crop growing year was cooler than that of the first crop growing year (Figure 1a). Rainfall was low during the first and second potato crops, with totals of 18.1 and 10.5 mm, respectively that was slightly lower than the long-term average with a value of 23 mm (Figure 1b).

3.1.3. Cucumber

The monthly mean maximum temperature during every crop growing period of cucumber (March to May) was comparatively lower than the long-term average with a lower of 0.7 to 5.3 °C in the first year and 0.9 to 6.7 °C in the second crop growing year. Interestingly, the monthly mean minimum temperature of the whole cucumber growing period was similar to the long-term average (Figure 1a). Rainfall during the cucumber crop growing period of each year was 262 and 279 mm, comparatively higher than the long-term average (200 mm), especially near about double during the vegetative stage (in April) in the first year but reverse at the harvesting stage (in May) (Figure 1b).

3.1.4. Transplanted Aus Rice

The monthly mean maximum and minimum temperature were slightly higher in both the crop growing period of T. Aus (Last week of May to Last week of August) compared to the long-term average (Figure 1a). Likewise, the crop received more rainfall in both the crop year (484 mm in 2018–19 and 698 mm in 2019–20), which was more than that of the long term (459 mm). Among the two-crop season, in the second year, the crop received more than double rainfall in July (>256 mm) during the vegetative period (Figure 1b).

3.1.5. Transplanted Boro Rice

The monthly mean maximum temperature was lower in both the crop growing period of T. Boro (February to May) compared to the long-term average with a value of 2.6 to 6.7 °C across the year and the monthly mean minimum temperature were slightly higher in both the crop year than the long-term average with a deviation of 0.4 to 2.8 °C, but the second year was comparatively cooler than the first year (Figure 1a). Rainfall of the whole crop period was similar (276 mm in 2018–19 and 278 mm in 2019–20), higher than the long-term average with a value of 208 mm (Figure 1b).

3.2. Crop Duration

The in-field duration of T. Aman (Gutiswarna) from transplanting to harvest was 126 to 129 days (d) over the two years whereas, it was about 80 to 84 d in BRRI dhan57, about one and half of month less than the local T. Aman crop variety (Table 4). The duration of potato was about 85 to 87 d in the local (Lalpakri) variety and 88 to 90 d for BARI Alu-25, like the local potato variety. The duration of T. Boro was 104 to 108 d with an average of 106 d over the two years. The duration of Cucumber was 84 to 86 d in both the year, with an average of 85 d and the T. Aus duration was 88 d in 2018–19 and 90 d in 2019–20 with an average of 89 d. The in-field duration of all crops was slightly more in the second year compared to the first crop growing year due to the cooler weather throughout the year (Figure 1a). Thus, the total in-field duration of the T. Aman-Potato-T. Boro- (existing) cropping system (315 to 324 d) was less (about 25 d) than that of the T. Aman-Potato-Cucumber-T. Aus- (improved) cropping system (340 to 350 d), mainly due to the replacement of the local T. Aman (duration 128 days) by BRRI dhan57 (duration 82 d)

crop variety as well as discard long duration of T. Boro crop. It revealed that about 25 d were more used in the improved cropping system as well as to minimize the turn-around time, resulted in significantly higher system productivity.

Table 4. Field duration (d) of Potato, Cucumber, T. Aus, T. Aman and T. Boro crops and of the total (annual) cropping system.

Crop Years	Existing Cropping System (CS1)			Improved Cropping System (CS2)				Total System ^a	
	T. Aman (Gutiswarna)	Potato (Lalpakri) (Local)	T. Boro (BRRI dhan28)	T. Aman (BRRI dhan57)	Potato (BARI Alu-25)	Cucumber (Local)	T. Aus (BRRI dhan48)	CS1	CS2
2018–19	126 ± 2	85 ± 2	104 ± 3	80 ± 2	88 ± 2	84 ± 2	88 ± 2	315 ± 2	340 ± 2
2019–20	129 ± 2	87 ± 2	108 ± 3	84 ± 2	90 ± 2	86 ± 2	90 ± 2	324 ± 2	350 ± 2
Mean	128 ± 2	86 ± 2	106 ± 3	82 ± 2	89 ± 2	85 ± 2	89 ± 2	320 ± 2	345 ± 2

^a CS1 = T. Aman-Potato-T. Boro (Existing cropping system), CS2 = T. Aman-Potato-cucumber-T. Aus (Improved cropping system).

3.3. Crop and System Rice Equivalent Yield

Grain yield of the T. Aman crops ranged from 3.90 to 4.90 t ha^{−1} across treatments and years. The grain yield of T. Aman crop was significantly higher in the existing cropping system than the improved cropping system mainly due to the use of the high yielded Gutiswarna (local long duration Aman) variety. In both the year T. Aman yielded 23% higher rice grain compared to the T. Aman in improved cropping system (Table 5). Conversely, the tuber yield of potatoes ranged from 19 to 24.5 t ha^{−1} over the treatments and years. The tuber yield was significantly higher (26%) in the improved cropping system due to the introduction of high-yielding potato (BARI Alu-25) crop variety instead of the local potato (Lalpakri) variety. The grain yield of T. Boro was 5.50 and 5.30 t ha^{−1} in the first and second crop years. The fruit yield of cucumber ranged from 13.7 to 14.1 t ha^{−1} over the two years. The grain yield of T. Aus was 4.20 and 4.00 t ha^{−1} in 2018–19 and 2019–20, respectively. In all the rice crop grain yield was slightly lower in the second year due to some cool temperature during the crop growing period (Figure 1a).

Table 5. Grain yield (t ha^{−1}) of individual crops and annual cropping system rice equivalent yield (REY, t ha^{−1}) during 2018–19 to 2019–20 and sustainable yield index (SYI) averaged over the two years.

Crops/Systems	Cropping Systems			
	CS1	CS2	t-Value	Level of Significance
2018–19				
T. Aman	4.90	4.00	4.19	**
Potato	19.00	24.00	5.17	**
T. Boro	5.50	-	-	
Cucumber	-	13.7	-	
T. Aus	-	4.20	-	
System REY	22.52	33.47	13.4	**
2019–20				
T. Aman	4.80	3.90	3.69	**
Potato	19.50	24.50	6.69	**
T. Boro	-	-	-	
Cucumber	-	14.1	-	
T. Aus	-	4.00	-	
System REY	22.48	33.74	15.9	**
Mean system REY	22.50	33.60	21.9	**
Mean system SYI	0.90	0.91	0.41	NS

CS1 = T. Aman-Potato-T. Boro (Existing cropping system), CS2 = T. Aman-Potato-Cucumber-T. Aus (Improved cropping system); **, significant at 1% level of probability.

System REY ranged from 22.48 to 33.74 t ha⁻¹ over treatments and years. There was a consistent trend of higher REY in the improved (four crop-based) cropping system (33.47 t ha⁻¹ in 2018–19 and 33.74 t ha⁻¹ in 2019–20 with an average of 33.60 t ha⁻¹) than of farmers' existing (three crop-based) cropping system (22.52 t ha⁻¹ in 2018–19 and 22.48 t ha⁻¹ in 2019–20 with an average of 22.50 t ha⁻¹). The REY was 49% higher in the improved cropping system compared to the existing cropping system due to the higher yield of potato and cucumber as well as the higher price received by the farmers. Reports are available on the increase of REY due to crop intensification as well as diversification. Cropping intensification from single to double increase the system REY by two to four times higher in rice-based cropping system [28–30], even varied 9–34% from rice-rice to rice-non rice crop based cropping systems [31] in India. Cropping system intensification from double (rice-rice or rice-wheat) to triple cropping system (Wheat-Mungbean-T. Aman) increased the system REY by 10–75% in the High Ganges River Floodplain and Madhupur tract of Bangladesh [5,32,33]; three times more in the active Brahmaputra-Jamuna Floodplain Chars of Bangladesh [34], but 42% more wheat equivalent yield (WEY) in India [35], as well 82% higher system REY when compared to double to four crop-based systems [36]. In other, reported that cropping system intensification from three to four crop-based system increased system REY by 38–44% across the different agroecological zones of Bangladesh [37–39], similar to our study, whereas it was lower by 26% [40] and much higher (81%) as reported by Islam et al. [41] compared to our study. In the recent, Saha et al. [42] reported cropping system intensification increased 211 to 360% more REY by two to four crop based cropping system in the salt-affected coastal zones of Bangladesh. The amount of increase REY varies due to the number of crops involved in the cropping system (two or three or four crop bases system) and types of crops as well as different ecosystems across the world.

Bangladesh has about 0.18 Mha of land under Potato-T. Boro-T. Aman cropping system occupies 2.11% of the total net cropped area; from which 10,652 hectares under the LBT agro-ecological zone. The exclusion of T. Boro rice from the conventional (Potato-T. Boro-T. Aman) cropping system and adding T. Aus rice in the improved cropping system will reduce the rice production by only 13,748 t approximately which is a very negligible amount of the total rice production. On the other hand, the REY will be increased by 0.12 Mt in the improved cropping system as compared to the conventional system which is more than 8 times higher compared to the amount of less rice production. Therefore, it can be said that because of the introduction of T. Aman-Potato-Cucumber-T. Aus cropping system, will not only decrease the rice production significantly but also increase the REY. As a result, food production in Bangladesh will be safe and sustainable. Moreover, the mean system sustainable yield index (SYI) in the improved (T. Aman-Potato-Cucumber-T. Aus) cropping system (0.91), similar to the existing cropping system (0.90), clearly indicated that the replacement of T. Boro by the cucumber and T. Aus rice never showed any negative effect on sustainable crop production. Besides, a significant amount of groundwater saves due to the discard of T. Boro rice, which ultimately play a positive role in sustainability.

3.4. System Protein Output

There was a significant difference on system protein output in both the year (Table 6). In both the year system protein output was decreased (by 17–18%) in the improved cropping system than that of the existing cropping system. The reason was mainly due to the higher yield of rice (especially the T. Boro rice) as well as the high protein content (8.8%) compared to the cucumber (higher yield but low protein content, 0.7%) in the improved cropping system. However, the averaged protein output over the two years was also increased by 21% in the existing cropping system. Alam et al. [5] reported that intensification of cropping system from double (T. Boro-T. Aman) to triple (Wheat-mungbean-Aman) increased total system protein output by 3%, due to the introduction of high protein content (mungbean) crop; that is reverse to our current study. Cropping system intensification from wheat-wheat (double) to wheat-wheat-wheat (triple) system increased the system protein output

by 7% and from wheat-wheat-wheat (three crops) to wheat-canola-wheat-field pea (four crops) by 56% in a long term study (2004–2015) in Saskatchewan, Canada [43]. In other Sharma et al. [44] showed that system protein output has been increased by 30–46% in rice-potato-mungbean and 19–26% in rice-rapeseed-mungbean cropping system compared to the rice-wheat cropping system in India. The variation of system protein output among the cropping systems due to the inclusion of various crop in the crop sequence that produced various protein.

Table 6. Annual cropping system protein output (kg ha^{-1}) during 2018–19 and 2019–20, and averaged over both years.

Crops/Systems	Cropping System			
	CS1	CS2	<i>t</i> -Value	Level of Significance
2018–19				
T. Aman	371	303	4.19	**
Potato	79	94	4.77	**
T. Boro	416	-	-	-
Cucumber	-	3	-	-
T. Aus	-	318	-	-
System total	866	718	4.53	**
2019–20				
T. Aman	363	295	3.69	**
Potato	82	96	4.99	**
T. Boro	401	-	-	-
Cucumber	-	3	-	-
T. Aus	-	303	-	-
System total	846	697	4.68	**
Mean system total	856	708	6.61	**

CS1 = T. Aman-Potato-T. Boro (Existing cropping system), CS2 = T. Aman-Potato-Cucumber-T. Aus (Improved cropping system); **, significant at 1% level of probability.

3.5. System Energy Output (Grain, Harvested Straw)

There was a significant difference in the energy output of potato and T. Aman crop each year, as well as the total system (Table 7). The energy output of the T. Aman-Potato-T. Boro cropping system (mean 446 GJ ha^{-1}) over the two years was significantly higher (averaged by 9%) compared to the T. Aman-potato-cucumber-T. Aus cropping system each year. The lower system energy output in the T. Aman-potato-cucumber-T. Aus cropping system mainly due to the low energy output of cucumber (0.8 MJ kg^{-1}), while it was much higher for T. Boro rice (14.7 MJ kg^{-1} from grain and 15.6 MJ kg^{-1} from straw) in the existing T. Aman-potato-T. Boro cropping system. The intensification and diversification of cropping from the two to three crop based cropping system increased the system energy output by 15–42% [26,32,35,45]; reverse to this study. In India, the system energy out was lower by 6% in rice-potato, by 2% in rice-veg. pea-wheat-green gram and by 4% in the rice-mustard-green gram cropping system compared to the rice-wheat cropping system [46,47]. The system energy output increased by 59% from single to double, 14–38% from double to triple crop-based system and by 5% from three to four crop based cropping system in India [44,48–50]. The reason for variations among the different cropping systems mainly due to the variations of crops used (produced various energy output) in the cropping system.

Table 7. Individual crop and annual cropping system energy output (GJ ha^{−1}) during 2018–19 and 2019–20 and averaged over the two years.

Crops/Systems	Cropping System			
	CS1	CS2	t-Value	Level of Significance
2018–19				
T. Aman	180	153	3.51	**
Potato	77	97	5.17	**
T. Boro	196	-	-	-
Cucumber	-	11	-	-
T. Aus	-	152	-	-
System total	454	413	3.17	**
2019–20				
T. Aman	175	148	3.03	**
Potato	79	99	6.69	**
T. Boro	185	-	-	-
Cucumber	-	11	-	-
T. Aus	-	144	-	-
System total	439	403	2.36	**
Mean system total	446	408	3.96	**

CS1 = T. Aman-Potato-T. Boro (Existing cropping system), CS2 = T. Aman-Potato-Cucumber-T. Aus (Improved cropping system); **, significant at 1% level of probability.

3.6. Crop and System Profitability

All crops in both the cropping systems were profitable, with positive gross margin and net return, as well as BCR > 1, regardless of the amount of labour cost in the analysis (Table 8). The gross margin of cucumber used in the improved cropping system was 18–59% higher compared to the other crops due to the high yield as well as received good price of cucumber. However, with 100% activity, the total cost of potato production was about 35–72% higher than that of the other crops, mainly due to the high seed price of potato (1200 US\$ ha^{−1}) and labour costs (Tables 2 and 3). The total variable cost for all crops decreased with the decrease rate of labour cost in the analysis (Table 8).

The net result was similar gross margins (means US\$ 1032–1265 ha^{−1}) for potato and cucumber crops, near about double gross margins for T. Aman (mean US\$ 758 ha^{−1}) and T. Boro (mean US\$ 666 ha^{−1}) and lowest gross margin for T. Aus (mean US\$ 521 ha^{−1}). Similarly, the net return was ranked the highest for cucumber (mean US\$ 1119 ha^{−1}), slightly lower (21%) in potato (mean US\$ 885 ha^{−1}) with a great extent of 49–67% for the rice crops. The net return of T. Aus and T. Boro were low at US\$ 198 and US\$ 246 ha^{−1} when 100% of labour was costed, due to more labour required (about 80 no.) as well as high labour wedges. Mean BCR was highest for T. Aman, similar to cucumber, and least for T. Boro. Both the cropping systems were also profitable (Table 9).

The gross return for the improved (T. Aman-potato-cucumber-T. Aus) cropping system (US\$ 8065 ha^{−1}) was about 49% more than the existing (T. Aman-potato-T. Boro) cropping system (US\$ 5399 ha^{−1}), while the total cost was slightly higher (by 28%). Gross margin ranged from US\$ 3078–4569 ha^{−1}, while net return ranged from US\$ 2490–3981 ha^{−1} and BCR from 1.45–1.97 across the different levels of labour costed (0–100% activity). The gross margin of the improved (T. Aman-potato-cucumber-T. Aus) cropping systems was US\$ 1426–1805 ha^{−1}, much higher (74%) compared to the existing (T. Aman-potato-T. Boro) cropping system, with an average net return of US\$ 1617 ha^{−1}. The intensification and diversification from three to four crop based cropping system increased gross margin by 13–29% [38,40]; even though doubled from in Mustard-Mungbean-T. Aus-T. Aman (1914 US\$ ha^{−1}) cropping system compared to Mustard-Dibbled Aus-T. Aman (924 US\$ ha^{−1}) cropping system [41]. In another, Alam et al. [5] reported that intensification from double to triple cropping system increased gross margin by 26% and net return by double due to higher returns and lower production cost in the High Ganges River

Floodplain of Bangladesh. Recently, Mondal et al. [51] reported that cropping system intensification increased profitability by 2 to 5 folds in the coastal zone of West Bengal, India. The wide range of variations on gross margin and economic profitability due to the type of crops involved in the cropping system and also price received by the farmers with low input cost.

Table 8. Economics of the five crops grown in the cropping systems.

Economic Parameter ^a	Potato	Cucumber	T. Aus	T. Aman	T. Boro
A. Gross Return					
Activity 0–100%	3132 ± 39	2502 ± 58	1052 ± 19	1133 ± 16	1382 ± 31
B. Total Variable Cost					
Activity 100%	2316	1448	707	516	915
Activity 75%	2208	1342	619	446	816
Activity 50%	2100	1236	531	375	716
Activity 25%	1992	1130	442	305	617
Activity 0%	1884	1024	354	234	517
C. Total Fixed Cost					
Activity 100%	147	147	147	184	221
Activity 75%	147	147	147	184	221
Activity 50%	147	147	147	184	221
Activity 25%	147	147	147	184	221
Activity 0%	147	147	147	184	221
D. Total Cost (B + C)					
Activity 100%	2463	1595	854	700	1136
Activity 75%	2355	1489	766	630	1037
Activity 50%	2247	1383	678	559	937
Activity 25%	2139	1277	589	489	838
Activity 0%	2031	1171	501	418	738
E. Gross Margin (A – B)					
Activity 100%	816 ± 39	1054 ± 58	345 ± 19	617 ± 16	467 ± 31
Activity 75%	924 ± 39	1160 ± 58	433 ± 19	687 ± 16	566 ± 31
Activity 50%	1032 ± 39	1266 ± 58	521 ± 19	758 ± 16	666 ± 31
Activity 25%	1140 ± 39	1372 ± 58	609 ± 19	828 ± 16	765 ± 31
Activity 0%	1248 ± 39	1478 ± 58	698 ± 19	899 ± 16	865 ± 31
F. Net Return (A – D)					
Activity 100%	669 ± 39	907 ± 58	198 ± 19	433 ± 16	246 ± 31
Activity 75%	777 ± 39	1013 ± 58	286 ± 19	503 ± 16	345 ± 31
Activity 50%	885 ± 39	1119 ± 58	374 ± 19	574 ± 16	445 ± 31
Activity 25%	993 ± 39	1225 ± 58	462 ± 19	644 ± 16	544 ± 31
Activity 0%	1101 ± 39	1331 ± 58	551 ± 19	715 ± 16	644 ± 31
G. BCR (Undiscounted)(A/D)					
Activity 100%	1.27 ± 0.02	1.57 ± 0.04	1.23 ± 0.02	1.62 ± 0.02	1.22 ± 0.03
Activity 75%	1.33 ± 0.02	1.68 ± 0.04	1.37 ± 0.02	1.80 ± 0.03	1.33 ± 0.03
Activity 50%	1.39 ± 0.02	1.81 ± 0.04	1.55 ± 0.03	2.03 ± 0.03	1.47 ± 0.03
Activity 25%	1.46 ± 0.02	1.96 ± 0.05	1.78 ± 0.03	2.32 ± 0.03	1.65 ± 0.04
Activity 0%	1.54 ± 0.02	2.14 ± 0.05	2.10 ± 0.04	2.71 ± 0.04	1.87 ± 0.04

^a Activity % is the % of total labour requirement cost in the analysis. Data are mean ± standard error in US\$ (1 US\$ = 84.58 BDT).

Table 9. Economics of treatments under the two cropping systems evaluated in the field experiment.

Economics	Mean	
	CS1	CS2
A. Gross Return		
Activity 0–100%	5399 ± 69	8065 ± 131
B. Total Variable Cost		
Activity 100%	3747	4987
Activity 75%	3470	4615
Activity 50%	3191	4242
Activity 25%	2914	3869
Activity 0%	2635	3496
C. Total Fixed Cost		
Activity 100%	589	588
Activity 75%	589	588
Activity 50%	589	588
Activity 25%	589	588
Activity 0%	589	588
D. Total Cost (B + C)		
Activity 100%	4336	5575
Activity 75%	4059	5203
Activity 50%	3780	4830
Activity 25%	3503	4457
Activity 0%	3224	4084
E. Gross Margin (A – B)		
Activity 100%	1652 ± 69	3078 ± 131
Activity 75%	1929 ± 69	3450 ± 131
Activity 50%	2208 ± 69	3823 ± 131
Activity 25%	2485 ± 69	4196 ± 131
Activity 0%	2764 ± 69	4569 ± 131
F. Net Return (A – D)		
Activity 100%	1063 ± 69	2490 ± 131
Activity 75%	1340 ± 69	2862 ± 131
Activity 50%	1619 ± 69	3235 ± 131
Activity 25%	1896 ± 69	3608 ± 131
Activity 0%	2175 ± 69	3981 ± 131
G. BCR (Undiscounted)(A/D)		
Activity 100%	1.25 ± 0.02	1.45 ± 0.02
Activity 75%	1.33 ± 0.02	1.55 ± 0.03
Activity 50%	1.43 ± 0.02	1.67 ± 0.03
Activity 25%	1.54 ± 0.02	1.81 ± 0.03
Activity 0%	1.67 ± 0.02	1.97 ± 0.03

CS1 = T. Aman-Potato-T. Boro (Existing cropping system), CS2 = T. Aman-Potato-Cucumber-T. Aus (Improved cropping system). Data are mean ± standard error in US\$ (1 US\$ = 84.58 BDT).

4. Conclusions

From the results and discussion of the present study, it can be concluded that crop diversification in the existing T. Boro-based cropping system of Level Barind Tract of Bangladesh with the introduction of the high yielding potato, cucumber, and T. Aus rice, improved the system productivity, profitability and sustainability in terms of higher gross margin (by 74%), net return (double) and benefit-cost ratio (BCR) (1.69 vs. 1.44). The improved cropping system increased the gross return by 2666 US\$ ha^{−1} (49%) and net return by 1616 US\$ ha^{−1} (double) as well as higher BCR (1.69) as compared to the existing system as a result of the higher prices for potato, cucumber and two rice crops

in the improved cropping system than the existing system. Although the productivity and profitability of the improved cropping system were found the maximum, while the output of protein and energy were found lower (by 17% and 9%, respectively); it is the result of the less content of protein and energy value in cucumber. However, the improved cropping system did not show any significant difference on SYI (0.91 vs. 0.90), indicated that this is a sustainable cropping system. Therefore, the implementation of the improved four crops-based cropping system may be recommended for the well-drained Level Barind Tract of Bangladesh, which lead to ensure the sustainable food production of the increasing population and also reduce the adverse effect on the environment.

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