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Research Article

Cropping System Intensification: An Approach to Increase Yield, Water Productivity, and Profitability in North-West Bangladesh

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Water productivity improvement is getting the prime concern to sustain irrigated rice production in the water-scarce areas of Bangladesh under changing climate. Besides, profitable cropping pattern selection is one of the major indicators of commercial agriculture. The study was conducted at Mithapukur and Pirganj Upazilas of Rangpur district during 2018–2020 to evaluate the water saving and profitability of three crop cropping patterns over two crops pattern. The experiment involved two improved patterns, T. Aman-Mustard-Boro (CP1) and T. Aman-Potato-Boro (CP2), and one locally popular pattern, T. Aman-Fallow-Boro (CP3). Irrigation management involved supplemental irrigation for T. Aman rice, irrigation application after disappearing standing water for Boro rice, and two irrigations at critical stages of potato and mustard. Both CP1 and CP2 received higher rainfall than CP3 because the delayed transplanting of Boro rice captured more rainfall. The improved patterns of CP1 and CP2 saved 22–40% of irrigation water compared with CP3. Among the patterns, CP2 achieved the highest rice equivalent yield (REY) of 21.1–33.6 $t{\cdot}ha^{-1}$ due to excellent potato production. Similarly, CP2 provided the highest irrigation water productivity because of higher REY as well as less irrigation requirement. Both CP1 and CP2 patterns returned a higher gross margin than CP3. The findings indicated that the inclusion of potato and mustard in the T. Aman-Fallow-Boro cropping pattern saved irrigation water as well as increased production and economic benefit. Adoption of these water-efficient cropping patterns may reduce groundwater irrigation in the water-scarce areas of Bangladesh.

1. Introduction

The cropping systems in the northwestern region of Bangladesh, part of the eastern Gangetic Delta Plain, are dominated by rice, the major cereal crop of Bangladesh agriculture. As rice is the staple food of inhabitants of this country, the major cropping patterns throughout the country are generally rice-based. Rice is grown in 80% of total cultivable land and around 63% of people are engaged in rice production directly or indirectly, while rice contributes to the national gross domestic product (GDP) by 19.6% [1]. Among the rice-dominated major cropping patterns, the rice-rice-non-rice cropping pattern covers 37% of the rice area followed by rice-fallow-non-rice crop (34%) and rice-rice-fallow (21%) patterns [1]. However, other non-rice cereals like wheat and maize, potato, jute, vegetables, oilseed, fiber crops, and pulse are grown in sequence with rice within rice-dominant cropping patterns [2, 3]. The rice-non-rice combination in the major cropping patterns usually maintains the supply of the main diet item rice along with other essential components. In recent years, erratic distribution of rainfall, lack of water resources, irrigation scarcity, labor, and energy insufficiency as well as a sharp increase in production cost and reduction in benefit, are making the rice-oriented crop cultivation more complicated and less profitable [4]. However, the present agricultural production must be increased because the demand for rice and other non-rice crop is going to double by 2050 with the current population growth rate [5].

A cropping pattern or cropping sequence is a yearly strategic plan of a farmer to enhance crop yield as well as economic return to a sustainable level. When constructing very own cropping pattern, a farmer always judicially considers timely availability of inputs like seed and fertilizer, weather and field condition, rainfall pattern, water sources, irrigation facility, storage and transport cost, product market price, community decision, and government policy [2]. Practically, all possible factors such as climatic variability, environment, land use, resource availability, historical crop performance, institutional supports, socioeconomic status, and local hydrology are evaluated critically when selecting a best-possible cropping pattern [6]. Cropping sequence selection for a region plays a vital role because it has a substantial influence on soil physical properties, soil organic matter, carbon, and nitrogen fixation into the soil, soil erosion, rainwater infiltration, agricultural technology adoption, resource utilization and management, weed and pest infestation, postharvest processing and distribution, product price and market risk [7–11]. Therefore, a cropping pattern reflects the overall picture of the agriculture of a locality.

Rangpur region, situated in the northwest part of Bangladesh, has five major cropping patterns, where rice leads are unparalleled [2]. The net cultivable area (NCA) in the Rangpur region is 696,420 ha [12]. The popular cropping pattern, T. Aman-Fallow-Boro has the major coverage (53.33% of NCA) in that region. Despite single or mono rice cropping pattern coverage, T. Aman-Potato-Boro and T. Aman-Mustard-Boro cropping patterns are the third and fourth dominant patterns in the Rangpur region with a coverage of 5.16% and 3.28% of NCA, respectively. After rice harvesting, potato is cultivated mostly as a vegetable crop. In some parts of the region, mustard has a high acceptance as an oilseed crop. However, climate change has already started to show its effect in this region [13]. Some previous studies tried to fit an additional crop in between Boro and T. Aman cropping system but they did not focus on water saving or water productivity [14, 15].

The monthly rainfall distribution of Bangladesh has changed rapidly within the last two decades. Usually, the northwest and middle parts of the county receive around 1500 mm of rainfall while the northeast and southeast parts get more than 3000 mm of rainfall annually [16]. Though June-September is considered the rainy season in Bangladesh, the rainfall occurrence has shifted to April-mid August [17]. During the monsoon, 70–90% of rainfall accumulated in April-August, and only 10% occurred in the late monsoon. The shifting of monsoon in April is fulfilling the irrigation demand of late transplanted Boro rice. However, the early ceasing of rainfall in September is increasing supplemental irrigation demand for late transplanted T. Aman rice [18,19]. Hence, the traditional T. Aman-Fallow-Boro cropping pattern in the Rangpur region tremendously suffered from irrigation water scarcity both in Boro and T. Aman seasons. So, a cropping pattern must be chosen based on the accessibility to irrigation water. But this can ultimately increase the withdrawal of excess groundwater and potentially create a threat to available water, energy, or power. Instead, introducing and covering more cultivable areas with water-saving and irrigation-efficient cropping patterns, and consequently replacing the water-demanding cropping pattern could be an effective and profitable option to be adopted. Considering the context, the present study was set to evaluate the irrigation water saving, yield performance, and profitability of three cropping patterns in two locations in the Rangpur region.

2. Materials and Methods

2.1. Study Location. The study areas were Mithapukur (25.54°N, 89.27°E) and Pirganj Upazilas (25.50°N, 89.22°E) in the Rangpur district in Bangladesh. The mean annual temperature of the Rangpur region is 24.9°C. April to May is the hottest period and December to January is the coldest period of the year. Annual normal rainfall is 2200 mm [20] and 80% of which occurs during the monsoon (June to October) period [21]. The topography of both Upazilas is dominated by medium highland to highland. The texture of the topsoil is silt loam. The soil is moderately acidic (pH of 4.6–6.5) and the organic carbon content is 0.94% [13]. Overall, the soils in these areas have low to medium fertility status with good water-holding capacity. In the study areas, Rice (Boro, T. Aman, and Aus) is the dominating cereal; however, other crops such as potato, wheat, vegetables, etc. also have the large coverage [12].

2.2. Experimental Setup and Treatments. The experiment was completed in two consecutive cropping cycles from the cropping year 2018–2019 to 2019–2020. We repeated the cropping patterns to be tested in four different fields at each location. The individual plot size was 1335 m^2 for each crop. The experiment involved three cropping patterns: two improved patterns and one popular existing pattern. The existing pattern was considered a control. The improved patterns were T. Aman-Mustard-Boro (CP1) and T. Aman-Potato-Boro (CP2), and the control pattern was T. Aman-Fallow-Boro (CP3). The setup of the experiment was a randomized complete block design (RCBD) with four replications. Figure 1 shows the detailed crop calendar of the three cropping systems in the Rangpur region.

2.3. Cultivar Selection and Agronomic Management

2.3.1. T. Aman (Transplanted Aman) Rice. Bangladesh Rice Research Institute (BRRI)-developed popular cultivar BRRI dhan49 was used during T. Aman rice in both locations. BRRI dhan49 has an average growth duration of 135 days with an average yield of 4.5 $t{\cdot}ha^{-1}$ [22]. We transplanted 30-old seedlings from 19 July to 24 July each year. A 20 cm × 20 cm (line to line × plant to plant) spacing was maintained during transplanting. BRRI recommended fertilizer doses at 164-60-104-67 $kg{\cdot}ha^{-1}$ of urea-TSP-MoP-gypsum, respectively, were applied. All the fertilizers except

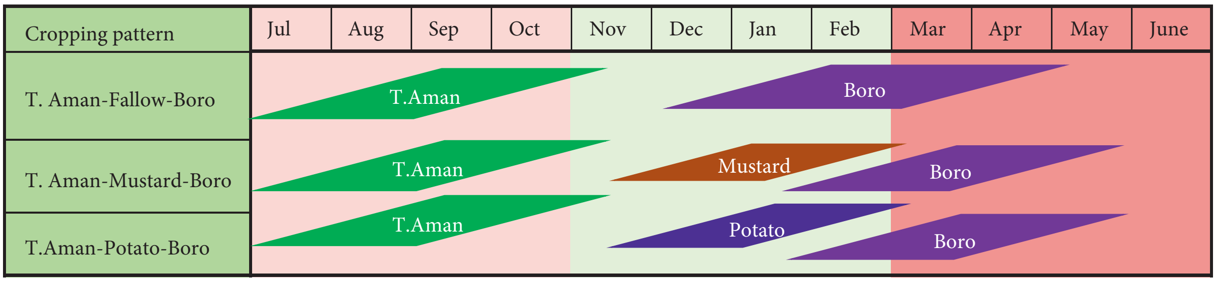

FIGURE 1: Overview of crop planning in different cropping patterns at Mithapukur and Pirganj, Rangpur.

urea were applied during the final land preparation. Urea was applied in three equal splits at 15 days after transplanting (DAT), 30 DAT, and 45 DAT. Hand weeding was done at 30 DAT. Insecticides at recommended doses were sprayed thrice at active tillering, booting, and grain filling period of rice.

2.3.2. Mustard. Bangladesh Agricultural Research Institute (BARI)-developed short duration (75–80 days) popular mustard variety BARI Shorisha-14 was sown following broadcasting method after T. Aman rice harvesting. The cultivar has an average yield ranging from 1.4 to 1.6 t·ha^{-1} [23]. Fertilizers were applied at 300-180-100-180-7 kg·ha^{-1} of urea-TSP-MoP-gypsum-zinc, respectively. Half of the urea fertilizer along with other fertilizers was applied during final land preparation and the rest half of the urea fertilizer was applied during the flowering stage. A hand weeding was done 25 days after sowing (DAS).

2.3.3. Potato. Newly developed potato cultivar BARI Alu-25 was used in CP3. The average yield of the cultivar ranges from 25 to 30 t·ha^{-1} in 90 to 95 days of growth days [23]. Potato seed was sown from 25 November to 30 November (Figure 1) after proper land preparation at 60 cm × 25 cm spacing. Urea-TSP-MoP-Gypsum-Zinc-Boron fertilizers were applied at 350-220-300-120-10-9 kg·ha^{-1}, respectively. All fertilizers but urea were applied during final land preparation. Half of the urea fertilizer was applied during land preparation and the rest amount at 35 DAT.

2.3.4. Boro Rice (Irrigated). Popular Boro varieties BRRI dhan29 and BRRI dhan58 were used at Pirganj and Mithapukur, respectively. BRRI dhan29 (160 days) and BRRI dhan58 (150 days) are long-duration varieties with a national average yield of 7.5 t·ha^{-1} and 7.2 t·ha^{-1}, respectively [22]. Forty-day-old seedlings were transplanted at 20 cm × 20 cm spacing. In CP3, Boro rice was transplanted within 20–25 January. However, in the other two treatments, transplantation was done after potato and mustard harvesting and usually shifted up from 25 February to 3 March. Urea-TSP-MoP-gypsum-zinc fertilizers were applied at 300-100-165-165-7 kg·ha^{-1}, respectively. Urea fertilizer was applied in three replications at 15, 30, and 45 DAT. Insecticides and fungicides were sprayed when pest infestation was observed.

2.4. Crop Irrigation Scheduling. Usually, T. Aman rice is grown in rainfed conditions as adequate rainfall occurs during the growing period. However, uneven distribution of rainfall often causes drought. We installed a perforated PVC pipe to monitor perched water table depletion in each field. Supplemental irrigation was applied when the perched water table went 15 cm below the ground surface. Boro rice fully depends on irrigation; thus, irrigation was applied when the standing water level disappeared from the rice field. For potatoes, BARI-recommended irrigation scheduling was followed where furrow irrigation was applied at the stolonization stage (20 days after sowing, DAS) and bulking stage (50 DAS) [23]. The same scheduling, flood irrigation at flowering (25 DAS) and pod formation stage (55 DAS), was applied for the mustard crop.

2.5. Data Collection and Analysis. Daily rainfall of both locations was recorded from a rain gauge installed near the field. The amount of applied water in each irrigation event for each crop was recorded. The maturity date of each crop was logged. The grain yield and its moisture content for each plot were recorded. Rice and Mustard yield were adjusted to 14% and 10% moisture content, respectively. However, the harvested yield of potato was considered the mature yield and yield adjustment was not required. The mustard yield was taken after proper sun drying for 3 consecutive days. The farm-gate price of all crops during the harvesting period was collected. Finally, the yield of each crop in a cropping pattern was converted to rice equivalent yield (REY) following Verma and Modgal [24]. All the data were analyzed by statistical program R 3.4.0 using the "agricolae" package.

$$\text{REY}\left(\text{t} \times \text{ha}^{-1}\right) = \frac{\text{Price of other crop (Tk.)}}{\text{Price of rice crop (Tk.)}} \times \text{Yield of other crop}\left(\text{t} \times \text{ha}^{-1}\right). \quad (1)$$

Table 1: Rainfall (mm) received by different crops in the three cropping patterns (CP1: T. Aman-Mustard-Boro, CP2: T. Aman-Potato-Boro, CP3: T. Aman-Fallow-Boro) during 2018–2019 and 2019–2020 seasons

Cropping pattern	Mithapukur (mm)				Pirganj (mm)			
	T. Aman	Mustard/potato	Boro	Total	T. Aman	Mustard/potato	Boro	Total
2018–2019								
CP1	476	7	472	955	445	7	472	924
CP2	476	7	472	955	445	7	472	924
CP3	476		356	832	446		283	729
2019–2020								
CP1	690	8	651	1349	663	8	613	1284
CP2	690	6	743	1439	640	6	667	1314
CP3	690		339	1029	662		258	920

2.6. Irrigation Application and Water Productivity. Following the predefined scheduling, irrigation was applied to the crops. During the irrigation application, the pump discharge was calculated by the volumetric method (time required to fill up the 100 L bucket). The volume of irrigation water applied in one application was calculated by multiplying the irrigation time with pump discharge. The total volume of water needed for each cropping pattern was recorded from individual crops. Irrigation water productivity of cropping pattern was calculated from REY and total applied irrigation following Alam et al. [15].

$$\mathrm{WP_{irri}}\left(\mathrm{kg} \times \mathrm{m}^{-3}\right) = \frac{\mathrm{TREY}\left(\mathrm{t} \times \mathrm{ha}^{-1}\right)}{\text{Applied irrigation (mm)} \times 100}. \quad (2)$$

2.7. Economic Analysis. Total variable costs of each crop production and the gross return from it were taken into consideration during the economic performance analysis of each cropping pattern. The total variable cost involved all input costs (seed, fertilizer, weedicide, pesticide, irrigation, machinery hired for tillage and threshing, labor engagement for seedling raising, seeding and transplanting, weeding, harvesting, threshing, winnowing, etc). Gross return was calculated by multiplying the economic yields (grain and straw) of the crops by the farm-gate price during harvesting time [15]. Thus, the gross margin was calculated as:

$$\mathrm{GM} = \mathrm{GR} - \mathrm{TVC}, \quad (3)$$

where GM is gross margin, GR is gross return, and TVC stands for total variable cost. The cropping patterns' cost and returns were calculated by adding the cost and net returns of all crops harvested within the cropping year. Finally, the economic data were converted to US$ using the exchange rate (1 US$ is equal to 84 BDT).

3. Results

3.1. Cropping Pattern-Wise Rainfall Distribution. In Bangladesh, July to October is the monsoon period, which experiences huge rainfall. In the present study, T. Aman rice received 476 and 472 mm of rainfall at Mithapukur and Pirganj, respectively, in 2018 (Table 1). Between two experimental years, T. Aman received higher rainfall (690 mm in Mithapukur and 640–663 mm in Pirganj) in 2019 than in the previous year. A few rainfalls (<10 mm) were recorded during the Rabi season (November to February) in both years. Hence, Rabi crops and Boro rice exhibited irrigation demand to meet their consumptive use up to March each year. However, there was a considerable rainfall from April onward, and Boro rice showed less demand for irrigation. Farmers in the study locations practiced timely transplanting (within January) of Boro rice in CP3 treatment and it matured at the end of April (Figure 2). Thus, Boro rice in CP3 experienced the minimum rainfall (258 mm) at Pirganj and the maximum rainfall (356 mm) at Mithapukur during the study period (Table 1). Accommodation of a third crop (Rabi) in the existing cropping pattern (CP3), delayed the transplanting of Boro rice and it received higher rainfall (472–667 mm). Hence, the T. Aman-Potato-Boro cropping pattern utilized the maximum rainfall in both locations each year.

3.2. Cropping Pattern-Wise Irrigation Application. T. Aman rice received enormous rainfall since it passed through the wet period of the year. Nevertheless, the uneven rainfall distribution created a soil moisture deficit during T. Aman in 2018, thereby irrigation water was applied to protect the crop from terminal drought. However, ample rainfall and its good distribution demanded no irrigation in T. Aman rice in the following year (Table 2). For potato and mustard crops, two irrigations were applied in their critical stages (20 DAS and 50 DAS for potato and 20 DAS and 45 DAS for mustard) since little rainfall was found during their growing period. Potato received comparatively less irrigation than mustard due to flood irrigation being applied in mustard whereas potatoes received furrow irrigation. Boro rice cultivation in CP1 and CP2 treatments required comparatively less irrigation than CP3 treatment. Boro rice transplanted after the 1st week of March became mature by the end of May. Higher accumulated rainfall in CP2 and CP3 reduced irrigation demand. Compared with CP3 treatment, CP1 and CP2 saved 22–40% of irrigation water in both seasons (Table 2).

3.3. Yield Performance. The grain yield of T. Aman rice was similar in all cropping patterns since the same variety, water management, and transplanting time were followed (Table 3). Both mustard and potato gave higher yield in

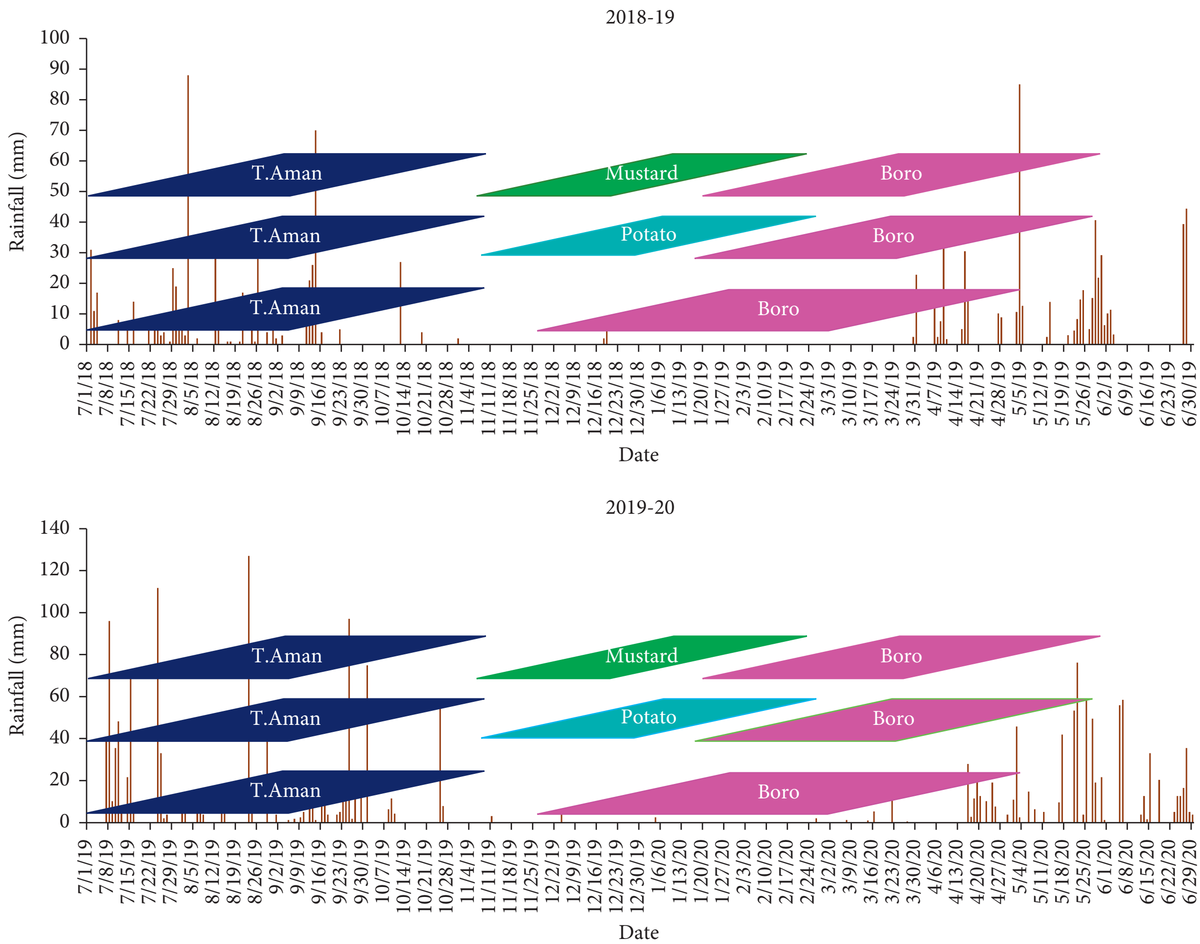

Figure 2: Rainfall distribution in three cropping patterns at Mithapukur and Pirganj of Rangpur during 2018–2019 and 2019–2020 seasons.

Table 2: Irrigation applied (mm) in different cropping patterns (CP1: T. Aman-Mustard-Boro, CP2: T. Aman-Potato-Boro, CP3: T. Aman-Fallow-Boro) at Mithapukur and Pirganj, Rangpur during 2018–2019 and 2019–2020.

Cropping pattern	T. Aman (mm)	Rabi (mm)	Boro (mm) Mithapukur	Total (mm)	Irrigation saved over CP3 (%)	T. Aman (mm)	Rabi (mm)	Boro (mm) Pirganj	Total (mm)	Irrigation saved over CP3 (%)
2018–2019										
CP1	162	112	890	1164b	24	174	63	975	1112b	23
CP2	171	93	758	1023b	33	193	61	777	1032b	29
CP3	132		1405	1537a		208		1240	1448a	
LSD (0.05)				316					186	
CV (%)				26					11.6	
2019–2020										
CP1	0	95	954	1049b	22	0	99	727	826b	35
CP2	0	79	725	804c	40	0	64	776	840b	37
CP3	0		1342	1342a		0		127	1272a	
LSD (0.05)				196					338	
CV (%)				8.4					15.3	

Mithapukur compared with Pirganj. In both locations, delayed transplanting of Boro rice gave a lower yield than early transplanting. Among the cropping patterns, the highest rice equivalent yield, REY, was observed in CP2 and the lowest REY was observed in CP3 in both locations. CP1 and CP2 gave significantly higher REY than the control pattern, CP1 (Tables 3 and 4). The higher yield capacity of potatoes led to the maximum REY in CP2 than the other two

Table 3: Total rice equivalent yield (REY) of different cropping patterns (CP1: T. Aman-Mustard-Boro, CP2: T. Aman-Potato-Boro, CP3: T. Aman-Fallow-Boro) at Rangpur during 2018–2019.

Cropping pattern	Mithapukur, Rangpur				Pirganj, Rangpur			
	T. Aman	Rabi	Boro	Total REY	T. Aman	Rabi	Boro	Total REY
CP1	5.3	1.4	6.1	15.1b	5.3	1.24	7.37	16.2b
CP2	5.4	18.5	6.4	21.0a	5.3	16.7	7.37	21.0a
CP3	5.4		6.8	12.1c	5.0	—	8.07	13.1c
LSD (0.05)				2.6				1.57
CV (%)				9.7				6.0

Price of mustard Tk. 55 kg^{-1}, potato Tk. 10 kg^{-1}, rice Tk. 20 kg^{-1}.

Table 4: Total rice equivalent yield (REY) of different cropping patterns (CP1: T. Aman-Mustard-Boro, CP2: T. Aman-Potato-Boro, CP3: T. Aman-Fallow-Boro) in Rangpur during 2019–2020.

Cropping pattern	Mithapukur, Rangpur				Pirganj, Rangpur			
	T. Aman	Rabi	Boro	Total REY	T. Aman	Rabi	Boro	Total REY
CP1	5.7	1.5	6.1	15.4b	5.4	1.2	6.3	15.1b
CP2	5.1	33.6	5.7	31.3a	4.9	19.6	6.4	21.2a
CP3	5.3		7.6	12.8c	5.1		7.8	12.9c
LSD (0.05)				2.4				2.0
CV (%)				7.0				8.4

Price of mustard Tk. 42 kg^{-1}, potato Tk. 11 kg^{-1}, rice Tk. 20 kg^{-1}.

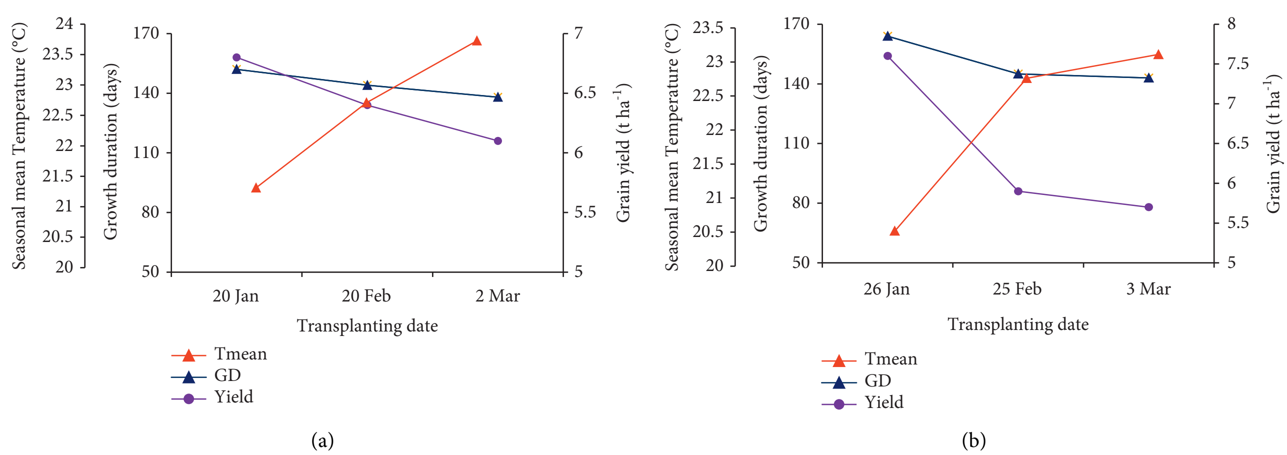

Figure 3: Effect of seasonal mean temperature on grain yield and growth duration (GD) of (a) BRRI dhan58 during Boro 2018–2019 and (b) BRRI dhan29 during Boro, 2019–2020 seasons.

patterns. Two years' findings revealed that the inclusion of potato or mustard crops in existing cropping patterns (CP1) maximized grain yield production in the study locations.

3.4. Temperature Effect on Growth Duration and Grain Yield of Boro Rice. The temperature effect on growth duration and grain yield was analyzed (Figure 3). Results showed that delayed transplanting of Boro rice received a higher seasonal mean temperature than transplanting on 20 January. During 2018–2019, BRRI dhan58 received a 1.5°C higher seasonal mean temperature on 3 March (22.8°C) transplanting than 20 January (21.3°C) transplanting. This increased mean temperature caused 12 days shorter growth duration than 20 January transplanting. Similarly, 2.6°C increased temperature reduced growth duration by 21 days for BRRI dhan29 in 2019–2020 at Pirganj.

3.5. Irrigation Water Productivity. Cultivating three crops in a year (CP1 and CP2) gave the highest irrigation water productivity than cultivating two crops in a year (CP3), because the third crop (Rabi) contributed to the total REY without using much irrigation water. In addition, T. Aman rice experienced significant rainfall during its growing period resulting in less irrigation demand. In both locations, CP2 gave the highest irrigation water productivity followed by the CP1 pattern (Figure 4). Compared with Pirganj, higher irrigation water productivity was observed in Mithapukur due to the better yield performance of Rabi crops in that location.

3.6. Economic Performance of Crops and Cropping Patterns. Cost of production and returns from different crops and cropping patterns during the trial period (2018–2020) were

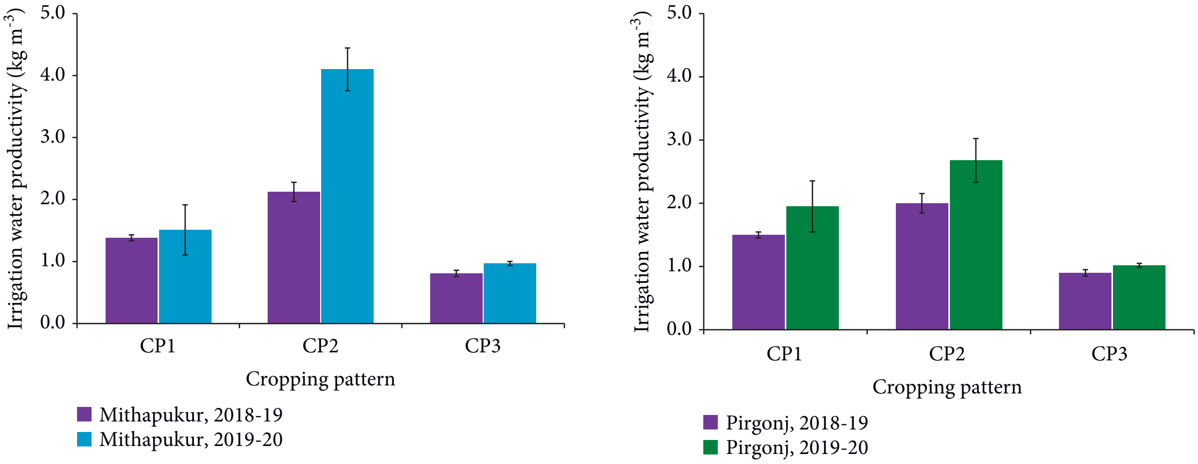

Figure 4: Irrigation water productivity of different cropping patterns at Mithapukur and Pirganj of Rangpur during 2018–2019 and 2019–2020. Error bar indicates standard error.

Table 5: Gross margin (GR), total variable cost (TVC), and gross margin (GM) of different cropping patterns (CP1: T. Aman-Mustard-Boro, CP2: T. Aman-Potato-Boro, CP3: T. Aman-Fallow-Boro) at Rangpur during 2018–2019.

Cropping patterns	GR (US$ ha^{-1})				TVC (US$ ha^{-1})				GM (US$ ha^{-1})
	T. Aman	Rabi	Boro	Total	T. Aman	Rabi	Boro	Total	
Mithapukur, Rangpur									
CP1	1402	917	1826	4145	844	551	1123	2518	1628
CP2	1450	2202	1750	5402	844	1700	1123	3667	1736
CP3	1455		1819	3275	844		1123	1967	1308
Pirganj, Rangpur									
CP1	1429	812	2006	4246	866	444	1160	2470	1776
CP2	1455	1988	1904	5348	866	1744	1160	3770	1578
CP3	1391		2092	3483	866		1160	2026	1457

Table 6: Gross margin (GR), total variable cost (TVC), and gross margin (GM) of different cropping patterns (CP1: T. Aman-Mustard-Boro, CP2: T. Aman-Potato-Boro, CP3: T. Aman-Fallow-Boro) at Rangpur during 2019–2020.

Cropping patterns	GR (US$ ha^{-1})				TVC (US$ ha^{-1})				GM (US$ ha^{-1})
	T. Aman	Rabi	Boro	Total benefit	T. Aman	Rabi	Boro	Total cost	
Mithapukur, Rangpur									
CP1	1600	750	1796	4145	844	551	1123	2518	1628
CP2	1507	4400	1735	7643	844	1700	1123	3667	3976
CP3	1582		2172	3753	844		1123	1967	1786
Pirganj, Rangpur									
CP1	1579	620	2181	4380	866	444	1160	2470	1910
CP2	1486	2567	2080	6133	866	1744	1160	3770	2363
CP3	1534		2219	3753	866		1160	2026	1728

analyzed (Tables 5 and 6). The gross return of rice crop involved return from grain and straw yield. The gross margin from T. Aman rice was similar due to common agronomic management, which led to parallel biological yield in all cropping patterns. The timely establishment of Boro rice in CP3 has a better yield and resulted in a good economic return. However, delayed transplanting of Boro crops in three crop cropping patterns often sacrificed grain yield and resulted in less economic return. Less total variable cost (TVC) was found in T. Aman rice than in Boro rice because of no or few irrigation costs involved in it. Though less gross return was obtained from mustard, the less cost involvement led to a good gross margin from the crop. On the contrary, potatoes required higher production costs, but the good yield performance led to a better economic return. The two years trial showed that both CP1 and CP2 resulted in a better economic return relative to CP3. However, the pattern with potato resulted in the best gross margin among the three patterns.

4. Discussion

The accumulated rainfall by the cropping patterns varied due to the insertion of the third crop in the system. Although the

Rangpur region receives higher rainfall compared with some parts of the country, the rainfall distribution is mostly season-based. About 75% of annual normal rainfall (2290 mm) occurred during the monsoon period [21] and was exclusively higher than the crop evapotranspiration of T. Aman rice. Hossain et al. [21] also reported 1717 mm of normal monsoon rainfall in Rangpur of which only 426 mm is required to meet the consumptive use of T. Aman rice. The rest of the amount remained unutilized during the period and was lost as runoff and percolation. Mojid et al. [25] also found more than double effective rainfall than the potential evapotranspiration during T. Aman season at Bogura and Rajshahi districts adjacent to Rangpur. Thus, no irrigation was required for T. Aman rice cultivation except in drought years [21,26]. Other than the monsoon, crops suffered from rainfall shortages. Both mustard and potato are dry season crops and grown in winter after T. Aman harvest and irrigation at critical stages are enough for good yield. Akhter-Ul-Alam et al. [27] and Azad et al. [23] recommended two irrigations at stolonization and bulking stages for optimum yield of potato and two irrigations for mustard at flowering and pod formation stages in Rangpur. The seedling establishment of Boro rice (irrigated rice) starts in the winter season (November-December) and the growth time went up to May depending on the cultivar's growth duration. Thus, the later part of the crop receives some rainfall. Accommodation of Rabi crops (mustard, potato, vegetables, etc.) delayed the Boro rice season and it received higher rainfall and less irrigation demand than normal time transplanting. Ali [28] reported a similar result where the irrigation requirement of BRRI dhan29 was reduced by 14% and 16% for delayed transplanting on 15 February and 7 March, respectively, from 21 January. The air temperature was found minimum in January in the Rangpur region, and it showed a rising trend after the months. Thus, Boro rice transplanted after January grew up under comparatively high temperatures. This increased seasonal mean temperature due to the delay in the transplanting of Boro rice shortened the field duration and consequently decreased irrigation requirement. The higher accumulated temperature promoted the Boro rice growth and resulted in shortening the life span [13,29]. Rice growth duration decreased by 6–8 days for 1°C mean temperature rise depending on cultivar and location [13,30,31]. Therefore, the combined effect of reduced growth duration and more accumulated rainfall from delayed transplanting saved huge irrigation water in the Rangpur region. This reduced irrigation water can create a huge impact on groundwater withdrawal and power requirements from irrigation equipment operation.

The common cultivar and agronomic management ensured the similar grain yield of T. Aman rice in both the study years. However, the inclusion of mustard and potato in CP1 and CP2, respectively, increased the system rice equivalent yield. Potato yield was huge however the market price was marginal. On the other hand, mustard produced a lower yield compared with other crops, but it had a very good sale price. The combined effect of production and market price for potato and mustard contributed the most to the REY of CP2 and CP3, respectively.

The reduced life span from delayed transplanting of Boro rice in CP2 and CP3 caused significant yield loss to timely transplanting in CP1. This may be attributed to the fact that the cultivar was forced to be matured earlier which also caused less tiller production, increased sterile grain, and less grain number per panicle. Maniruzzaman et al. [31] showed country-wise mean yield loss of 3.44% and 5.03% per 1°C temperature rise for BRRI dhan29 and BRRI dhan58. Hossain et al. [13] estimated 0.69 $t \cdot ha^{-1}$ yield reduction from 1°C temperature rise in Bangladesh. However, the less production of Boro rice in CP1 and CP2 due to elevated temperature was minimized by the outstanding production of mustard and potato. Thus, the REY of both the patterns (CP1 and CP2) was found higher than that of CP1. Khatun et al. [32] also reported a similar result where they found 4.7 $t \cdot ha^{-1}$ more REY in the T. Aman-Mustard-Boro pattern (14.49 $t \cdot ha^{-1}$) over T. Aman-Fallow-Boro in the Rangpur region. The findings conclude that despite the reduced grain yield of Boro rice, both CP2 and CP3 yielded higher than CP1 in the Rangpur district.

The higher REY and irrigation saving in CP2 and CP3 ensued improved irrigation water productivity (IWP) over CP3. The highest IWP in CP2 can be explained by the higher production of potato with only two irrigations in the furrow method. Studies showed that potato has irrigation water productivity ranging from 4.9 to 7.1 $kg \cdot m^{-3}$ (in terms of REY), which was 6–2 times higher than Boro rice (0.6 to 1.0 $kg \cdot m^{-3}$) in Bangladesh [15,18,33]. In another trial at Gazipur, Paul et al. [34] also noticed the highest irrigation water productivity in the T. Aman-Potato-Boro cropping pattern.

The results of economic analysis of different cropping patterns suggest that CP1 and CP2 are the potential options to increase farmers' income in the study locations. Boro rice accounted for higher TVC compared with T. Aman rice, because it included irrigation cost, a vital input for Boro rice production. However, the higher biological yield (grain and straw) in Boro rice headed to a higher gross margin. Compared with mustard, potatoes showed the maximum TVC and gross margin in both years. This result is identical to the findings of Rahman et al. [35] who found GM of 1767 US$ from T. Aman-Mustard-Boro pattern in the Rangpur region. Paul et al. [34] found the maximum net return of US$4448 from T. Aman-Potato-Boro followed by US$1801 in T. Aman-Mustard-Boro, which was much higher than the T. Aman-Fallow-Boro cropping pattern (US$1378) during the cropping year 2009–2010 in Gazipur.

5. Conclusion

The study investigated the prospect of cropping intensification as an option to improve land and water productivity than the existing cropping system. The T. Aman-Mustard-Boro (CP1) and T. Aman-Potato-Boro (CP2) patterns saved 22–35% and 33–40% irrigation water, respectively, with significantly higher yields than the T. Aman-Fallow-Boro cropping pattern in two study locations. The higher yield and water saving in CP1 and CP2 increased the system water productivity as well as gross margin. The better water productivity reduced the water abstraction for irrigation, mostly from a groundwater source. Thus, the adoption of the improved water-saving cropping patterns can restrict the groundwater level depletion in the study area as well as in the water-scarce northwest hydrological region of Bangladesh. Besides, less groundwater abstraction can save power from irrigation pumps and help mitigate greenhouse gas emissions from burning fuel. The additional economic output from the improved cropping patterns may improve farmers' socioeconomic status. In addition, the three crop options in a year will increase the total food production for the country and generate income opportunities in the areas. This study considered Boro-based cropping patterns only; however, we suggest taking T. Aus and/or other cereal-based patterns to verify our findings. In addition, future research should focus on varietal variation, better agronomic management, modern on-farm water-saving technologies, and socioeconomic aspects in the trial.

Data Availability

The data are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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