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Research Article

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Water-Saving Cropping Pattern as A Strategy to Combat Climate Change Effects and Sustain Groundwater Resource in The Dry, North-Western Region of Bangladesh

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Abstract
Increased groundwater use in the Barind area during the last few decades has caused serious groundwater level decline, decreased pump discharge and hence increased irrigation cost, and many associated hydrological problems which have become the biggest threat to sustainable agricultural production under climate change situation. The aims of this research were (i) to identify optimum/water-saving irrigation schedule of possible crops of different seasons, and (ii) yearly total yield and irrigation need assessment of different crop rotations to identify water-saving crop rotation. Field experiments were conducted for three consecutive years at four locations with four new cropping patterns, intervening non-rice crops (wheat, mustard, lentil) as well as natural rainfall matching 'Aus rice' crop. Irrigation water savings and economic benefits of each cropping pattern were evaluated. The results revealed that cultivation of non- rice crops instead of irrigation-intensive 'Boro rice' along with efficient irrigation schedule can reduce a substantial amount (48 - 58%) of irrigation demand along with higher economic benefits (both net profit and Benefit Cost Ratio). The findings of this research will help to plan management decisions to combat the declining trend of groundwater table, as well as the consequences of climate change and drought.

Keywords: Aus Rice, Climate Change, Economic Cropping Pattern, Groundwater, Sustainability, Barind Area.

Introduction

The excessive extraction of groundwater (compared to natural groundwater recharge) for agricultural, industrial and domestic use is a major concern worldwide [1-4]. The problem is more intensive in south-east Asia, where agriculture consumes about 70% of total water use [5-8].

Bangladesh, the most densely populated country in the world except tiny, city-like countries (<1200 km^2) is striving to increase food production to feed its everincreasing population. Decrease in cultivable land due to other activities (e.g. urbanization, housing, industry set up, etc.) is pressing the need for more crop yield per unit of land [9]. Improved crop cultivation along with high inputs (i.e. irrigation and fertilizer) is the major pathway to achieve the goal. The demand for water is also increasing in other sectors such as industry, and other livelihood improvement aspects. The rainfall vagaries and climate change are also pressing demand on available water resources (Aliet al. 2021a). It is also anticipated that water resources stress will be intensified in the future as a result of climate variability (IPCC 2014) [10].

Although Bangladesh falls in the humid region, and average yearly rainfall is good (~2200 mm), faces water scarcity. The monsoonal rainfall heavily concentrated over several few months of the year (May –August). The pattern of cropping seasons of the country is such that the main Boro rice crop season (Jan.– April) is almost rainless, dry [11, 12]. The surface water of monsoonal rainy season finds its way to the sea, as there are no scopes to hold the huge surface flow. The North-western part of the country, the Barind Track area, which covers major part of Rajshahi Division, is in worse condition in terms of water resources, where average yearly rainfall is about 1400 mm (Amin et al. 2004b) [13]. The rapid declining trend of groundwater level in that region becomes a great ecological concern and threat to sustainable agricultural production in the area, and hence can cause a disruption of food security of the country. Recent climate change and rainfall variability makes the situation more vulnerable [14, 8].

Bangladesh is trying hard to harmonize increasing demand of freshwater with already overused renewable groundwater [15-17]. Conventional cropping systems with rice-rice pattern render the reduction of water consumption in agricultural sector. Under the current demand of high yielding irrigated culture of crops, irrigation water use accounts for nearly 65% of total water use. The socio-cultural food habit (rice as a staple food) urges for rice-rice cropping pattern. Taking rice as the major crop, replacement of irrigation-intensive 'Boro rice' by rainfall-matching 'Aus rice' can be a hope to reconcile irrigation demand [18]. Ghazvi and Ebrahimi (2019) also suggested that climate change adaptation strategies in the arid and semi-arid region should include changing the crop type, as well as water productivity and irrigation efficiency enhancement at the farm and regional scale.

Numerous studies regarding different cropping patterns were reported focusing the yield or profitability of the system but a few of them focused on yearly irrigation water savings or on utilization of natural rainfall. Sarkar et al. (2013) made efforts to increase cropping intensity through conserving and utilizing profile soil moisture and applying supplemental irrigation at Nachol Upazila, Chapainawabganj District of Bangladesh [19-25]. Field experimental results revealed 'Rice – Chickpea – Mungbean' as the most economic pattern. Ali (2018) studied the response of supplemental irrigation and levee management on rice cultivars in drought prone area of Bangladesh. He found that levee height of 20 cm showed positive impact on yield and saves about 25 – 39% water with insignificant yield reduction.

Mojid and Mainuddin (2021) stressed to quantify regional hydrological outcome for proper water management policy aiming at sustainable agricultural production. Acharjee et al. (2020) tried to identify and prioritize adaption options for mitigating water demand due to climate change. They used literature review and stakeholder consultation information, and then performed multi-criteria analysis. Under different categories of in-system and out-system dependent options, they recommended for implementation of achievable adaptation measures based on local agricultural system.

Considering the circumstance of Barind, dry area, several cropping patterns were studied (along with optimum/water-saving irrigation schedule for individual crop) to compare the yearly rice-equivalent yield, irrigation requirement, and economic return with a view to find out a water-saving economic pattern, which could be suggested for sustainable groundwater utilization in that area.

Materials and Methods

Description of The Study Area

Study Site

North-western area of Bangladesh is largely engaged by Pleistocene deposits (Morgan and McIntire 1959). Present study is, however, based on part of a configuration of two districts (Chapainawabganj and Naogaon). The studied locations are Nachol Upazila [Charmanpara (24.781378 deg. N, 88.433723 deg. E) and Jonakipara (24.702121 deg. N, 88.420095 deg. E)] of Chapainawabganj district and Niamatpur Upazila [Verendibazar (24.742633 deg. N, 88.427444 deg. E) and Sirajpur (24.829304 deg. N, 88.439163 deg. E)] of Naogaon district. The location map of the studied area is shown in Figure1:

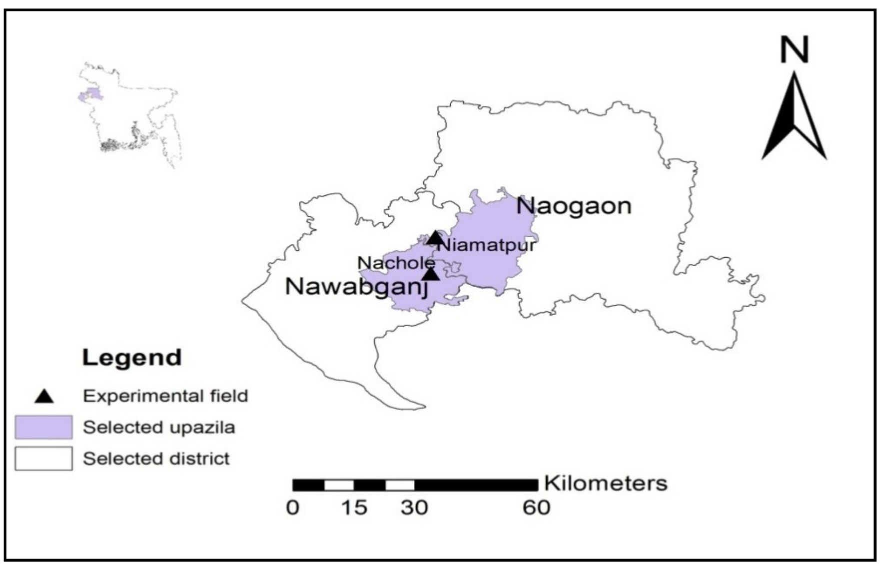

Figure 1: Location map of the study area (nachol and niamatpur)

Hydro-Geological Conditions and Topography

The topography of the region is characterized by two distinct landforms: (a) The Barind tract – dissected and undulating, and (b) The floodplains. The elevated Barind tract is characterized by less infiltration due to clayey and semi- to impermeable Barind clay with excessive surface runoff. Morpho-stratigraphically, the region is subdivided into three geological units: (1) Barind clay residuum – overlies and developed on Pleistocene alluvium, (2) Holocene Ganges flood-plain alluvium, (3) Active channel deposits of the Ganges and major distributaries (modern alluvium). The lithology types include alluvial sand, alluvial silt, Barind clay residuum, and Marsh clay and peat [26]. Hydrogeologically, the area is covered by semi-impervious clay-silt aquitard of Recent-Pleistocene period (thickness 3.0 – 47.5 m), and is characterized by single to multiple layered (2 – 4) aquifer system of Plio-Pleistocene age (thickness 5.0 – 42.5 m) [27].

Rainfall Pattern of The Area

The monthly pattern of rainfall data collected from Bangladesh meteorological Department (BMD) is presented in Figure. 2 (mean of 1975 to 2019). The yearly rainfall fluctuates considerably (792 – 2241 mm); having mean, standard deviation and coefficient of variation of 1447 mm, 297.4 mm, and 20.5 %, respectively. Approximately 83% of this rainfall occurs during the months of May – September which is noted as monsoon season.

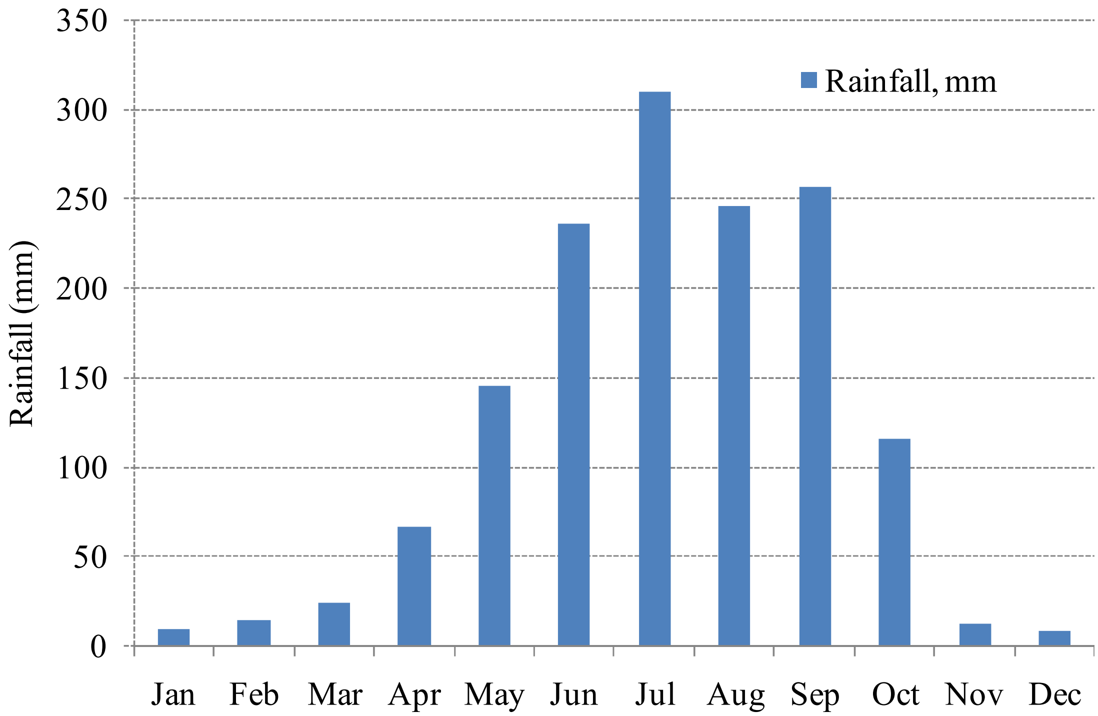

Figure 2: Mean monthly rainfall distribution at the study area (of year 1975-2019)

Groundwater Pattern of The Area

The patterns of yearly maximum and minimum water-table (1980-2019) at Nachol and Niamatpur are depicted in Figure.3.1 and Figure.3.2, respectively. Here, the magnitude between maximum and minimum depth to water-table (WT) is decreasing over time and the decreasing rate is approximately 0.43 m/year and 0.33 m/year, respectively for Nachol and Niamatpur.

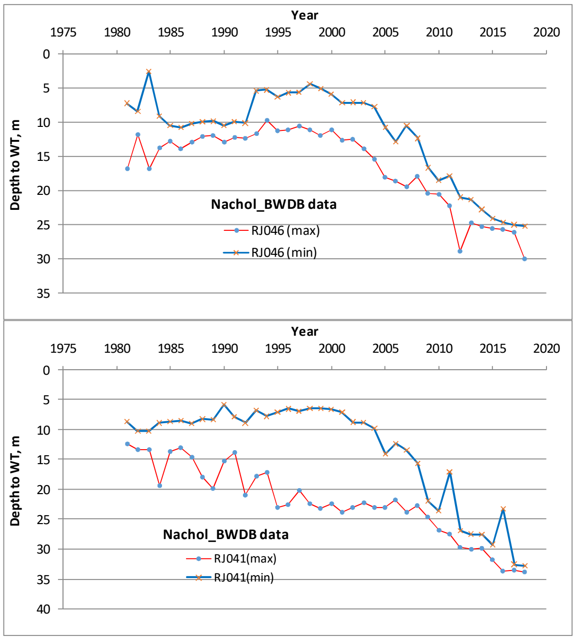

Figure 3.1: WT pattern of two wells at Nachol

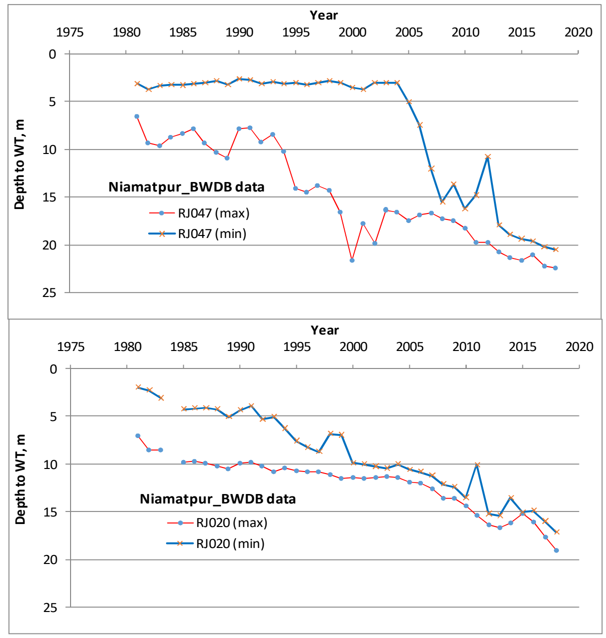

Figure 3.2: WT pattern of two wells at Niamatpur

Studies on The Effect of Irrigation Regimes on Yield and Water Savings in Different Crops

In the first year, different irrigation management options were investigated to find out the optimum/water- saving option. Details of irrigation treatments for different crops are given in Table 1. The treatments were based on the recommended irrigation management surrounding the study areas, and also water- saving regime(s) studied other parts of the country.

Table 1: Irrigation treatments for different crops

Crop	Treatments
Lentil	T_1 = No irrigation (only the use of profile soil moisture) T_2 = One irrigation at flowering stage (40-60 days after sowing)
Wheat	T_1 = 03 irrigation (at CRI, vegetative, booting-heading stage) T_2 = 04 irrigation (at CRI, vegetative, booting-heading, soft-dough stage)
Mustard	T_1 = Control (Farmers practice: 01 irrigation at vegetative stage) T_2 = Irrigation at early (15-17 DAS) and vegetative stage (28-30 DAS)
T.Aus	T_1 = Control [normal levee (Farmer's practice), and 3 days AWD] T_2 = 20 cm height levee around the plot, and rainfed T_3 = 20 cm height levee around the plot, and supplemental irrigation if ASM drops below 85%
T. Aman	T_1 = Control [normal levee (Farmer's practice), and 3 days AWD] T_2 = 20 cm height levee around the plot, and rainfed T_3 = 20 cm height levee around the plot, and supplemental irrigation during booting to soft-dough, if ASM drops below 85%
Boro	T_1 = 3 days AWD (5 cm ponding) T2 = 5 days AWD (5 cm ponding)

<u>Note</u>:

CRI = Crown root initiation stage; AWD = Alternate wetting and wetting; 3 days AWD = Irrigation after 3 days of water disappearance from the soil surface; ASM = Available soil moisture

ET Calculation

The evapotranspiration (ET) for different crops was estimated as follows:

A) For Dry-Land Crops (Lentil, Mustard, Wheat)

For the dry-land crops (where, $(I + R_e) \leq ET$), the ET was calculated from the following water balance equation (Ali 2010; Ali and Mubarak 2017):

$$I + R_e = ET \pm \Delta S \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\text{or, } ET = I + R_e \pm \Delta S \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where:
I = Irrigation amount (mm)
R_e = Effective rainfall (mm)
□S = Change in soil moisture within the effective root-zone of the crop (cm)
ET = Crop evapotranspiration (mm)

A) For Wet-Land Crops (Boro, Aus, And Aman Rice)

For wet-land crops, where the ‘rainfall’ or ‘sum of rainfall and irrigation’ exceeds or equals the crop evapotranspiration demand, the ET was calculated as (04 and Mubarak 2017):

$$ET_a = ET_0 \times Kc \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where:
ET_0 = Reference evapotranspiration (mm)
Kc = Crop coefficient
ET = Crop evapotranspiration (mm)

Studies on Different Crop Rotations with Best/Water-Saving Irrigation Practice

From the survey of the study area, it is revealed that the major cropping patterns practiced by the farmers are: (1) Aman-Boro-Fallow, (2) Aman – Rabi/Kharif - Fallow. Along with local existing cropping pattern, different 'low water demanding'/ 'water-efficient' cropping patterns (including technological intervention, such as new drought tolerant Aman variety, drought tolerant transplanted Aus varieties) were studied to find out an economic and water-efficient cropping pattern.

The following new cropping patterns were selected for trial in the area: (a) Aus – Aman – Rabi (Mustard/Lentil/Wheat), and (b) Boro - Aman – Rabi (Mustard/Lentil). New cropping patterns are elaborated in Table 2. The experimental design was Randomized Complete Block Design (RCBD), with cropping patterns as treatments and replicated at four locations. The schematic of layout of the experiment is shown in Figure. 4.

Table 2: Details of cropping pattern selected for intervention

Major crop for pattern	Cropping pattern	Pattern No.	Treatment
Aus based	Aus - Aman – Rabi (Mustard)	Pattern-1	T1
	Aus - Aman – Rabi (Lentil)	Pattern-2	T2
	Aus - Aman – Rabi (Wheat)	Pattern-3	T3
Boro based	Boro - Aman – Rabi (Mustard)	Pattern-4	T4
	Boro - Fallow - Aman	Pattern-5 (Control, existing practice)	T5

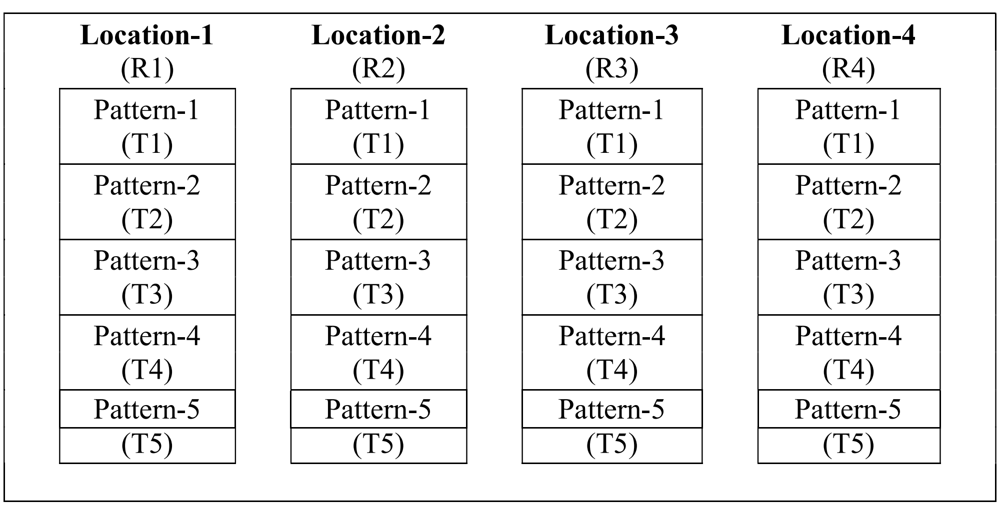

Figure 4: Schematic of Layout of cropping pattern experiment

Date of sowing or transplanting and harvesting of different crops under different crop rotations (or cropping patterns) is presented in Table 3.

Table 3: The date of sowing/transplanting and harvesting of the crops

Cropping Pattern	Crop	Date of sowing or transplanting		Date of Harvesting
		Direct Sowing	Transplanting	
Pattern-1	T. Aman	-	05 August	10 November
	Mustard	18 November	-	19 February
	T. Aus	-	16 March	30 June
Pattern-2	T. Aman	-	02 August	8 November
	Lentil	18 November	-	10 March
	T. Aus	-	18 March	3 July
Pattern-3	T. Aman	-	02 August	8 November
	Wheat	16 November	-	13 March
	T. Aus	-	18 March	2 July
Pattern-4	T. Aman	-	02 August	8 November
	Mustard	13 November	-	14 February
	Boro	-	3 March	4 June
Pattern-5	T. Aman	-	19 July	24 November
	Fallow	-	-	-
	Boro	-	29 January	24 May

The best irrigation management option for a particular crop identified in the first year experiment was
used in different crop rotations.

Irrigation System and Method

For all crops, surface irrigation system was used. The water application method used was flood irrigation (In the studied irrigation scheme area, buried irrigation pipe system with 'surface outlets' are existed).

Calculation of Equivalent Rice Yield

For each cropping pattern (as mentioned in Table 2), the crops other than rice were transformed to equivalent rice. Equivalent rice yield of a non-rice crop (i) was calculated as:

$$Y_{eq-i}(t/\text{ha}) = \frac{Y_i(t/\text{ha}) \times P_i(\$/t)}{P_r(\$/t)} \quad \text{........................} \ (4)$$

Where,
Y_{eq-i} = Equivalent rice yield, t/ha
Y_i = Yield of a non-rice crop, t/ha
P_i = Price of a non-rice crop, \$/t
P_r = Price of rice, \$/t

Economic Analysis

In this analysis, total cost of production was included. The cost items were categorized as following heads for analytical advantages:

Operating cost:

Operating cost consists of cost of human labor; power tiller hiring; cost of seed, fertilizer, insecticide, irrigation application; and land use cost.

Human labor requirement consists of sowing, weeding and thinning, insecticide spraying, harvesting, carrying, threshing and cleaning. Land use cost was estimated using seasonal rental value or lease value of the land used.

Interest on operating capital:

The operating capital actually represents the average operating costs over the period because all costs are not incurred at the beginning or at any fixed time. The costs were incurred throughout the whole production period. Interest on operation cost was estimated by using the following formula [28-29]:

Interest on operating capital = (Operating capital / 2) x rate of interest x time considered
....(5)

Total cost = Operating cost + Interest on operating cost
Per hectare gross return was calculated by multiplying the total amount of product and by-product by their
respective market prices.

Net profit (NP) was calculated as: NP = Gross return – total cost

Benefit Cost Ratio (BCR) was calculated as:

CR = Total benefit (per hectare) / Total cost (per hectare)

Statistical Analysis

The statistical analyses were performed using "STAR" software of 'International Rice Research Institute' (IRRI), version 2.0.1 [30].

Results and Discussion

Effects of Irrigation Regimes on Yield and Irrigation Requirement

The yield and irrigation water requirement of different crops under different irrigation regimes are summarized in Table 4.1 to Table 4.7.

Yield of Lentil

The seed yield of lentil under different treatments (Table 4.1) demonstrated that except one location (Chairmanpara), application of irrigation had no benefit but reduced yield. On average, the yield under 'no irrigation' is higher than that of 'one irrigation'. The response of lentil to irrigation regimes at similar or other parts of the country supports the result. Sarkar et al. (2000) studied the response of irrigation on lentil in a dry area, Ishwardi (North-western part, Rajshahi Division), Bangladesh. From three years results, they noted that the highest seed yield was recorded from 'no irrigated' plot. They also noted that the seed yield gradually decreased with the increase in irrigation amount. They concluded that stored soil moisture is sufficient to produce its optimum yield, and application of irrigation seemed harmful to the crop. Bell et al. (2019) also reported good yield of lentil without irrigation under conservation agriculture at Rajshahi region.

Table 4.1: Yield of Lentil (Binamasur-8) at different locations

Upazila	Location/Village	Seed Yield (t/ha)		Irrigation Amount (cm)		ET (cm)	
		T_1	T_2	T_1	T_2	T_1	T_2
Nachol	Chairmanpara	1.28	1.44	0	5	9.10	14.10
	Jonakipara	1.55	1.45	0	5	8.90	13.90
Niamatpur	Verendibazar	1.46	1.41	0	5	9.00	14.00
	Sirajpur	1.57	1.48	0	5	9.30	14.30
Average		1.47	1.45	0	5	9.1	14.1

Note:

T_1 = No supplemental irrigation (only the use of profile soil moisture)

T_2 = One supplemental irrigation at flowering stage (40-60 days after sowing)

Yield of Mustard

With a slight variation of seed yield among locations, the average seed yields are very close among the treatments (one or two irrigations) (Table 4.2). Sarkar et al. (2012-13) in a cropping pattern study at dry, Barind area (Cosba village, Nachol Upazila) found good yield of mustard (1.8 t/ha) with 2 irrigations applied at vegetative and flowering stage. Ali et al. (2013) evaluated irrigation response on mustard mutants at Ishwardi area (north-western, dry area). They tested the effect of single irrigation at vegetative or flowering stage, and also two irrigations at vegetative and flowering stage. They noted the highest yield with 2 irrigations, but comparable yield (only 12% less) with one irrigation at vegetative stage. Mila et al. (2013) studies the response of mustard to different irrigation regimes at Mymensingh area. They found that yield from one irrigation at vegetative stage was similar to that of two irrigations applied at vegetative and flowering stages.

Table 4.2: Yield of Mustard (Binasarisa-9) at different locations

Upazila	Location/Village	Seed Yield (t/ha)		Irrigation Amount (cm)		ET (cm)	
		T_1	T_2	T_1	T_2	T_1	T_2
Nachol	Chairmanpara	1.72	1.78	5	10	12.3	17.3
	Jonakipara	1.84	1.88	5	10	12.8	17.8
Niamatpur	Verendibazar	1.8	1.77	5	10	12.7	17.7
	Sirajpur	1.66	1.81	5	10	13.2	18.2
Average		1.76	1.81	5	10	12.8	17.8

Note:

T_1 = Control (Farmers practice: Irrigation at vegetative stage)

T_2 = Irrigation at early (15-17 DAS) and vegetative stages (28-30 DAS

Yield of Wheat

Table 4.3: shows the grain yield of wheat at different locations. Here, the average yield from 3 and 4 irrigations are almost similar.

Table 4.3: Yield of Wheat (BARI Gom 26) at Nachol and Niamatpur

Upazila	Location/Village	Grain yield (t/ha)		Irrigation Amount (cm)		ET (cm)	
		T_1	T_2	T_1	T_1	T_1	T_1
Nachol	Chairmanpara	3.69	3.71	12	16	21.4	25.4
	Jonakipara	3.78	3.89	12	16	21.6	25.6
Niamatpur	Verendibazar	3.91	3.78	12	16	22.4	26.4
	Sirajpur	3.95	4.14	12	16	22.5	26.5
Average		3.83	3.88	12	16	22.0	26.0

***Note**:*

T_1 = 03 irrigations (at CRI, vegetative, booting-heading stage)

T_2 = 04 irrigations (at CRI, vegetative, booting-heading, soft-dough stage)

Sarkar et al. (2012-13) reported good yield of wheat (3.6 – 4.2 t/ha) at different locations of Nachol and Gomostapur area (Barind, Rajshahi) applying 2 irrigations. At Ishwardi (Rajshahi Division) area, Ali et al. (2007) investigated a range of irrigation regimes (no irrigation, full irrigation (4 nos), and different combinations of stage-wise irrigation). From 3 years average data, they noted the highest yield with 4 irrigations applied at four growth stages (CRI+vegetative+booting-heading + flowering-softdough). The "three irrigations" treatment showed statistically similar yield to that of "four irrigations". They obtained highest water productivity from 2 irrigation regimes applied at CRI and booting-heading stages.

Parveen et al. (2015) tested different irrigation treatments at Gazipur area: one irrigation (at 19 DAS – Days after sowing), two irrigations (at 19, 58 DAS), and three irrigations (at 19, 58, 72 DAS). They obtained highest yield from 3 irrigations, but comparable yield from 2 irrigations (only 14% less than that of 3 irrigations).

Yield of Boro rice

The response of grain yield of Boro rice under different locations are summarized in Table 4.4. There was a title variation of irrigation water demand over locations within the same treatment. This may be due the micro-climate variation (soil and weather). On an average, 3 days AWD treatment produced 6.13% higher yield but with 15.9% additional irrigation water compared to that of 5 days AWD.

For Boro rice, Parveen et al. (2015) tested continuous standing water, saturation level, and 3 days AWD. They found almost similar yield in all treatments. Ali (2020) investigated the impact of AWD on rice yield, water productivity and irrigation water savings at Mymensigh region. The irrigation treatments comprised of: Normal farmer's practice (continuous ponding, 3-5 cm (CP)), alternate wetting and drying (AWD) for 3 days after disappearance of ponded water, 5 days AWD, and a combination. He noted that the grain yields varied from 3.9 to 4.4 t ha–1 with no significant difference in yield attributes, grain yields and straw yields between AWD and CP. The productivity of water in AWDs was about 6 - 40% higher than that of CP, and the water savings in AWDs compared to CF were 22 – 35%. He also noted that alternate wetting and drying for 5 days saved substantial amount of irrigation water without sacrificing yield.

Table 4.4: Treatment-wise yield of Boro rice at Nachol and Niamatpur

Upazila	Location/ Village	Crop variety	Grain yield (t/ha)		% Yield decreas ed over T_2	Irrigation Amount (cm)		% Irrigation increas ed over T_2	ET (cm)	
			T_1	T^2		T_1	T^2		T_1	T^2
Nachol	Chairman para	Binadhan-18	6.18	5.87	5.28	75	66	13.64	70.0	61.3
		BRRI dhan58	6.12	5.79	5.70	75	66	13.64		
		Banglajira	6.06	5.58	8.60	75	66	13.64		

	Jonaki-para	Binad-han-18	6.0	5.77	3.99	72	60	20.00	70.0	60.0
		BRRI dhan58	6.03	5.81	3.79	72	60	20.00		
		Banglajira	6.16	5.69	8.26	72	60	20.00		
Niamat pur	Verendiba zar	Binad-han-18	5.61	5.32	5.45	72	60	20.00	68.0	62.7
		BRRI dhan58	6.59	6.27	5.10	72	60	20.00		
		Banglajira	6.12	5.78	5.88	72	60	20.00		
	Sirajpur	Binad-han-18	5.77	5.12	12.70	66	60	10.00	74.0	
		BRRI dhan58	6.19	5.78	7.09	66	60	10.00		
		Banglajira	5.5	5.41	1.66	66	60	10.00		
Average			6.03	5.68	6.13	71.25	61.50	15.91	70.5	62.7

Note: *AWD = Alternate Wetting and drying*

T_1= 3 days AWD (5 cm ponding)

T_2= 5 days AWD (5 cm ponding)

Different rice varieties were tested in Aus season. There were significant variations of average grain yield and irrigation amount between irrigation treatments (Table 4.5). The rice varieties also showed a little variation.

Ali (2018) investigated yield response of Aus rice cultivars at drought-prone area, Nachole and Tanor Upazila of Rajshahi district. The results of the field study demonstrated that the cultivars Binadhan-17, Binadhan-19 and BRRI dhan48 produced good yield under 20 cm height levee, and levee plus supplemental irrigation at 75% depletion of ASM (and also insignificant variation with normal irrigation).Similar trend of grain yield was also reported from lysimeter study.

Table 4.5. Yield of Transplanted Aus rice at Nachol and Niamatpur

Upazila	Location/ Village	Crop variety	Grain yield (t/ha)			Irrigation Amount (cm)			ET (cm)		
			T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
Nachol	Chairmanp ara	Binadhan-17	4.08	3.8	4.23	30	0	18	51.5	21.5	39.5
		BRRI dhan55	4.12	3.72	4.07	30	0	18			
	Jonakipara	Binadhan-17	4.31	3.57	4.28	25	0	18	46.5	21.5	39.5
		BRRI dhan55	4.18	3.87	4.35	25	0	18			
Niamat- pur	Verendibaz ar	Binadhan-17	4.19	4.19	4.14	24	0	12	45.5	21.5	33.5
		BRRI dhan55	4.27	3.5	3.81	24	0	12			
	Sirajpur	Binadhan-17	3.96	4.13	4.46	24	0	12	45.5	21.5	33.5
		BRRI dhan55	4.35	3.47	4.17	24	0	12			
Average			4.18	3.78	4.19	25.75	0	15	47.2	21.5	36.5

Note:

T_1 = normal levee (Farmer's practice), and irrigation at 3 days AWD

T_2 = 20 cm height levee around the plot, and rainfed.

T_3 = 20 cm height levee around the plot and supplemental irrigation if ASM drops below 85%

Yield of T. Aman rice

Yield of different Aman rice varieties under different irrigation treatments are summarized in Table 4.6. On average, the treatment T1 (normal levee and 3 days AWD) produced the highest grain yield, and T2 (20 cm levee and rainfed) the least. The treatment T1 and T3 (20 cm levee and supplemental irrigation) produced almost similar yield. But considering irrigation water saving, the yield of treatment T2 seems reasonable.

In field trial with Aman rice cultivars, Ali (2018) observed at Nachol and Chapainawabgonj Upazila that, the management of "20 cm height levee around the plot and rainfed" produced good and comparable/similar yield to that of normal levee (farmers practice) and supplemental irrigations (1- 2 nos). For Aman rice, tested at Nachol and Gomostapur Upazila, Sarkar et al. (2012-13) reported good yield of Binadhan-7 (4.0 – 4.76 t/ha) under rainfed condition, averaging 4.4 t/ha over 13 locations.

Parveen et al. (2015) investigated 3 irrigation treatments for T.Aman namely, rainfed (T1), irrigation at vegetative + reproductive stage (T2), irrigation at vegetative + 2 irrigations at reproductive stage (T3). They found almost similar yield (only 3% variation) from T2 and T3. Ali (2019) reported that late Boro rice (Feb.15 to March 30 transplanting) required less irrigation water because of partial fulfillment of irrigation demand from natural rainfall throughout different regions of the country.

Table 4.6: Yield of Transplanted Aman at Nachol and Niamatpur

Upazila	Location/ Village	Crop variety	Grain yield (t/ha)			Irrigation Amount (cm)			ET (cm)		
			T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
Nachol	Chairma npara	Binadhan-17	4.95	3.58	4.78	20	0	16	38.4	18.4	34.4
		BRRI dhan55	4.79	3.49	4.83	20	0	16			
	Jonakip ara	Binadhan-17	4.86	3.58	4.87	20	0	12	38.4	18.4	30.4
		BRRI dhan55	4.91	3.66	4.83	20	0	12			
Niamat pur	Verendi bazar	Binadhan-17	4.81	4.55	4.74	20	0	12	38.4	18.4	30.4
		BRRI dhan55	4.78	4.76	5.04	20	0	12			
	Sirajpur	Binadhan-17	4.95	4.71	4.76	20	0	12	38.4	18.4	30.4
		BRRI dhan55	4.87	4.58	4.83	20	0	12			
Average			4.87	4.11	4.84	20	0	13	38.4	18.4	31.4

Note:

T_1 = normal levee (Farmer's practice), and irrigation at 3 days AWD

T_2 = 20 cm height levee around the plot, and rainfed.

T_3 = 20 cm height levee around the plot and supplemental irrigation if ASM drops below 85%

Selection of Best Irrigation Management Option for Cropping Pattern Study

The Irrigation management options selected from the field trial of first year (considering yield and rrigation water use/ irrigation water savings) are summarized in Table 4.7.

Table 4.7. Irrigation management option selected based on yield and water use.

Crop	Selected irrigation management option	Comment / Compare with nearest irrigation management option
Lentil	No irrigation (only based on existing soil moisture)	Application of irrigation adds no benefit, but reduces yield.
Wheat	03 irrigation (at CRI, vegetative, booting-heading stage)	With 04 irrigation (at CRI, vegetative, booting-heading, soft-dough stage), yield increased only by 5%.
Mustard	Irrigation at vegetative stage (28-30 DAS)	Applying irrigation at early (15-17 DAS) and vegetative stages (28-30 DAS), yield increased by only 4%.
T.Aus	20 cm height levee around the plot and supplemental irrigation if ASM drops below 85%	With 3 days AWD, yield increased by 8% with 15 cm additional irrigation water
T.Aman	20 cm height levee around the plot, and supplemental irrigation during booting to soft-dough, if ASM drops below 85%	With normal levee (Farmer's practice), and 3 days AWD, yield increased by 2% with 10 cm additional irrigation water.
Boro	3 days AWD (5 cm ponding)	The traditional farmer's practice (long duration cultivar) with continuous ponding water - increased only 4.5% yield with 15 cm additional irrigation water than the 3 days AWD.

Yield, Irrigation Water Use, And Net Profit Under Different Cropping Patterns

Year-wise rice-equivalent yield, water productivity, net income, BCR, and irrigation water savings in different cropping patterns are presented in Table 5. Rice-equivalent yield of all introduced cropping patterns (T1 – T3) were higher than that of existing pattern (T5, T.Aman-Fallow-Boro). In case of Aus based cropping patterns, maximum rice-equivalent yield was found in Pattern-1 (T. Aman-Mustard-T. Aus). Total seasonal irrigation amount, water productivity, BCR and Net income under this pattern were 52 to 55 cm, 238 to 281 kg/ha/cm, 1.42 to 1.66, and 1001 to 1523 $/ha, respectively. Having Boro rice and additional rabi crop (Mustard) in Pattern-4 (T. Aman-Mustard-Boro), irrigation amount was less than that of existing farmer's practice, Pattern-5 (T. Aman-Fallow-Boro). This is because; high yielding and short duration Aman rice (i.e. Binadhan-17, Binadhan-22 and BRRI dhan71), Mustard (i.e. Binasarisha-9, Binasarisha-10 and BARI Sarisha-14) and Boro rice (i.e. Binadhan-14) were used in Pattern-4 (T. Aman-Mustard-Boro). The REY was the highest in pattern-4, but irrigation requirement was higher compared to pattern-1, 2 & 3. In terms of water savings, all introduced new cropping patterns were water saving as well as profitable than that of existing pattern. Percent increase in rice-equivalent yield as well as net income was comparatively low in year 2020-2021 because of high market price of rice during that time. The cropping patterns performed some differences in different years, which may be due to micro-climate differences (weather & soil fertility).

Mainuddin et al. (2021) evaluated the productivity and profitability of Boro rice production through collecting data directly from 420 farmers' field over two consecutive years at Barind region (Rajshahi), and reported that total cost and gross benefit differed among the sites mainly due to irrigation cost. They also noted that the cost of irrigation always comprised the highest input cost (20 – 25 % of total production cost).

Sarkar et al. (2013) investigated the possibility of increasing cropping intensity in dry area of Rajshahi (with no facility of irrigation irrigated rice) through conserving and utilizing profile soil moisture and supplemental irrigation application. They used three cropping patterns: Rice-Chickpea-sesame, Rice- Chickpea-Mungbean, and the existing 'Rice-Fallow-Fallow'. They got the highest net profit from Rice- Chickpea-Mungbean pattern amounting BDT 1,38,000 (US$1734). Parveen et al. (2015) studied the water productivity and profitability of three rice-based cropping patterns (T.Aman-Boro-Fallow, T.Aman- Wheat-Mungbean, T.Aman-Potato-Mungbean) at Gazipur area of Bangladesh. They got the highest profit from "T.Aman-Potato-Mungbean" pattern. They noted that the price of potato contributed to maximum return. Total water was highest in Boro-based pattern, followed by potato-, followed by wheat-based pattern.

To identify profitable cropping pattern at Satkhira district (south-western part of Bangladesh), Paul et al. (2016) investigated 4 rice-based cropping pattern using recommended irrigation practices, such as, AWD for Boro and Aman rice, 2 irrigations for mustard, 3 to 4 irrigations for wheat and potato. They observed from the results that the productivity of the common cropping pattern "T.Aman-Boro-Fallow" can be increased by 2 to 3 fold through the adoption of high yielding T.Aman rice followed by high yielding non-rice crops such as mustard, wheat, potato and jute.

Table 5: Rice-equivalent yield REY), water productivity, net income, BCR, and irrigation water saving in different cropping patterns at study area

Year	Cropping Pattern	REY yield (t/ha)	Irri. Amount, cm (seasonal total)	Water Productivity, kg/ha/cm	Net Income ($/ha)	BCR	% Irrigation Saving	% Yield Increase	% Net income Increase
2018-19	Pattern-1	14.53 b	52 d	281 b	1001 b	1.42 b	56	20	30
	Pattern-2	14.01 c	47 e	297 a	956 c	1.42 b	60	16	24
	Pattern-3	13.89 c	58 c	241 c	988 bc	1.43 b	51	15	28
	Pattern-4	16.05 a	89 b	180 d	1213 a	1.49 a	24	33	57
	Pattern-5	12.09 d	118 a	102 e	770 d	1.38 c	-	-	-
	F-test at (5%)	S	S	S	S	S	-	-	-

2019-20	Pattern-1	14.82 b	55 d	270 b	1158 b	1.49 b	52	24	36
	Pattern-2	14.64 b	50 e	293 a	1116 bc	1.48 bc	56	22	31
	Pattern-3	14.17 c	61 c	232 c	1068 c	1.45 c	46	18	25
	Pattern-4	16.35 a	85 b	193 d	1405 a	1.57 a	25	36	65
	Pattern-5	11.98 d	114 a	106 e	852 d	1.42 d	-	-	-
	F-test at (5%)	S	S	S	S	S	-	-	-
2020-21	Pattern-1	13.18 b	55 d	238 b	1523 b	1.66 b	52	8	22
	Pattern-2	12.96 b	51 e	257 a	1471 b	1.64 b	56	7	18
	Pattern-3	13.05 b	62 c	212 c	1526 b	1.66 b	47	7	22
	Pattern-4	15.23 a	88 b	172 d	1836 a	1.73 a	24	25	47
	Pattern-5	12.15 c	116 a	105 e	1250 c	1.59 c	-	-	-
	F-test at (5%)	S	S	S	S	S	-	-	-

Note: 1 US$ = 85 BDT. Means with the same letter are not statistically different at 5% probability level by Tukeys's Honest Significant Difference (THSD) test [Appropriate test statistic is selected by the software automatically].

Combined Yield, Irrigation Water Use, And Net Profit

Combined analysis of rice-equivalent yield, irrigation amount and water productivity were performed (over locations and years) and presented in Table 6. Cultivation of Rabi crops like mustard, lentil or wheat, and Aus rice instead of Boro, requires less amount of irrigation water, but produces higher annual rice-equivalent yield (REY) and net profit (pattern-1, 2 & 3).

Instead of the traditional two cropped "Aman-Fallow-Boro" pattern, the three-cropped "Aman-Rabi (lentil/mustard/wheat) - Aus" pattern saves an average of about 48 - 58 percent irrigation water and increases the equivalent rice yield to about 14-17 percent. But considering irrigation water savings and REY, pattern-1 is the most attractive, then pattern-2 and then pattern- 3

Table 6: Mean rice-equivalent yield (REY), water productivity (WP), net income, BCR, and irrigation water saving (Over locations and years).

Cropping Pattern	REY (t/ha)	Irri. Amount, cm (seasonal total)	WP, kg/ha/cm	Net Income ($/ha)	BCR	% Irrigation Saving	% Irrigation Excess over P-1	% Yield Increase	% Net income Increase
Pattern-1	14.18 b	54 d	263 b	1227 b	1.52 b	53	-	17	28
Pattern-2	13.87 bc	49 e	283 a	1181 b	1.51 b	58	-9	15	23
Pattern-3	13.71 c	60 c	229 c	1194 b	1.52 b	48	11	14	25
Pattern-4	15.88 a	88 b	182 d	1485 a	1.60 a	25	62	32	55
Pattern-5	12.07 d	116 a	104 e	958 c	1.46 c	-	115	-	-
F-test at (5%)	S	S	S	S	S	-	-	-	-

Note: 1 US$ = 85 BDT. Means with the same letter are not statistically different at 5% probability level by Tukeys's Honest Significant Difference (THSD) test [Appropriate test statistic is selected by the software automatically].

Considering the average water savings of 'Aus-based' cropping patterns (T1 to T3, 61 cm) [from Table 6], the yearly water savings in the studied two Upazila (Nachol and Niamatpur) is about 0.447 km^3; and for the corresponding two districts (Chapainawabganj and Naogaon) is about 3.134 km3 (Table 7).

Table 7: Water savings at local (Nachol and Niamatpur Upazila) and regional scale (Chapainawabganj and Naogaon District)

Location	Area (km^2)	Average irrigation savings, depth (cm)	Total water savings (km^3)
Nachol and Niamatpur Upazila	732.78	61	0.447
Chapainawabganj and Naogoan District	5138.23	61	3.134

Discussion and Policy Implications

Among the United Nations SDG's goals (UN 2020), goal number 1 & 2 are related to sufficient food production (i.e. stresses the issues of increasing productivity) and goal number 6 & 11 are related to clean water and sustainability (i.e. efficient or effective use of water, sustainability of water resources). Numerous efforts have been made in different parts of the world to increase food production for the rapidly growing population. In many cases, there has been success but with a deterioration of production- linked resources, such as water and soil. The soil health can be improved/ sustained through organic or inorganic amendments (which can be produced as demanded), which involves money. But the water problem or crisis cannot be solved by money itself, if there is no alternative source(s). One of the ways to resolve the problem is to manage or reduce the demand of water (i.e. demand-side management of water). For sustainable agricultural growth in an area, such demand-side management might be a nice, environment friendly option.

According to the results of the present study, the Cropping Pattern-1 to Cropping Pattern-3 saved 48 - 58 percent irrigation water and increased the 'equivalent rice yield' to about 14-17 percent compared to existing pattern "Aman-Fallow-Boro" at study area. Under the perspectives of Barind area of Bangladesh (which have been described in section 1 & 2), the demand-side management of water, that is, modifying the existing cropping pattern with low water-demanding Rabi crops, and also introducing "Aus rice" in which major part of water demand is fulfilled by natural rainfall; can be the viable, economic option and sustainable for the groundwater resource, upon which the agricultural growth and drinking water supply is depended. Thus, for irrigation demand management, revision of existing Boro-based cropping pattern can be a good choice. Aus-based three-cropped pattern (pattern-1 to 3) as compared to the existing two- cropped pattern is economically beneficial.

The findings of this research will help to plan management decisions to combat the declining trend of groundwater table (i.e. sustainable management of groundwater resources), as well as the consequences of climate change and drought. The effectiveness of such modified cropping patterns is largely determined by relevant policy support, and human responses and choices in the uptake of such approaches. For the sustainability of agricultural production and also for sustainability of groundwater resource, the government may impose regulation/limit for Boro rice cultivation (which requires huge irrigation amount, entirely taken from groundwater), and promote for alternate crops – Rabi crops, and Aus rice cultivation.

Summary and Conclusion

The large scale intensive cultivation of Boro cultivation is one of the major factors contributing to declination of groundwater resource in the North-western Barind area of Bangladesh. To cope of the situation, it needs urgent measures through technological intervention to increase water productivity of crops/cropping systems. This study was conducted for 3 years at 4 locations of Barind area intervening four new cropping patterns aiming at identifying water saving cropping pattern.

The results revealed that the pattern "Aman-Rabi (lentil /mustard / wheat)-Aus" saves an average of about 53 percent irrigation water and increases the 'equivalent rice yield' to about 11-17 percent (along with higher benefit-cost ratio) compared to existing pattern "Aman-Fallow-Boro" at study area. Although pattern-4 showed the highest REY, but with the cost of about 62% higher irrigation water compared to pattern-1, which could not be recommended for the groundwater depleted area.

Thus, for irrigation demand management, revision of existing Boro-based cropping pattern can be a good choice. Aus-based three-cropped pattern (pattern-1 to 3) as compared to the existing two-cropped pattern is economically beneficial.

The findings of this research will help to plan management decisions to combat the declining trend of groundwater table (i.e. sustainable management of groundwater resources), as well as the consequences of climate change and drought.

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