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Water and Fertilizer Productivity in Dry Season Irrigated Rice at Farmer's Field

M Maniruzzaman*[1] and J C Biswas[2]

ABSTRACT

Two on-farm experiments were conducted during dry seasons, 2001-04 at Kurigram and Pirgonj in Thakurgaon districts to select the best water management practices and to find out the suitable and economically viable combination of irrigation scheduling and fertilizer dose for maximizing irrigated rice yield. In alternate irrigation at saturation (AIS) treatment, about 28% water was saved compared to continuous flooding (CF), but it was needed to apply water frequently. However, alternate wetting and drying (AWD) method saved 31% and 39% water in Kurigram and Pirgonj, respectively compared to CF. In both the sites, there was no significant yield difference among the water treatments, though the applied water varied from 836-1046 mm in Kurigram and 802-1092 mm in Pirgonj. The water productivity in Kurigram ranged from 0.62 to 0.89 kg m^{-3}, whereas in Pirgonj it varied from 0.54 to 0.75 kg m^{-3}. Besides, AWD had the highest water productivity irrespective of locations and farmer can follow AWD practices for achieving competitive rice yield with reduced irrigation cost. The soil test based (STB) fertilizer management gave the highest grain yield followed by BRRI recommend dose irrespective of water managements. About 33-35% less amount of water was required in AWD compared to farmer's practice (FP) in both the sites having 0.5-1.0 t ha^{-1} yield advantage. In both the locations, the water productivity was the highest with STB fertilizer in combination with AWD water management which required additional fertilizer cost of Tk. 2800 ha^{-1}, but resulted in added benefit of Tk. 8400 ha^{-1} compared to FP. In STB fertilizer treatment, nutrient uptake was more compared to BRRI recommendation and FP. It was concluded from the study that AWD water management practice was the best option for water saving and improving water productivity. The combination of AWD with STB fertilizer management is suitable for maximum return from rice cultivation in light textured soils.

Key words: Soil test based fertilizer, evapo-transpiration, nutrient uptake.

INTRODUCTION

The availability of freshwater for agriculture is declining in many Asian countries including Bangladesh (Postal, 1997), while the demand for rice is increasing in Asia (Pingali *et al.*, 1997). Approximately 50% of the freshwater is used for rice production (Guerra *et al.*, 1998). However, this resource is no longer unlimited in Bangladesh like many other countries (Bindraban, 2001). Increasing demand for rice along with the increasing scarcity of water indicates that there would require more rice production with less water (Guerra *et al.*, 1998) from gradually declining soil fertility. In some areas, water shortages have already been caused crop failure, which is largely associated with inefficient water distribution system, evaporation, seepage and percolation losses (Bouman *et al.*, 1994). Agronomic practices are not followed systematically not only to save irrigation water in rice production, but also balanced use of fertilizers and biocides are not in practice at farmers fields. Integrated crop and resource management (ICM) is a good option in such situations for increased rice productivity, increased farmers' income and sustainable use of natural resources.

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[1] Principal Scientific Officer, Irrigation and Water Management Division, Bangladesh Rice Research Institute, Gazipur-1701

[2] Chief Scientific Officer, Soil Science Division, Bangladesh Rice Research Institute, Gazipur-1701

*Corresponding authors' email:mmziwmbrri@gail.com

In ICM, the synergistic effect of water, plant, and nutrient management is utilized for higher productivity of water, land and labor (Kartaatmadja and Fagi, 2000). Manipulations of cultural technologies like water and fertilizer management, etc. significantly influence rice yield (Biswas *et al.*, 2004a). Soil test based fertilizer management significantly influence grain yield of rice compared to farmer's fertilizer management (Biswas *et al.*, 2004b). However, literature on influence of irrigation scheduling and fertilizer rates is available mostly as single input (Mondal *et al.*, 2004, Saleque *et al.*, 1999), but not much information is available on the combined effect of water and fertilizers on rice yield. The objectives of this study were: a) to improve the water and fertilizer productivity; and b) to find out the suitable and economically viable combination of irrigation scheduling and fertilizer dose for maximizing dry season irrigated rice.

MATERIALS AND METHODS

Study sites

Two on-farm experiments were conducted during dry season of 2001-04 at Kurigram and Pirgonj in Thakurgaon district. Kurigram site is located approximately between 25⁰05' and 26⁰25' N latitude, 88⁰25' and 88⁰50' E longitude. The soil of this site belongs to Teesta Flood Plain group (FAO, 1988). Pirgonj site under Thakurgaon district is located approximately between 25⁰45' and 26⁰15' N latitude, 88⁰10' and 88⁰45' E longitude. The soil of this site belongs to Himalayan Piedmont Plain group (FAO, 1988). The field had been cropped in rice (*Oryza sativa* L.)-rice, rice-wheat (*Triticum aestivum* L.) and rice-vegetables rotations for more than 10 years.

Experimental Procedures

Experiment 1: In experiment 1, amount of irrigation water required along with its application schedule was determined to find out economically viable irrigation strategy for dry season irrigated rice cultivation. In each site, shallow tubewell (STW) based three farmers were selected, who was cultivating BRRI dhan28. Following water treatments were imposed:

1. Continuous flooding (CF): The field was kept flooded with 2-7 cm standing water and irrigation water was applied when water depth reduced to 2-3 cm;
2. Alternate irrigation at saturation (AIS): Irrigation water was applied upto 2-3 cm depth and wait up to saturation and then reapplied;
3. Alternate wetting and drying (AWD): Irrigation water was applied upto 5-7 cm depth and then reapplied after 3-days of disappearing standing water; and
4. Farmer's practice (FP): Same as treatment 1 with higher depth (3-9 cm) of irrigation water and sometimes dried their land for 5-7 days.

The treatments were followed in a randomized complete block design (RCBD) and dispersed over farmers' field. All treatments were implemented in one farmer's plot. In treatments CF, AIS and AWD, fertilizers were applied as per BRRI recommendation (100:24:42:10 kg NPKS ha^{-1}) (BRRI, 2004); but farmers used fertilizers as per their decision in treatment FP (108-115: 15-21: 30-36: 6-8 kg NPKS ha^{-1}). The sowing dates in Kurigram site were 10-15 December, 2001 and 40-45 days old seedlings were transplanted with 2-3 seedlings per hill at 25 x 15 cm spacing. However, sowing dates in Pirgonj, Thakurgaon site were 1-5 January, 2002 and 40 days old seedlings were transplanted similarly as stated above.

Experiment 2: In experiment 2, economically viable combination of irrigation scheduling and fertilizer doses for maximizing rice yields were investigated. In each site, STW based three farmers were selected who were cultivating BRRI dhan28. The treatments were laid out in split-plot design with four replications. Irrigation level was in the main plots and fertilizer doses were in the sub-plots. Irrigation level was selected based on the findings of experiment 1. The treatments were:

A. Irrigation water management

I_1 = AWD: Irrigation water was applied upto 5-7 cm depth and then reapplied after 3-days of disappearing standing water; and

I_2 = FP: Continuous flooding with higher depth (3-9 cm) of irrigation water and some times dried their land for 5-7 days.

B. Fertilizer dose

F1 = BRRI recommendation (100: 24: 42: 10 kg NPKS ha^{-1})
F2 = Soil test based (126-175: 35-40: 55-122: 11-12: 1.0-1.8 kg NPKSZn ha^{-1})
F3 = Farmers practice (115-130: 15-25: 30-42: 6-8 kg NPKS ha^{-1})

The collected soil samples were analyzed in Soil Science laboratory, BRRI, Gazipur for determination of STB dose after harvest of T. Aman. The water and fertilizers were applied as per treatments. The sowing dates in Kurigram site were 10-15 December, 2002 and 40-45 days old seedlings were transplanted with 2-3 seedlings per hill at 25 x 15 cm spacing. However, sowing dates in Pirgonj, Thakurgaon site were 1-5 January, 2003 and 40 days old seedlings were transplanted with the same number of seedlings and spacing. The experiments were continued for two years.

Data collection and analyses

The amount of applied irrigation water was measured by V-Notch. Rainfall and percolation data were recorded through rain gauge and percolation gauge respectively during crop growing periods. The depth of flooded water was also recorded daily at both the sites. Field water level was monitored with perforated PVC pipes upto 50 cm below soil surface. The seasonal total amount of percolation water was computed by adding the daily measured percolation rate. It was assumed that there was no percolation without standing water in the field. Fifteen centimeter height soil bund was used along the boundary line of each plot to minimize the seepage and fertilizer losses. Yield and yield contributing data of rice was recorded following the standard method. The plant and grain samples were analyzed at Soil Science laboratory, BRRI, Gazipur for determining the nutrient uptake from the soil. The collected data were analyzed statistically by using IRRISTAT software package and Duncan's New Multiple Range Test (DMRT) was used to determine the significance levels among the treatment means. The level of confidence was set at 95%. Water productivity was calculated as the weight of grain per unit of water. Fertilizer productivity was computed in comparison with farmer's practice.

RESULTS AND DISCUSSION

Soil data analysis

Soil pH and initial soil nutrient parameters are summarized in Table 1. In both the sites, soils are silty loam to sandy loam in texture with pH 5.26-5.31; organic matter content 1.60-2.26%; N 0.12-0.13%; P 8.10-10.63 ppm; K 0.04-0.09 meq/100g; S 15-16 ppm; Ca 1.31-1.24 meq/100g and Mg 0.18-0.22 meq/100g (Table 1). Moderate variations (CVs, 4-53%) were observed for all these variables, with the exception of P (226%) and K (144%) in Kurigram and that of P

(109%) and Mg (199%) in Pirgonj. Soil properties revealed that nutrient status of that locality was moderate to low. So, proper fertilizer management is necessary for optimal crop production.

Table 1. Some statistical information about initial soil nutrients at Kurigram and Pirgonj

	pH	OM	N	P	S	K	Ca	Mg
		-------- % ----------		--------- ppm ------		----------- meq/100g -----------		
Kurigram								
Mean	5.31	1.60	0.13	10.63	15.00	0.04	1.31	0.22
Max.	6.50	2.47	0.21	159.00	43.00	0.40	2.60	0.54
Min.	4.67	0.81	0.03	1.00	5.00	0.01	0.52	0.01
CV, %	5.39	21.51	30.60	226.3	45.04	143.89	34.34	53.04
Pirgonj								
Mean	5.26	2.26	0.12	8.10	16.00	0.09	1.24	0.18
Max.	5.71	5.50	0.26	44.00	39.00	0.23	3.52	2.89
Min.	4.60	0.86	0.06	1.00	7.00	0.03	0.23	0.04
CV, %	4.74	39.79	28.92	108.55	45.86	41.33	46.24	198.69

Experiment 1:

Agro-hydrological conditions

Rainfall, pan evaporation and seepage and percolation (S&P) from transplanting to harvest are shown in Table 2. These parameters were different for both the sites, because they had different transplanting dates and crop growth durations. Rainfall was slightly lower in Pirgonj than in Kurigram.

In both the sites, all of the four water regimes had similar water depth pattern (Fig. 1). To maintain continuous flooding (CF), maximum irrigation water was needed in both the sites, which were 670 mm for Kurigram and 750 mm for Pirgonj. In AIS treatment, about 28% less water was required compared to CF, but it was needed to apply water frequently. However, AWD required the lowest quantity of water compared to CF for both the sites. There was 31% less water requirement in Kurigram site and that of 39% less in Pirgonj site. In non-flooded periods, the field water table dropped about 15 cm below the surface. The highest field water depth was recorded in CF treatment and the lowest in AWD. The number of days with flooded conditions was higher in all the treatments at Kurigram site than that of the Pirgonj site, which was statistically similar with other treatments (Table 3).

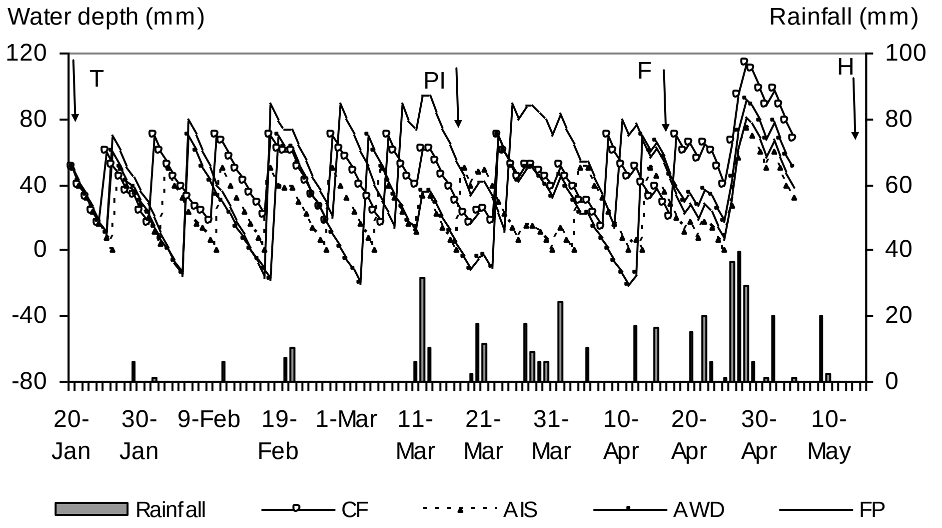
Table 2. Weather data, seepage & percolation and crop duration for BRRI dhan28 at Kurigram and Pirgonj, 2001-02

Site	Rainfall (mm)	Pan evaporation (mm)	Seepage and percolation (mm)	Crop's field duration (days)
Kurigram	376	436	338	110
Pirgonj	342	449	354	106

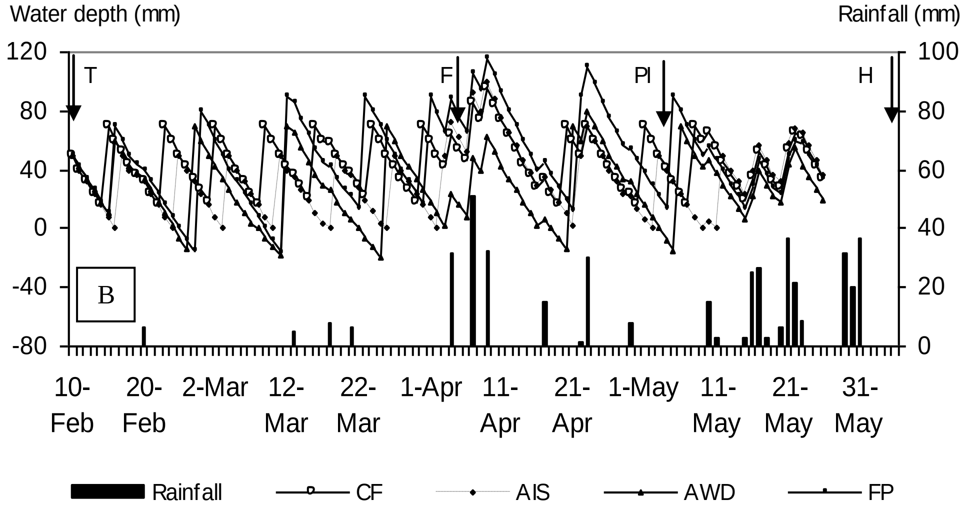
Table 3. Number of days with standing water in the field, Kurigram and Pirgonj, 2001-2002

Treatment	Kurigram	Pirgonj
Continuous flooding (CF)	100 ± 2	96 ± 2
Alternate irrigation to saturation (AIS)	77 ± 3	72 ± 2
Alternate wetting and drying (AWD)	75 ± 4	70 ± 4
Farmer's practice (FP)	93 ± 2	88 ± 2

The total amount of rain water received during the season was about 376 mm in Kurigram and 342 mm in Pirgonj, respectively. Rainfall was distributed during the whole rice growing period (Fig. 1) and thus provided congenial environment for crop growth. The total water supply (rainfall + irrigation) in Kurigram site ranged from 836 to 1046 mm, of which 376 mm was rainfall. But in Pirgonj site it was 802 to 1092 mm with 342 mm rainfall. There was no drainage outflow because of low rainfall during crop growing season. In both the sites, nearly similar amount of water was needed for CF (945-1025 mm) and FP (974-1092 mm) treatments. But the differences in irrigation and total water inputs were significantly different among all the water treatments ($P<0.05$). There was no significant difference in evapotranspiration (ET) and S&P losses between the two sites (Table 2).



A) Kurigram site

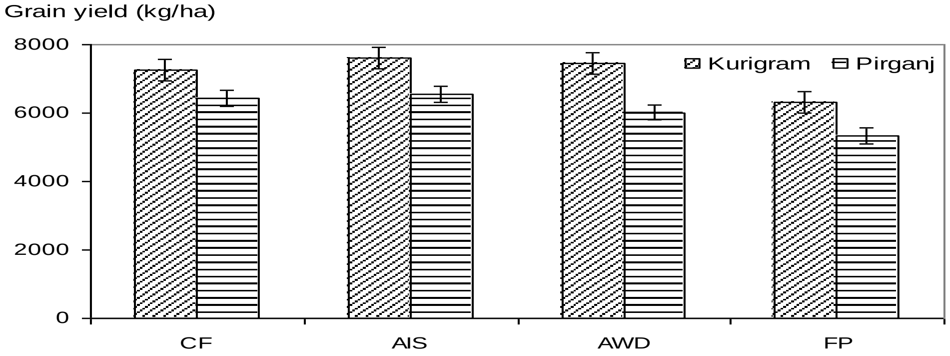


B) Pirgonj site

CF = continuous flooding, AIS = alternate irrigation at saturation, AWD = alternate wetting and drying and FP = farmers' practice

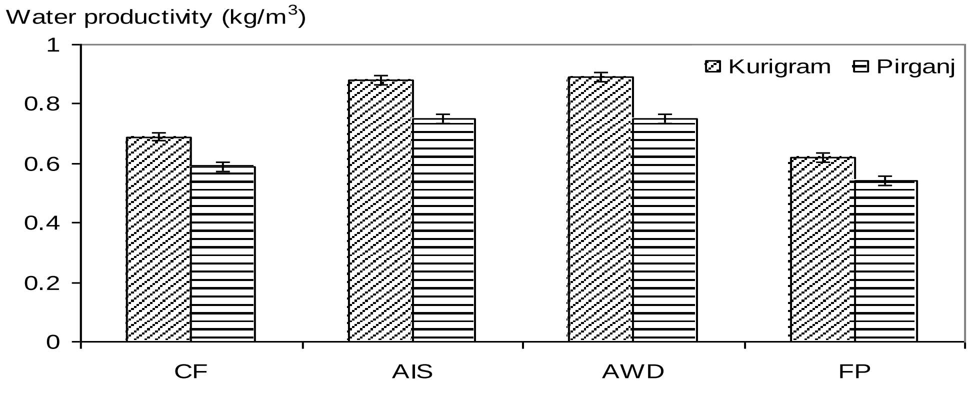
Fig. 1. Mean ± SE field water depth in Kurigram (A) and Pirgonj (B) experimental sites during crop season, 2001-02 Grain yield and water productivity.

In both the sites, there was no significant yield difference because of CF, AIS and AWD treatments (Fig. 2), though the quantity of water applied varied from 836-1046 mm in Kurigram site and that of 802-1092 mm in Pirgonj site (Fig. 1). The insignificant yield differences might be due to total rainfall received by the growing crops, which was adequate to meet up crop's demand. However, in farmer's practice grain yield was significantly lower than researcher's water management (Fig. 2). The most probable reason is that although they used more amounts of irrigation water, they used imbalanced fertilizer doses resulting in poor grain yield. In both the sites, the highest grain yield was recorded in AIS with about 28% less water applied compared to CF. In treatment AWD, about one-third less water was applied but produced competitive yield. These findings are in agreement with Bouman and Toung (2001), who reported that this technique could save about 30% of irrigation water compared to maintaining continuous standing water in the rice field. The present findings indicate that balanced use of fertilizer is very much crucial for higher grain yield at optimum water application.



CF = continuous flooding, AIS = alternate irrigation at saturation, AWD = alternate wetting and drying and FP = farmer's practice

Fig. 2. Grain yield of rice as affected by water management practicing during dry season, 2001-02



CF = continuous flooding, AIS = alternate irrigation at saturation, AWD = alternate wetting and drying and FP = farmer's practice

Fig. 3. Water productivity as influenced by water management during dry season, 2001-02

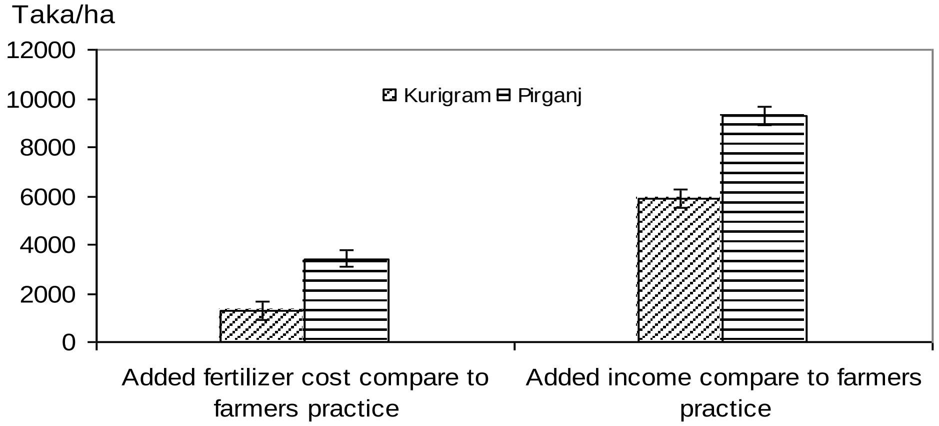


Fig. 4. Additional income due to water and fertilizer management at farmer's field

In Kurigram, the water productivity ranged from 0.62 to 0.89 kg m^{-3}, whereas in Pirgonj it varied from 0.54 to 0.75 kg m^{-3} (Fig. 3). Our findings are similar with Bouman and Toung (2001) who reported 0.3 to 1.1 kg grain m^{-3} water productivity with continuous submergence regimes. However, water productivity in water saving treatments was as high as 1.9 kg grain m^{-3}, which is greater than our findings. The water productivity was always higher in Kurigram compared to Pirgonj irrespective of treatments due to greater grain yield, though the applied water was nearly similar. Besides this, AWD had the highest water productivity and farmers practice had the lowest one irrespective of locations. The difference between AIS and AWD were not significant.

Although soil properties were almost similar in both the locations, rainfall varied slightly during the rice growing period. The rainfall variation and early transplanting in Kurigram resulted in significant yield difference of about 1 t ha^{-1} compared to Pirgonj, Thakurgaon (Fig. 2), even though the applied fertilizers and water was almost same. It is concluded from this study that farmers can follow AWD practices for achieving competitive rice yield with reduced irrigation cost.

Experiment 2:

Grain yield and water productivity

In both the sites, there were significant yield differences because of water and fertilizer managements. The soil test based (STB) fertilizer management gave the highest grain yield followed by BRRI recommendation irrespective of water managements (Table 4). This indicated that BRRI recommended fertilizer dose in those areas were inadequate resulting in imbalanced nutrient status compared to STB. Dobermann *et al.* (1996a, b, c) also stated that imbalance use of P and K may limit grain yield and N use efficiency. The insignificant influence of varied irrigation levels might be because of rain water received by the crop during the crop's growing period. Total rain water received by the crop was about 362 mm and 254 mm in Kurigram site and that of 338 mm and 226 mm in Pirgonj site during 2002-03 and 2003-04, respectively. Moreover, rainfall was distributed during the whole rice growing period and thus crop did not suffer from water deficit and so no yield difference. About 33-35% less amount of water was required in AWD compared to FP in both the sites having 0.5-1.0 t ha^{-1} yield advantage (Table 4). This yield advantage was mostly due to variations in fertilizer rate used for crop production. The average grain yield increase of site-specific nutrient management over farmers fertilizer practice was 0.2 t ha^{-1} in southern Vietnum, 0.3 t ha^{-1} in the Philippines and 0.8 t ha^{-1} in southern India (Pampolino *et al.*, 2007). Whereas, the grain yield was increased by 0.52 t ha^{-1} in Philippines, which was significantly higher in dry season (0.63 t ha^{-1}) than in wet season (0.40 t ha^{-1}) (Dobermann *et al.*, 2004). In both the locations, the water productivity was greater in AWD compared to FP. The water productivity was similar as it has been observed in experiment 1. In both the water treatments, water productivity was the highest with STB fertilizer management. Moreover, Kurigram site had the higher water productivity compared to Pirgonj site might be because of early transplanting and higher grain yield (Table 4).

In STB fertilizer treatment, more fertilizer was required compared to BRRI recommendation and FP. However, farmers in Kurigram site used the highest amount of urea. Although farmers applied more water, they got lower yield because of imbalanced fertilizer use. About 1.0 t ha^{-1} higher yield was observed at Kurigram site compared to Pirgonj areas, which might be due to early transplanting and minor variations in soil properties (Table 4). Use of STB fertilizer in combination with AWD, required additional cost of Tk. 2800 ha^{-1}, which resulted in added benefit of Tk. 8400 ha^{-1} compared to farmer's practices (Fig. 4). This result indicates that if there is a cash flow and farmers are aware of using balanced fertilizer dose for rice production, they could harvest higher grain yield from unit area.

Nutrient uptake

All kinds of nutrient uptake were highest in STB fertilizer management irrespective of location and water management practices followed by the BRRI recommended fertilizer management practices (Table 5). The lowest nutrient uptake was found in farmer's practice of fertilizer management, which may be due to imbalanced fertilizer use. The STB based fertilizer dose varied for the locations, but BRRI recommended fertilizer was the same for the locations. However, the nutrient uptake varied significantly over the locations and consequently varied the crop yield. The nutrient uptake was higher in Kurigram than that of Pirgonj, which may be due to the management and soil factor.

Table 4. Influence of fertilizer and irrigation water on grain yield and water productivity of BRRI dhan28 during 2002/03 to 2003/04

N-P-K-S-Zn (Kg/ha)	**Amount of water* (mm)**		**Yield (kg/ha)**		**Water productivity (kg/m^{3})**	
	AWD	**FP**	**AWD**	**FP**	**AWD**	**FP**
Kurigram						
100-24-42-10-3.5 (BRRI)	742	1017	6393b	5193b	0.86	0.51
175-35-122-11-1.8 (STB)			6938a	5848a	0.94	0.58
188-16-40-9-0 (FP)			5626c	4627c	0.76	0.46
Pirgonj						
100-24-42-10-3.5 (BRRI)	780	1032	5698b	4998b	0.73	0.49
126-40-55-12-1 (STB)			6199a	5382a	0.80	0.51
105-17-25-11-0 (FP)			4817c	4516c	0.62	0.44

** Rain water was 362 mm in Kurigram and 338 mm in Pirgonj during 2002/03 and that was 254 mm and 226 mm during 2003/04. AWD = Alternate wetting and drying and FP = Farmers practice*

In a column under each location, means followed by a common letter are not significantly difference at the 5% level of DMRT.

Comparison	S.E.D	LSD (5%)	LSD (1%)
2-F means at each L*I	140.6	237.3	395.8

Table 5. Nutrient uptake by rice as influenced by water and fertilizer management practicing during 2002/03 to 2003/04

Location	Fert. Treat.	Uptake (kg/ha)								
		N	P	K	Ca	Mg	Fe	Mn	Zn	S
Alternate Wetting and Drying										
Kurigram	BRRI	126.37	32.14	162.19	12.95	23.82	14.98	5.16	0.49	11.26
	STB	137.88	35.08	178.66	14.22	26.13	16.43	5.68	0.53	12.31
	FP	111.66	28.41	144.34	11.50	21.13	13.29	4.59	0.43	9.97
Pirgonj	BRRI	104.55	21.39	156.12	11.40	16.61	14.38	5.03	0.35	10.06
	STB	113.51	23.21	168.86	12.34	18.00	15.59	5.44	0.38	10.91
	FP	88.57	18.13	132.79	9.68	14.10	12.21	4.28	0.30	8.53
Farmer's Practice										
Kurigram	BRRI	103.01	26.21	133.04	10.60	19.49	12.25	4.23	0.40	9.19
	STB	115.75	29.44	148.93	11.88	21.85	13.74	4.74	0.45	10.32
	FP	91.67	23.32	118.13	9.42	17.32	10.89	3.76	0.35	8.18
Pirgonj	BRRI	91.51	18.71	136.12	9.95	14.51	12.57	4.38	0.31	8.80
	STB	98.48	20.14	146.31	10.70	15.61	13.52	4.71	0.33	9.47
	FP	83.42	17.08	126.12	9.17	13.34	11.55	4.06	0.28	8.05

CONCLUSION

Rainfall, evaporation and seepage & percolation varied due to the difference in transplanting date and crop growth duration. Rainfall was slightly lower in Pirgonj than in Kurigram. In AIS treatment, about 28% water was saved compared to CF, but it was needed to apply water frequently. However, AWD required the lowest quantity of water compared to CF for both the sites, which saved 31 and 39% water in Kurigram and Pirgonj, respectively. In both the sites, there was no significant yield difference among the water treatments, though the applied water varied from 836-1046 mm in Kurigram of which 376 mm was rainfall and that of 802-1092 mm in Pirgonj of which 342 mm was rainfall. However, in farmer's practice grain yield was significantly lower than researcher's water management, which may be due to using more water with imbalanced fertilizer doses. The water productivity ranged from 0.62 to 0.89 kg m^{-3} and 0.54 to 0.75 kg m^{-3} in Kurigram and Pirgonj, respectively. Besides, AWD had the highest water productivity and farmers practice had the lowest one irrespective of locations. It is concluded from the study that farmers can follow AWD practices for achieving competitive higher rice yield with reduced irrigation cost.

The STB fertilizer dose gave the highest grain yield followed by BRRI recommendation irrespective of water managements. About 33-35% less water was required in AWD compared to FP in both the sites having 0.5-1.0 t ha^{-1} yield advantage. This yield advantage was mostly due to variations in fertilizer rate used for crop production. In both the locations and water regimes, the water productivity was the highest with STB fertilizer combination with AWD compared to FP and also required additional cost of Tk. 2800 ha^{-1}, which resulted in added benefit of Tk. 8400 ha^{-1}. Moreover, Kurigram had the higher water productivity compared to Pirgonj might be because of early transplanting and higher grain yield. In STB fertilizer treatment, more fertilizer was required and also uptake was higher compared to BRRI recommendation and FP. Although farmers applied more water, they got lower yield because of imbalanced fertilizer use. This indicates that if there is a cash flow and farmers are aware of using balanced fertilizer dose for rice production, they could harvest higher grain yield from unit area.

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