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Investigating water productivity and yield of boro rice under conventional and conservation irrigation practices in Bangladesh

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ABSTRACT

Irrigation is one of the vital inputs to rice production in Bangladesh, where 78% of irrigation is dependent on groundwater (GW) resources. For the past two decades, GW level has been significantly declining across the country and on the other hand, surface water is limited in the dry season. This poses a great challenge to meet burgeoning irrigation demand of the country. Amid this situation, optimal and judicial use of water for irrigation is being thought to be a way out without compromising crop yield. In such context, an experiment was performed at the Field Irrigation Laboratory, Bangladesh Agricultural University in Mymensing to investigate the water productivity, growth and yield characteristics of BRRI dhan28 under three different irrigation techniques *i.e.* alternate wetting and drying (AWD), raised bed (RB), and conventional continuous flooding (CF). Six treatments including four AWD variants with three replications for each treatment were laid out randomly in 18 plots. The highest yield was 6.63±0.65 t ha^{-1} under 10 cm disappearance AWD treatment (T2). But the lowest yield was (5.73±1.25 t ha^{-1}) under mixed AWD treatment (T5) which did not show a significant variation on the yield of different techniques. CF treatment (T1) needed 68.94±3.44 cm of water and its water productivity was 0.48±0.08 kg m^{-3}, where the T2 treatment needed average 52.10±3.21 cm of water and average water productivity was 0.59±0.04 kg m^{-3}. The study revealed that 10 cm, 15 cm, 20 cm disappearance AWD and mixed AWD treatments (respectively, T2, T3, T4, and T5) saved 24.42, 24.28, 28.92 and 38.56% of irrigation water, respectively, and where the RB also saved 15.52% over the conventional method. On the basis of the above consideration, it can be concluded that AWD technology can be adopted to increase the water productivity of dry season boro rice and thus to make its cultivation more profitable.

Keywords: Irrigation, water saving techniques, water productivity, yield

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1 Introduction

A large amount of the world's people, especially in Asia, has widely consumed rice as their principal food. It is the major energy source with respect to nutrition and caloric values, supplying more than one-fifth of the calories consumed globally by humans. Being an aquatic plant, rice requires a huge amount of water during cultivation irrespective of its varieties and geographic locations. Therefore, in many parts of rice growing regions where natural rainfall is scarce and/or other competitors juggle over limited useable water resources, rice cultivation faces a great challenge.

In case of agricultural utilization, the shortage of water has become one of the major restrictions globally (Hanjra and Qureshi, 2010). The limitation of water storage hampers the existence of agricultural crops scheme worldwide. Rice has enormous ability to save the input of irrigation water because of its water requirement in physiological processes (4,500 m^3 ha^{-1}), considerably fewer than that was once thought to be needed (Si, 2000). Zhao et al. (2011) suggested that the conventional flooding irrigation in rice production is no longer needed to produce higher biological yield. Water-saving techniques are becoming popular and highly acquired in the major rice producing countries of Asia like - Bangladesh, China, India, and Philippines (Bouman, 2007). In recent times, a number of water-saving technologies have been addressed to assist farmers in achieving high crop production and optimal water productivity (Liu et al., 2015). Wang et al. (2016) suggested that the water-saving techniques require to be carefully utilized to control plant water status during the dry season. Because of a lower level of groundwater, if all farmers select to utilize the conservation technologies in the agricultural field, these technologies need to be re-evaluated after adopting widely (Belder et al., 2005) since the water productivity of crops may also be varied due to different conditions of soil, agronomic practices, and climatic parameter variation (Mueller et al., 2005).

Boro is one of the most important crops in Bangladesh because of its larger production, and it has been continuously contributing to higher production of rice in the last successive years. Total Boro production of the financial year 2016-17 in Bangladesh had been estimated 1,80,13,749 metric tons compared to 1,89,37,581 metric tons of the financial year 2015-16 which was 4.878% lower than that of the former year (BBS, 2017). The domestic rice production cannot provide pace with increasing the pressure population. Due to the limitation of land in Bangladesh, it is difficult to enhance rice production by taking more land under cultivable condition. In a condition of higher requirement for rice and less yield per unit area, an improved method of cultivation is essential to be developed to gain higher production. Proper water management for irrigation is one of the most vital factors in rice production. Boro rice is normally cultivated under irrigation in the rabi season (dry spell of a year). Groundwater alone has been the source of about 80% of total dry season irrigation water withdrawals. Because the majority of the country's rivers suffer very lean flow, surface water contribution to boro irrigation is trivial. A strong correlation between the dramatic decline in groundwater level and irrigated agricultural practice has been reported in a number of past studies (Mustafa et al., 2017). In order to check the over-exploitation of groundwater resources and excess power consumption for pumping, the performance of various conservation water management techniques and their associated limitations are being assessed by many research organizations, NGOs and private levels.

Two conservation techniques namely alternate wetting and drying (AWD) and raised bed (RB) are considering more efficient water management techniques for rice cultivation compared to conventional continuous flooding (CF) method. AWD and RB methods can save a considerable amount of water without suppressing yields. Although the AWD approach has received much attention over the last few years, the RB approach is not well studied in Bangladesh perspective. Therefore, the study was conducted for investigating comparative rice water productivities for conventional (CF) and two conservation (AWD and RB) irrigation approaches through a field experiment.

2 Materials and Methods

2.1 Experimental setup

In order to fulfill the objectives of the study, an experiment was performed in the field irrigation laboratory, under the Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh, Bangladesh from 16 February to 18 May 2018. The soil type of the experimental field was silt loam. The soil was grey color and, the values of bulk density, field capacity and wilting point of soil were experimentally found to be 2.802 g cm^{-3}, 31.33%, and 16.05%, respectively.

The experiment involved 18 plots under three irrigation techniques (AWD, RB, and CF). There were six different treatments including T1 and T6 for conventional CF and RB, respectively, and T2, T3, T4, and T5 for AWD method as detailed in the following. Each treatment was replicated thrice in randomly chosen plots (3 m $\times$ 2 m). The field layout of the experiment is shown in Fig. 1.

T1 = Conventional CF method, where continuous standing water (1-5 cm),

T2 = AWD method, where water was applied after 10 cm of disappearing of standing water,

T3 = AWD method, where water was applied after 15 cm of disappearing of standing water,

T4 = AWD method, where water was applied after 20 cm of disappearing of standing water,

T5 = AWD method, where water was applied after 10 cm of disappearing of standing water for first one month after transplanting seedlings, then water applied 15 cm of disappearing of standing water for the next one month and finally, this water applied 20 cm of disappearing of standing water for the last month, and

T6 = RB method.

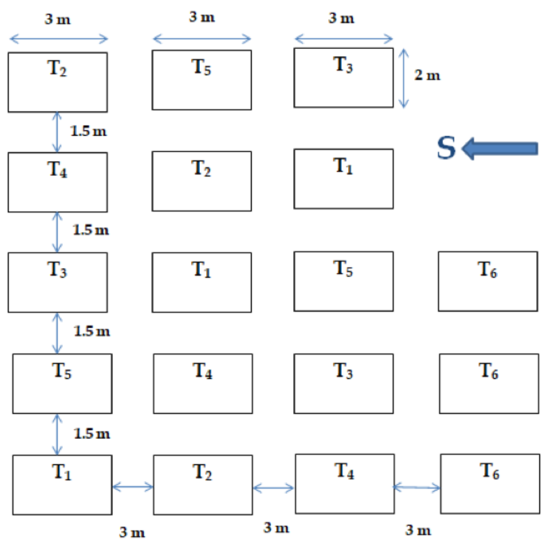

Figure 1. Field layout of the experiment with different treatments

Thirty-nine days old seedlings of BRRI dhan28 was transplanted on 16 February 2018. The irrigation techniques were the only variables whose effect was expected from the experiment. That's why different levels of irrigation techniques were applied. At the initial stage during 1st 30 days after transplanting (DAT), 5 cm standing water was kept in the plots to avoid infestation of plant. In AWD method, a PVC pipe with holes was installed in the rice field, and AWD was started at 15 DAT and allow the field to dry out. The field was re-flooded to a standing water layer of 5 cm. A standing water layer of 5 cm was kept for 1 wk at flowering, AWD cycle after flowering was continued prior to 15 d of harvest. In the RB method, crops were planted on a raised bed, and water was supplied through furrows. A favorable environment was created to develop the root system. It facilitated passage for easy passing of sufficient wind and sunlight. Water levels in the experimental plots with continuous standing water were measured with a sloping gauge before and after irrigation.

Recommended fertilizer doses were applied during the growing period. Urea, triple super phosphate (TSP), muriate of potash (MoP), zinc sulphate ($ZnSO_4$), and gypsum were applied as the rate of 90, 31, 49, 05 and 37 kg ha^{-1}, respectively during the land preparation and the nitrogen fertilizer was applied in three equal splits as top dressing. The second application of nitrogen to the field was 21 DAT, and the third was 55 DAT. Furthermore, weeding was done twice through the experiment. Any amounts of water applied to the plots were volumetrically measured with a bucket. The boundary of each plot was sealed with polythene sheets in order to control lateral seepage from and any influxes, other than applied irrigation, to the plot. Crop inside 1 m square (1 m $\times$ 1 m) of the land was harvested with a view to obtain the information related to yield contributing characters. Different types of data such as yield contributing, water budgeting and agronomic characters were recorded.

2.2 Determination of yield and harvest index of rice

Grain yield The dry weight of grains of 1 m^2 area was multiplied by the respective plot area to get the plot's yield; finally the grain yield was converted to kg ha^{-1}.

Straw yield The straw obtained from 1 m^2 sampled area of each plot was dried to 12% moisture content and weighed to record straw yield per plot (as calculated for grained yield) that was converted to kg ha^{-1}.

Biological yield The grain and straw yields together are considered as biological yield. The biological yield was recorded for each plot and it was converted to kg ha^{-1}.

Harvest index The harvest index was estimated with the following formula:

$$HI\ (\%) = \frac{Y_G}{Y_B} \times 100 \quad (1)$$

where, HI = harvest index (%), Y_G = grain yield, and Y_B = biological yield.

2.3 Determination of field water use efficiency (FWUE)

It was estimated by the following relationship (Michael, 1978):

$$FWUE = \frac{Y}{WU} \quad (2)$$

where, $FWUE$ = field water use efficiency (t ha^{-1} cm^{-1}), WU = seasonal crop-water use in the crop field (cm), and Y = grain yield (t ha^{-1}).

Table 1. Growth and yield attributes of Boro rice under different irrigation practices

	Plant height (cm)	Panicle height (cm)	No. of panicles	Prod. pro-tiller hill^{-1}	Unprod. tiller hill^{-1}	Grains hill^{-1}	Unfilled grain hill^{-1}	WTS ‡ (g)
T1 †	97.67±4.62	24.67±0.58	25.00±4.58	24.33±3.51	0.67±1.15	206.33±4.16	10.67±4.04	21.33±2.08
T2	92.67±3.06	24.33±0.58	23.67±3.06	23.67±3.06	0.00±0.00	197.00±14.53	17.00±6.56	21.67±0.58
T3	91.67±1.53	22.33±1.53	22.67±3.06	21.67±3.79	1.00±1.73	172.00±38.74	9.67±2.31	21.33±1.53
T4	97.33±4.04	23.67±0.58	23.33±4.04	22.00±2.65	1.33±1.53	184.67±38.74	12.67±1.53	21.00±2.00
T5	93.33±4.16	23.33±0.58	21.67±3.06	20.67±2.89	1.00±1.00	156.67±25.01	8.33±1.15	21.33±3.06
T6	85.00± 4.2	24.00±0.88	21.00±4.05	20.00±3.00	1.00± 1.00	129.00±30.00	11.00± 2.3	21.00±2.80

† T1 = Conventional CF method, where continuous standing water (1-5 cm), T2 = AWD method, where water was applied after 10 cm of disappearing of standing water, T3 = AWD method, where water was applied after 15 cm of disappearing of standing water, T4 = AWD method, where water was applied after 20 cm of disappearing of standing water, T5 = AWD method, where water was applied after 10 cm of disappearing of standing water for first one month after transplanting seedlings, then water applied 15 cm of disappearing of standing water for the next one month and finally, this water applied 20 cm of disappearing of standing water for the last month, and T6 = RB method;
‡ WTS = weight of 1000 grains

Table 2. Yield and harvest index of Boro rice under different irrigation practices

	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
T1	6.15±0.91	3.97±0.45	10.12±1.34	60.79±1.49
T2	6.63±0.65	4.23±0.68	10.87±1.32	61.04±1.58
T3	6.33±0.45	3.93±0.42	10.27±0.86	61.69±0.89
T4	6.33±0.55	3.90±0.79	10.23±1.32	61.89±3.27
T5	5.73±1.25	3.53±0.83	9.27±2.08	61.87±0.71
T6	6.00±1.50	4.00±0.50	10.00±2.50	60.00±3.50

Table 3. Crop water use, field water use efficiency and water productivity under irrigation practices

	Total irrigation (cm)	Total rainfall (cm)	WU † (cm)	Yield (t ha^{-1})	FWUE ‡ (t ha^{-1} cm^{-1})	Water productivity (kg m^{-3})
T1	68.94±3.44		129.07±3.44	6.15±0.91	0.048±0.008	0.48±0.08
T2	52.10±3.21		112.23±3.21	6.63±0.65	0.059±0.004	0.59±0.04
T3	52.20±4.33	60.13	112.33±4.33	6.33±0.45	0.056±0.002	0.56±0.02
T4	49.00±4.28		109.13±4.28	6.33±0.55	0.058±0.007	0.58±0.07
T5	42.35±5.26		102.48±5.26	5.73±1.25	0.056±0.011	0.56±0.11
T6	58.90±4.50		119.26±5.50	6.00±1.50	0.050± 0.009	0.50±0.09

† WU = seasonal crop-water use in the crop field (cm); ‡ FWUE = field water use efficiency (t ha^{-1} cm^{-1})

3 Results and Discussion

3.1 Growth, yield attributes and harvest index of rice

Effects of different irrigation practices (conventional, AWD and RB) on boro rice growth and yield contributing characters *viz.* plant height, number of effective tillers, length of panicle, number of filled and unfilled grains per panicle, 1000 grain weight, grain yield, straw yield, harvest index and water productivity of BRRI dhan28 was observed (presented in Table 1 and Table 2). Plant height is one of the most important parameters of the growth stage. The highest plant height (97.67±4.62 cm) was observed with conventional CF treatment (T1) in which soil was never allowed to go under water stress. The shortest plant height (85±4.2 cm) was observed in RB (raised bed) treatment (T6), might be due to poor water management practices (Cruj et al., 1975), and also reported that plant height was larger under submerged situation than that of other treatments. The lowest number of tillers hill^{-1} (21±4) was obtained under the treatment T6, whereas the highest number of tillers hill^{-1} (25±4.58) was observed under the treatment T1. The difference between the lowest and highest was 11%. This result is in agreement with the findings of Singh and Pande (1972), where the findings of different water management treatments on the yield contributing characters such as the maximum number of tillers hill^{-1} and panicle length were recorded from conventional treatment.

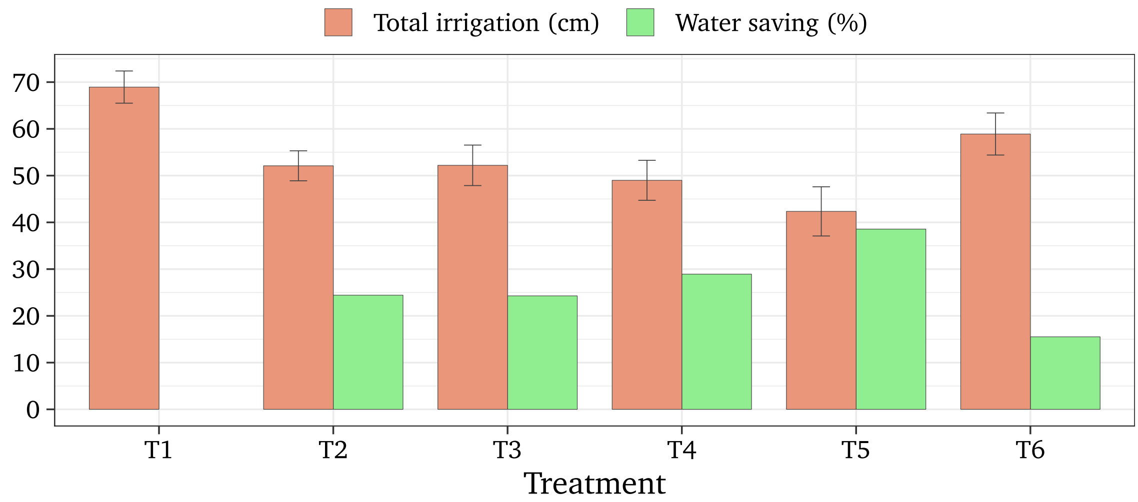

Figure 2. Percent saving of irrigation water under conservation techniques over the conventional method.

The highest number of grains (206.33±4.16) hill^{-1} was obtained under the treatment T1, whereas the treatment T6 gave the lowest number of grains (129±30) hill^{-1}. The parameters of unfilled grains, weight of 1000 grains, and weight of straws were less affected by different irrigation techniques. Harvest index showed the relationship between the economic yield and the biological yield of the crop. The maximum harvest index (61.89±3.27%) was obtained under the treatment T4, whereas the treatment T6 provided the minimum harvest index (60.00±3.50%). The harvest index in rice production normally varies from 17 to 56% (Bueno and Lafarge, 2009; Ju et al., 2009). The obtained harvest index from this study was slightly higher than the above range due to the lower straw yield for the shorter straw length. In this study, each rice plant was cut down at a shorter length during harvesting time. This is because our main target was to observe grain yield and water productivity rather than straw yield. Had the matured rice plants been harvested at higher length, the corresponding straw yield, thus biological yield too, would have been comparatively larger than the current results. From Table 2, it is seen that three AWD treatments (T2, T3, and T4) outperform other treatments in producing grain yield ha^{-1}.

3.2 Crop water use, field water use efficiency and water productivity

Table 3 shows that the field water use efficiency and water productivity were significantly varied under different irrigation treatments. As can be seen from Table 3, a clearer yield variation was noticed for different techniques. In all AWD treatments, water use was smaller than two other treatments; this superior performance prevails in crop yield too. The conventional T1 treatment gives lower crop yield compared to those of AWD treatments, although more water was required in the conventional method. Maximum water productivity (0.59 ± 0.04 kg m^{-3}) was obtained under the treatment of T2, whereas minimum water productivity (0.48 ± 0.08 kg m^{-3}) was obtained under the T1 treatment. This result is in agreement with the findings of Carrijo et al. (2017), where the maximum and minimum water productivity was recorded under the AWD and CF treatments, respectively.

3.3 Irrigation water saving

The experimental data for the calculation of the percentage of water saving is represented in Fig. 2. The AWD treatments unequivocally performed comparatively better than the conventional method to reduce water loss. The treatments T2, T3, T4, and T5 saved 24.42, 24.28, 28.92 and 38.56% irrigation water, respectively, whereas RB only saved 15.52% of irrigation water over the CF method as shown in Fig. 2. Almost similar result on the percent saving of irrigation water was also reported by Carrijo et al. (2017), where they observed that AWD reduced the use of water on average by 25.7% compared to the traditional CF method. These findings assert that AWD water management techniques could be a great avenue for saving a considerable amount of irrigation water that is not in fact necessary for rice growth as being currently exploited through conventional flooding irrigation method.

4 Conclusions

We conclude that the AWD technique performed comparatively better than conventional and raised bed techniques for profitable crop production of Boro rice and efficient crop water use. This research encountered a number of limitations that could be taken into account in any relevant future experiments. In order to reach a final conclusion on the water productivity and yield of boro rice under the conventional and conservation irrigation practices, more field experiments at different environments across Bangladesh should be undertaken. Unlike four AWD treatments, there were no variants of CF and RB treatments in our experiment. In future experiments, more versatile experiments need to be adopted with multiple variants of each main water management treatment.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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