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Effect of Water Management Practices on Rice Yield, Water Productivity and Water Savings under Irrigated Rice Paddy Ecosystem

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Abstract

A field experiment was carried out during the Boro season 2013 to find out the effects of water management practices on rice yield performance and water productivity index at Old Brahmaputra flood plain paddy land, Muktagacha, Mymensingh. The experiment was laid out in randomized complete block design (RCBD) with six (6) irrigation treatments. Two treatments, T_1 and T_3 were kept under continuous standing water levels (10 cm and 5 cm respectively) while in treatment T_5 irrigation water was supplied for 1st 3 weeks then followed mid season drain out and re-flooded at flowering stage. Three alternate wetting and drying irrigation treatments, T_2, T_4 and T_6 were selected in which irrigation water was applied when water level dropped 20cm, 10cm and 15cm below ground level, respectively. All the irrigation treatments significantly affected the rice yield and yield contributing parameters. The study revealed that the highest grain yield (5950 kg ha^{-1}) was found in treatment T_5 which was identical with AWDI treatment T_4 (5820 kg ha^{-1}) followed by AWDI treatment T_6 (5460 kg ha^{-1}). On the contrary, rice yield of 3350 kg ha^{-1}, 4470 kg ha^{-1} and 4810 kg ha^{-1} were found in the treatment T_1, T_2 and T_3, respectively. It was found that AWDI treatment T_2 showed maximum water savings (15.1%) followed by T_6 (11.3%), T_4 (7.59%) and T_5 (3.8%), however rice yield in the treatment T_2 (4470 kg ha^{-1}) was significantly lower compared to T_6, T_4 and T_5 treatment. Therefore, it may be inferred that treatment T_4 (AWDI; irrigation when water level fell 10 cm from ground level), T_5 (Irrigation for 1st 3 weeks, then mid-season drain out and re-flooding at flowering) and T_6 (AWDI; irrigation when water level fell 15cm from ground level) would be the feasible choice for the water savings, higher rice yield as well as maximum water productivity index (0.478, 0.472 and 0.467, respectively) for sustaining rice farming during the dry Boro season in Bangladesh.

Key words: AWDI, Productivity, Rice yield and Water savings

Introduction

Rice Paddy Ecosystem mainly consists of paddy soils, rice plants and natural water body (prolonged/temporarily submergence) or irrigated/rainfed lowland. Water is the vital component of sustainable rice farming in the Asian tropics and subtropics.More than 75 percent of the world's rice is produced under the conventional irrigation practices (i.e., continuous flooding) (Van der Hoek *et al*., 2001). Rice grown under traditional practices in the Asian tropics and subtropics requires 700-1500 mm of water per cropping season depending on soil texture (Bhuiyan, 1992). However, this conventional water management method leads to a high amount of surface runoff, seepage, and percolation that can account for 50-80 percent of the total water input (Sharma, 1989). Recently, the scarcity of water has been increasing worldwide. By 2025, the per capita available water resources in Asia are expected to decline by 15-54 percent compared with that of 1990 availability (Guerra *et al*., 1998). Producing more rice with less water is therefore a formidable challenge for achieving food and water security for these regions (Facon, 2000). Contrary to most lowland rice-growing practices used throughout the world, the rice field is not under continuous flooding but instead is irrigated intermittently during the production period (Van der Hoek *et al*., 2001).

Alternate Wet and Dry Irrigation (AWDI) is a water management system where rice fields are not kept continuously submerged but are allowed to dry intermittently during the rice growing stages. AWDI can increase the water use efficiency at the field level by reducing seepage and percolation during the production period. Experience with the System of Rice Intensification (SRI) techniques also shows that farmers who grow irrigated rice with continuous flooding have been wasting large volume of water (Uphoff, 2006). The SRI is a production system that emphasize the use of younger seedlings (< 15 days) planted singly and at wider spacing, together with the adoption of intermittent irrigation, organic fertilization, and active soil aeration to the extent possible (Stoop *et al*., 2002; Uphoff, 2007). The SRI system shows that keeping paddy soils moist but not continuously saturated gives better results, both agronomically and economically, than flooding rice throughout its crop cycle. SRI methods enable farmers to reduce their irrigation by 25-50% while realizing higher and more profitable production (Uphoff *et al*., 2002; Anthofer, 2004; Namara *et al*., 2004; Li *et al*., 2005; Sato, 2005; Uphoff, 2006). However, good water control and minimal use of water is both the most controversial component in rice farming and the factors most difficult for farmers to regulate. Also, due to the variation in climatic and edaphic factors, results from AWDI methods adopted in one area may not correlate with other areas. The current study, therefore, was undertaken to investigate the effects of alternate wetting and drying irrigation on rice yield, water productivity, soil properties and water savings under boro season field condition.

Materials and Methods

The field experiment was carried out at Chechua, Muktagacha, Mymensingh. The experiment was laid out in a randomized complete block design (RCBD) having 3 blocks and 6 irrigation treatments. The dimension of an experimental plot was 4.0 m x 2.5m.

The plot size was selected based on the facilities available for rice production. The experimental field was prepared by a power tiller and a ladder. It was then fragmented into 3 major blocks. Each block was then divided into 6 experimental plots. Standard recommended doses or fertilizers were used in the experimental plots. Triple superphosphate (TSP), Muriate of potash (MoP), gypsum and zinc sulphate fertilizers were applied only once before transplanting, whereas urea was applied thrice after transplantation. Twenty one days old seedlings of BRRl dhan 28 was transplanted in the field on 10th January, 2013. In this experiment, plots were equipped with a pipe irrigation system, along with water inlet and outlet devices which controlled timely irrigation and drainage. Some pieces of PVC pipes were used to measure the depletion of soil water in the field. The diameter of the PVC pipe was 7.5 cm. Different levels of irrigation were applied to determine the suitable one considering the rice growth and yield and water savings capacity. In each of the cases, the field was allowed to be dried up to a certain level. The depleted water table was observed from the pipes installed in the field. A wooden stick scale was used to measure the water level inside the pipe. The experimental treatments were T_1 = 10 cm standing water maintained 1st 3 weeks, then kept 5cm throughout the growing season; T_2 = Irrigation when water level in the pipe fell 20cm below the ground level; T_3 = 5 cm standing water maintained throughout the growing season; T_4 = Irrigation water when water level fell 10cm below ground level; T_5 = Irrigation water for 1st 3 weeks, then mid-season drain out, re-flooding at flowering; T_6 = Irrigation when water level in the pipe fell 15cm below the ground level. BRRl dhan 28 was harvested on 18 May 2013 and data on the rice yield and yield contributing parameters were taken before threshing the grains from the plant.

Water saving percentage was calculated as follows:

$$\text{Water Savings (\%)} = \frac{\text{Water Supplied in Flooded Plot - Water Supplied in AWDI Plot}}{\text{Water Supplied in Flooded Plot}} \times 100$$

Water Productivity Index was calculated as the ratio of crop yield (kgha^{-1}) per unit water (mha^{-3}) supplied as defined by Jaafar *et al.* (2000). It includes irrigation, rainfall and antecedent soil moisture.

$$\text{Water productivity index (kg m}^{-3}\text{)} = \frac{\text{Grain yield (kg/ha)}}{\text{Total vol. of water supplied (m}^3\text{/ha)}}$$

Results and Discussion

Water inputs under different irrigation treatments

During the first 15 days of rice seedling transplantation, 5 cm standing water was maintained in all the plots to avoid weed infestation (crop establishment period). Water required for crop establishment was estimated 27.2 cm (Table 1). Thereafter, field plots were irrigated according to irrigation treatments. Treatments T_1 was considered to be the control and the plots under this treatments were irrigated continuously throughout the growing season. Plots under the AWDI treatments were irrigated when water level in the perforated pipes dropped to specified depths from the ground surface. The time of water application was indicated by the depletion of water level in the perforated pipes measured from the round surface.

Table 1. Irrigation frequency and water application under different treatments

Treatments	No. of Irrigation	Water for land preparation (cm)	Water for crop establishment (cm)	Effective rainfall (cm)	Total irrigation (cm)	Total volume of water (L)supplied /10m^2	% water saved
T_1	10	20	27.2	34.6	131.8	13180	-
T_2	6	20	27.2	34.6	111.8	11180	15.1
T_3	10	20	27.2	34.6	131.8	13180	-
T_4	8	20	27.2	34.6	121.8	12180	7.59
T_5	9	20	27.2	34.6	126.8	12600	3.8
T_6	7	20	27.2	34.6	116.8	11680	111.3

- One irrigation means application of 5cm water

In our study, higher water saving plots were found under the treatments T_2, T_4, T_6 and T_5 compared to treatment T_1. Treatments T_2, T_4 and T_6 were selected as AWDI plots. During the rice growing season, the maximum number of irrigations 10, 10, and 9 were given to the plots under the treatments T_1, T_3, and T_5 respectively, while the treatments T_2, T_4 and T_6 received 6, 8 and 7 irrigations, respectively (Table1). Higher amount of irrigation water volume was required for the treatments T_1, T_3, and T_5 which were 13180 L, 13180 L and 12600 L respectively, while the lower amount of irrigation water was required for the AWDI treatments T_2 (11180 L), T_4 (12180 L) and T_6 (11680 L).

Tabbal *et al*. (1992) and Singh *et al.* (1996) reported that AWD may reduce water applications by 40-70% compared with the traditional practice of continuous shallow flooding, without a significant yield loss.

Keisuke *et al*. (2007) also reported that irrigation water requirement should be reduced by 20-50% for non-flooded rice field compared to flooded paddy field. Chapagain *et al.* (2010) found 29% saving of irrigation water without reducing grain yield from the AWDI plot compared to conventionally flooded plot.

Effect of irrigation treatments on yield and yield contributing parameters

Effect on number of effective tillers per Panicles

Table 2 shows that the effect of irrigation treatments on number of panicles was significant at 1 percent level of probability. The highest number of panicles (15.41) per hill was found in treatment T_5 and the number consistently decreased in treatments T_6 (15.21), T_4 (14.34), T_3 (12.20), T_2 (10.64) and T_1 (7.09) as shown in Table 2. The results showed that the number of panicles per hill in the AWDI treatments (T_4, T_5 and T_6) increased significantly compared to other treatments.

Effect on panicle length

The experimental results showed that there was no significant effects among the treatments on panicle length. Treatment T1 showed lower panicle length compared to other treatments which might be the insufficient photosynthesis from less vigorous crop canopy having reduced leaf area (Table 2).

Effect on number of filled grains per panicle

Table 2 shows that the number of filled grains per panicle increased consistently in the AWDI treatments. However, in this parameter T_5 (168.99) was significantly different from T_4 (140.49), T_6 (133.14), T_3 (101.70), T_2 (90.58) and T_1 (86.82).

Effect on 1000-grain weight

The highest 1000-grain weight (24.81g) was obtained in treatment T_5 followed by treatments T_2 (24.76g), T_6 (24.09g), T_1 (23.93g), T_4 (23.87g) and T_3 (23.43g). Table 2 shows that the variations in different treatments are not statistically significant.

Effect on percentage of ripened grains

The highest percentage of ripened grains (92.50) was obtained in treatment T_5 followed by treatment T_4 (87.81), T_6 (85.42), T_3 (81.62), T_2 (80.25) and T_1 (76.73). Table 2 shows that the variations in different treatment.

Effect of irrigation treatments on grain yield

Grain yield was significantly influenced by irrigation water treatments. The highest grain yield (5950 kg ha^{-1}) was obtained in the treatment T_5, whereas the AWDI treatment T_4 gave grain yield (5820 kg ha^{-1}) which was statistically similar to the yield in T_5 treatment. Again AWDI treatment T_6 also gave the satisfactory yield (5460 kg ha^{-1}) compared to other treatments. The lowest yield was found in continuously flooded treatment T_1 (3350 kg ha^{-1}) followed by AWDI treatment T_2 (Irrigation when water level fall 20 cm from the ground level) (4470 kg ha^{-1}) that might be due to more stress. Khan et al. (2015) found that AWDI treatment showed 18% more grain yield in BRRI dhan-28 and 22% more grain yield in BINA dhan-8 compared to different irrigation treatments. Chapagain *et al.* (2011) reported that rice grain yield was 7.8 t/h from the conventionally flooded plot compared to AWDI plot (7.2 th^{-1}), but required more water.

Effect of irrigation treatments on straw yield

Variation in straw yield under different treatments is shown in Table 2. Straw yields under different irrigation treatments were significantly different at 1 percent level of probability (Table 2). However, the straw yield difference between T_2 and T_3 is not statistically significant. This revealed that the straw yield was affected by different levels of irrigation. The highest yield was obtained from treatment T_4 (5930 $kgha^{-1}$) followed by T_5 (5890 kg ha^{-1}), T_6 (5810 $kgha^{-1}$), T_2 (5490 $kgha^{-1}$), T_3 (5120 kg ha^{-1}) and T_1 (4340 $kgha^{-1}$). Since the straw yield is the function of plant height and number of effective tillers, treatments resulting higher number of tillers and greater plant heights produced higher straw yield.

Effect on harvest index (HI)

The experiment showed that different levels of irrigation did not have any significant effect on the harvest index. The highest value of harvest index (55.92%) was found for the treatment T_5, which was statistically similar to those obtained in treatments T_4 (49.53%) (Table 2).

Effect on water productivity index

The highest water productivity index (0.478 kgm-3) was obtained in treatment T_4 followed by treatments T_5 (0.472 kg m^{-3}), T_6 (0.467 kg m^{-3}), T_2 (0.399 kg m^{-3}), T_3 (0.364 kg m^{-3}) and T_1 (0.254 kg m^{-3}) (Fig. 1). Water productivity index for the treatments T_4, T_5 and T_6 were statistically similar in the present study.

Table 2. Effect of different irrigation treatments on the yield and yield contributing parameters of rice (BRRI dhan 28)

Treatments	**Plant height (cm)**	**Tiller plant^{-1}**	**No of panicles plant^{-1}**	**Panicle length (cm)**	**Filled Grainpanicle^{-1}**	**% Ripened grains**	**1000-GW (g)**	**Grain Yield (kgha^{-1})**	**Straw Yield (kgha^{-1})**	**HI (%)**
T_1	79.96b	11.20d	7.09e	20.09b	86.82e	76.73	23.93	3350e	4340d	43.56b
T_2	81.08a	12.53c	10.64d	22.30a	90.58e	80.25	24.76	4470d	5490b	44.87b
T_3	81.95a	13.91b	12.20c	22.85a	101.70d	81.62	23.43	4810c	5120c	48.44b
T_4	82.50a	16.35a	14.34ab	22.22a	140.49c	87.81	23.87	5820a	5930a	49.53b
T_5	82.33a	14.64b	15.41a	22.95a	168.99a	92.50	24.81	5950a	5890b	55.92a
T_6	82.97a	16.52a	15.21b	22.55a	133.14b	85.42	24.09	5460b	5810b	48.44b
CV (%)	3.63	5.34	5.04	3.07	6.11	4.99	3.39	10.47	5.89	6.35
LSD	1.957	1.155	0.23	1.332	4.13	3.27	-	152.41	45.66	0.971
Level of Sig.	**	**	**	*	**	**	**NS**	**	**	**

- T_1 = 10 cm standing water maintained 1st 3 weeks, then kept 5cm throughout the growing season;
- T_2 = Irrigation when water level in the pipe fell 20cm below the ground level;
- T_3 = 5 cm standing water maintained throughout the growing season;
- T_4 = Irrigation water when water level fell 10cm below ground level;
- T_5 = Irrigation water for 1st 3 weeks, then mid season drain out, re-flooding at flowering
- T_6 = Irrigation when water level in the pipe fell 15cm below the ground level.

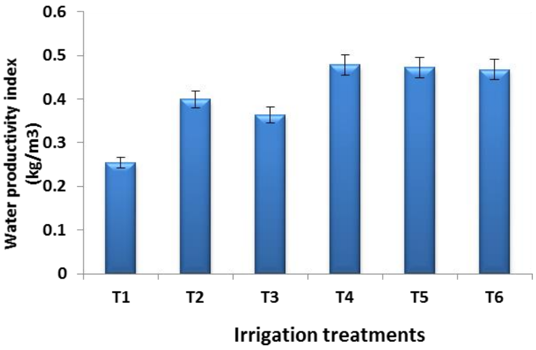

Fig. 1. Water productivity index under different

Tejendra *et al*. (2011) reported that water productivity index was significantly greater in the AWDI plot 1.7 kg m^{-3} compared to conventional irrigated plot 1.3 kg m^{-3}

Conclusions

The alternate wetting and drying irrigation treatments significantly affected the rice yield and water productivity. The results revealed that the highest grain yield (5950 kg ha^{-1}) was found in the treatment T_5, which was very close to the yield (5820 kg ha^{-1}) obtained in AWDI treatment T_4 followed by AWDI treatment T_6 (5460 kg ha^{-1}). In the present study, treatments T_5, T_4 and T_6 appeared to produce the best output considering the yield of rice grain as well as water saving percentages compared to other treatments. It was also observed that plant height, number of panicles per hill, grain yield, harvest index and water productivity index were higher in AWDI plots (T_4 and T_6) and in treatment T_5 plot compared to other treatments. Therefore, it may be inferred that practicing AWDI treatments T_4 (irrigated when water level fell 10cm), T_5 (Irrigation 1st 3 weeks with mid-season drain out and re-flooding at flowering) and T_6 (irrigated when water level fell 15cm) would be the feasible choice for farmers to obtain optimum grain yield with higher water productivity index irrigation treatments.

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