RESEARCH ARTICLE

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Performance evaluation of alternate wetting and drying irrigation for rice cultivation

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Abstract
An experiment was conducted during the 2009-2010 Boro season at the Shahjalal Science and Technology University campus, Sylhet, Bangladesh, to investigate the impact of alternate wetting and drying irrigation (AWDI) on rice production. Using a randomized complete block design (RCBD), four irrigation treatments were applied to a modern variety (MV) of rice (BRRIdhan 28). One control treatment, T_0, maintained a continuous standing water depth of 1-5 cm. Water was irrigated to three AWD treatments, T_1, T_2, and T_3 when the water level dropped 10, 20, and 30 cm below ground level, respectively. In spite of the fact that treatment T0 produced the highest grain yield (4.90 t/ha), its water use efficiency was 38.64 kg/ha/cm. Compared to treatment T_1, which produced 4.68 t/ha, treatment T_1 had a water use efficiency of 41.86 kg/ha/cm. Treatments T_2 and T_3 yielded 3.96 t/ha and 3.63 t/ha, respectively. When water levels fall below 10 cm below ground level, treatment T_1 may be the best option for rice cultivation in conditions of limited water availability.

Keywords: Alternate wetting and drying, Rice, Water use efficiency, Water save, Yield

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INTRODUCTION

More than half of the world's population consumes rice as a staple food. Rice is primarily grown in irrigated fields globally. Despite this, water is becoming a more and more scarce resource. Asia's available water per capita is expected to decline by 15 to 54 percent by 2025 (Guerra et al. 1998). As urban and industrial sectors compete for water, agriculture's share of available water will decline even further. It is important to develop and implement irrigation schemes that utilize water efficiently in order to meet the needs of urban and industrial areas. As freshwater resources become increasingly scarce, irrigated agriculture will have to produce more food with less water. According to estimates, rice is the world's most irrigated crop. It is possible to save water by intermittently drying rice fields rather than continuously flooding them during irrigated rice cultivation. The water is irrigated alternately by wetting and drying (AWD). During the rice growing stage, fields are not constantly submerged but are periodically allowed to dry. While rice production has steadily increased over the years, the cost of production has not decreased in that manner, but the higher production cost has resulted in higher yields. Due to the fact that irrigation costs approximately 25% of production costs, the AWD method may be an effective means of reducing these costs. Due to the efficient use of irrigation water, higher losses of water from the field can be easily eliminated, resulting in reduced production costs. Rice is known as a water-intensive crop, and conventional continuous flooding of fields consumes a substantial amount of water. AWD reduces water usage by allowing the fields to dry intermittently, promoting more efficient water utilization. By periodically drying the fields, farmers can significantly reduce the total water requirement for rice cultivation, helping to conserve water resources, especially in regions with water scarcity or competition for water resources. Pumping and maintaining continuous flooding require energy, typically in the form of electricity or fossil fuels. AWD reduces the energy input required for irrigation, resulting in cost savings for farmers and reducing greenhouse gas emissions associated with energy use. Continuous flooding can lead to soil problems such as reduced soil aeration, increased soil compaction, and reduced microbial activity. AWD allows the soil to dry out periodically, promoting better aeration and soil health. Enhanced soil health can lead to improved nutrient uptake by rice plants, potentially reducing the need for synthetic fertilizers and minimizing nutrient runoff into water bodies. Periodic drying of fields disrupts the life cycles of certain rice pests and weeds that thrive in submerged conditions. AWD can be used as an integrated pest management strategy, reducing the reliance on pesticides and herbicides. It also helps reduce the habitat for certain disease vectors, such as snails, which can transmit diseases like schistosomiasis. Continuous flooding of rice fields can lead to the anaerobic conditions that promote the production of methane, a potent greenhouse gas. AWD reduces methane emissions because it allows the fields to periodically dry out and aerate, inhibiting methane-producing microbes. Properly managed AWD can maintain or even increase rice yields while potentially improving grain quality. This depends on factors such as soil type, climate, and the specific rice varieties used. Enhanced grain quality can lead to higher market prices and better economic returns for farmers. AWD can help farmers adapt to changing weather patterns, including extended dry periods and irregular rainfall, which are becoming more common due to climate change. It provides a more flexible approach to rice cultivation that can better withstand erratic weather conditions. In some regions, governments and international organizations provide incentives and support for adopting AWD as part of sustainable agriculture initiatives. These programs encourage farmers to switch to more water-efficient practices. In summary, the rationale for adopting Alternate Wetting and Drying (AWD) irrigation for rice cultivation is based on its potential to conserve water, save energy, improve soil health, manage pests and diseases, reduce methane emissions, enhance yield and grain quality, adapt to climate change, and align with sustainable agriculture practices. However, the successful implementation of AWD requires careful management and monitoring to ensure that it is adapted to local conditions and effectively benefits both farmers and the environment.

MATERIALS AND METHOD

Experimental design, soil analysis, water management, crop growth monitoring, water table monitoring, yield measurement, environmental data collection, statistical analysis, economic analysis, field trials, replication, data interpretation, and etc are executed.

Experiment site

The research was conducted on the campus of Shahjalal Science and Technology University, Sylhet, Bangladesh. It was located between 24°46′ to 25°02′ North and 91°42′ to 92°00′ East.

Soil characteristics

Based on an analysis of the soil's physical properties, the soil in the experimental field was silty loam and grey. The parameters of soil fertility are presented in Table 1.

Climatic Data

Some weather data have been collected from Sylhet meteorological station for the experimental site during the experiment. Table 2 shows these data.

Field experimental design

In the field, a RCBD was used with 4 blocks and 4 irrigation treatments. Each block contained four experimental plots and represented a replication. In these plots, four irrigation treatments were randomly assigned. In total, 16 experimental plots were used.

Land preparation

The experimental field was prepared by a power tiller and a ladder. It was then fragmented into 4 major blocks. Each block was then divided into 4 experimental plots. The plots were surrounded by 25 cm wide and 20 cm high levees and separated by 1.0 m transition zones. A 1.5 m buffer zone was maintained between the blocks. The buffer zones were created to prevent seepage between adjoining plots. The dimension of an experimental plot was1.5m X 1.5m.

Soil water depletion measurement

In this experiment, some pieces of polyvinyl chloride (PVC) pipe were used to measure soil water depletion in the field. The diameter of the PVC pipes was 7.5 cm. The pipes were perforated to intake water from the saturated soil zone. The length of some of the pipes was 30 cm and that of the others was 40 cm. The 30 cm long pipes were installed in the treatments of T_1 and T_2 where the water level fell 10 and 20 cm below the ground level. Pipes 40 cm in length were installed in the treatment of T_3 where the water level fell 30 cm below the ground level. The pipe was installed in the field keeping 10 cm above the soil to check floating debris getting inside the pipe. After irrigation had been applied, water entered the pipe through small perforations and the water level inside the pipe was at the same level as that of outside.

As time went by, the water in the soil got depleted and at some moment the standing water above the ground level disappeared. But a close observation revealed that there was water inthe soil and that level was indicated by the water level inside the pipe. Thus, irrigation water was applied when the depleting water table inside the pipe reached a certain level.

Irrigation treatments

The experiment had four irrigation treatments. The treatments were:

- T_0 = 1-5 cm standing water, maintained throughout the growing season
- T_1 = Application of irrigation when the water level in the pipe fell 10 cm below the ground level
- T_2 = Application of irrigation when the water level in the pipe fell 20 cm below the ground level
- T_3 = Application of irrigation when the water level in the pipe fell 30 cm below the ground levelIn each irrigation, 5 cm ofwater was applied.

Seedlings

The specimen selected for this experiment was BRRIdhan 28. For this study, seedlings grown elsewhere were collected (Table 3).

Transplantation

The 35-day-old seedlings were collected and transplanted into the plots on the same day. Table 4 presents transplant details.

Fertilizer application

In the experimental plots, standard recommended fertilizer doses were applied. Table 5 shows the fertilizer dosesapplied to experimental plots.

Irrigation requirement Determination of effective rainfall

Effective rainfall is available in a plant's root zone, allowing it to germinate or grow. In its most basic form, effective rainfall refers to rain that is useful or usable. This study estimated effective rainfall using the United States Department of Agriculture (USDA) Soil Conservation

$$P\ effective = \frac{P\ total(125 - 0.2 \times P\ total)}{125}$$

Method (Smith, 1992). The equation is as follows:

For P total < 250 mm, and

P effective = 125 + 0.1 × P total

For P total > 250 mm

Where, P effective = effective rainfall, mmP total = total rainfall, mm

Crop water requirements estimation (WR)

Rice water requirements were calculated by adding applied irrigation water, effective rainfall during the growing season, and land preparation water (Rashid, 1997).

Harvesting activities

Each plot was harvested for the BRRIdhan 28, and 5 sample hills were chosen at random and harvested separately, Separately, the sample hills were investigated, threshed, and packed. Crops were harvested within a 1 m square (1m X 1m) plot of land to obtain yield and yield contributing parameters.

Determination of moisture content

The moisture content of the sample was determined using a moisture reader machine which was collected from the office of the Deputy Director of Department of Agriculture Extension (DAE), Sylhet.

Grain yield and straw yield

The grains were sun dried to lower the moisture content to 14 percent (weight basis) for the subsequent measurements. Similarly, the straw yield was also calculated by taking the weight of the sun-dried straw.

Table 1. Soil properties of the experimental site.

PH	Organic Matter (%)	N (%)	P (micro gram/ gm)	K (milli tullanko/ 100gm)	S (micro gram/ gm)	Zn (micro gram/gm)	Soil Texture
4.8	2.59	0.15	2	0.19	15	0.56	Silty loam

Table 2. Monthly weather data of the study area during the experimental period.

Month	Rainfall (cm)		Air temperature (°C)			Relative humidity (%)
	Total rainfall(mm)	No. ofrainydays	Maximum	Minimum	Average	
January	-	-	27.30	12.40	19.85	62
February	0.5	2	29.50	14.90	22.20	46
March	221.5	9	33.10	20.60	26.85	51
April	733.1	24	30.50	21.60	26.05	73

Table 3. Details of the seedlings collected for the experiment.

Variety	Supplying entity	Height of	Age of seedlings
BRRIdhan 28	Seedbed of Agricultural Training Institute of Sylhet	25 cm	35 days

Table 4. Information related to transplantation of seedlings.

Age of seedlings (days)	35
Hill to Hill distance (cm)	15
Row to Row distance (cm)	25
Number of seedlings per hill (nos.)	3

Table 5. Fertilizer doses kg/ha as applied to the experimental plots.

Before Transplantation		After Transplantation		
Fertilizer	Dose	Fertilizer	Days after	Dose
TSP	130	Urea	15	100
Gypsum	50			
Zink sulfate	9.52		30	180

Collection of data on yield and yield contributing parameters

Data on the following yield and yield contributing parameters were taken before threshing the grains from the plant.

- Plant height (cm)
- Number of effective tillers per hill
- Length of the panicle (cm)
- Total no. of spikelets per panical
- No. filled and unfilled grain per panicle
- The yield of unfilled grain (t/ha)
- Grain yield (t/ha)
- Straw yield (t/ha) and
- Harvest index (%)

RESULTS AND DISCUSSION

Irrigation treatments

During the first 15 days after transplantation, 5 cm of standing water was maintained in all plots to avoid weed infestation (crop establishment). Crop establishment required 27.2 cm of water. The plots were irrigated according to irrigation treatments. Treatment T_0 was considered the control and the plots under this treatment were irrigated when the surface water disappeared. Plots under the AWD treatments (T_1, T_2, and T_3) were watered when the water level inthe perforated pipes dropped to specified depths below the ground surface. The depletion of water level in the perforated pipes measured from the ground surface indicated the time of water application. Table 6, shows that the maximum number of irrigations (9 nos.) was given to plots under treatment T_0 (continuous flooding). Plots under treatments T_1, T_2, and T_3 received 6, 5, and 4 irrigations. Irrigation amounts for T_0, T_1, T_2, and T_3 were 72.2, 57.2, 52.2, and 47.2 cm, respectively. One irrigation means applying 5 cm of water.

Water use efficiency

The highest water use efficiency (WUE) was found at 81.79 kg/ha/cm and was obtained in treatment T_1 and the lowest was 67.85 kg/ha/cm in treatment T_0 (Table 7). The results showed that the WUE increased in general in the AWD treatments compared to the control. However, as the water level depleted more than 10 cm below the ground surface, the WUE dropped. It could be noted that the grain yield reduced with the reduction of irrigation frequency. Thus, in situations of water scarcity, a suitable water management practice, such as AWD, could be chosen that would increase the water use efficiency at some sacrifice of crop yield.

Effect of irrigation treatments on water saving

Table 8 presents data on reductions in grain yield and the corresponding water savings in treatments.

Effect of irrigation treatments on plant height

The effect of different irrigation treatments on plant height was analyzed statistically. According to the analysis, the effect on plant height was statistically significant at a 1 percent level of probability. Statistically, there was no significant difference in plant height between treatments T_0 and T_1. It was not statistically significant to distinguish T_2 from T_3. But the plant heights in both T0 and T_1 are significantly different from those of T_2 and T_3. Among the treatments, treatment T_0 (continuous submergence) achieved the highest average plant height (86.3 cm), while treatment T_3 (irrigation after 30 cm depletion of water below ground level) produced the lowest average (77.8 cm). The study found that increased water stress resulted in a significant decrease in plant height, while longer water stress affected plant growth and development in Table 9.

Effect of Irrigation treatments on the number of effective tillers per hill

Table 9, shows that the effect of irrigation treatments on several effective tillers was significant. The average highestnumber of effective tillers of 7.5 per hill was found in treatment T_0 and the average number consistently decreased intreatments T_1 (6.75), T_2 (6.25), and T_3 (5.25) in Table 9.

Effect of Irrigation treatments on panicle length

The experimental results showed that there was no effect of the treatments on panicle length in Table 9.

Table 6. Statement of water application to different irrigation treatments.

Treatment	No. of Irrigation	Water for land preparation (cm)	Water for crop establishment (cm)	Effective rainfall (cm)	The total amount of irrigation (cm)
T_0	9	20	27.2	34.6	126.8
T_1	6	20	27.2	34.6	111.8
T_2	5	20	27.2	34.6	106.8
T_3	4	20	27.2	34.6	101.8

Table 7. Water use efficiency for different treatments.

Treatment	Grain yield(t/ha)	Total water required(cm)	Water use efficiency(kg/ha/cm)
T_0	4.90	126.8	38.64
T_1	4.680	111.8	41.86
T_2	3.955	106.8	37.08
T_3	3.632	101.8	35.66

Table 8. Reduction of grain yield (%) and water saving (%) for different treatments.

Treatments	Grain yield (t/ha)	Percent of the highest yield	Grain yield reduction compared to control (%)	Total water required (cm)	Water saving compared to control (%)
T_0	4.90	100	00	126.8	To
T_1	4.68	95.51	4.49	111.8	11.83
T_2	3.96	84.51	15.49	106.8	15.77
T_3	3.63	77.61	22.39	101.8	19.72

Table 9. Statistical analysis of yield and yield contributing characters.

Treatments	Plant height (cm)	No. of effective tillers/ hill	Panicle length (cm)	No. of Spikelets/ panicle	No. of filled grains/ panicle	No. of unfilled spikelets/ panicle	1000 grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	HI %
T_0	86.3a	7.5a	21.6a	164.5a	158.8a	5.75b	22.38a	4.90a	7.1a	12.0a	40.5a
T_1	84.8a	6.75b	21.5a	157.0ab	152.3a	4.75c	21.02a	4.68a	6.7b	11.40ab	41.48a
T_2	80.2b	6.25b	21.7a	151.0b	147.3a	3.75d	20.83a	3.95b	6.1c	10..05bc	38.92a
T_3	77.8b	5.25c	21.7a	140.8c	133.3b	7.50a	19.05a	3.62c	6.0c	9.62c	37.63a
level of significance	**	**	NS	**	**	**	NS	**	**	**	NS
CV (%)	2.5	5.34	2.8	3.5	5.3	10.73	7.33	2.34	3.4	5.86	5.36
LSD	3.3	0.55	1.0	8.6	12.4	0.93	2.52	0.23	0.4	1.12	3.11

Effect of irrigation treatments on the number of spikelets per panicle

The number of spikelets per panicle in the AWD treatments decreased from that of the control (T_0) at a 1 per cent level of significance (Table 9). The maximum average number of spikelets (164.5) came in treatment T_0 and the minimum average (140.8) in T_3 (Table 9).

Effect of irrigation treatments on the number of filled grains per panicle

The AWD treatments showed a consistent decrease in filled grains per panicle. However, in this parameter, only T_3

was significantly different from those of the control (T_0) and the other two AWD treatments (T_1 and T_2) in Table 9.

Effect of irrigation treatments on 1000-grain weight

Treatment T_0 (continuous submersion) had the highest 1000-grain average weight (22.38g), followed by treatments T_1 (21.02g), T_2 (20.83g), and T_3 (19.05g). Table 9, indicate that there is no statistically significant difference in weights between the treatments.

Effect of irrigation treatments on grain yield

The highest average grain yield (4.90 t/ha) was obtained in the control treatment T_0 (continuous submergence). The yield consistently decreased in the AWD treatments (T_1, T_2, and T_3).

Statistical analysis showed that the yields in T_0 (control) and T_1 (irrigation after 10 cm depletion of water level) were not significantly different. However, the yield obtained in T_1, T_2, and T_3 were significantly different from one another in Table 9.

Effect of irrigation treatments on straw yield

At a 1 percent probability level, straw yields were significantly different in different irrigation treatments. T_2 and T_3 do not show any statistically significant differences. Table 9, shows that the highest yield was obtained for treatment T_0 (7.2 tons/ha), followed by treatment T_1 (6.6 tons/ha), treatment T_2 (6.2 tons/ha), and treatment T_3 (6.00 tons/ha).

Effect of water stress on harvest index (HI)

The experiment showed that different levels of irrigation did not have any significant effect onthe harvest index. The highest value of harvest index (41.48%) was found for the treatment T_1 which was statistically similar to those obtained in treatments T_0 (40.5%), T_2 (38.92%), and T_3 (37.63%) in Table 9.

CONCLUSION

The alternate wetting and drying irrigation treatments significantly affected the rice yield and some other yield- contributing parameters. The results revealed that though the highest grain yield (4.90 t/ha) was found in the treatment T_0, its water use efficiency was 38.64 kg/ha/cm. Treatment T_1, on the contrary, gave a yield of 4.68 t/ha which was very close to the highest one obtained in T_0; produced the highest water efficiency of 41.86 kg/ha/cm. Both the yieldsand WUEs in treatments T_2 and T_3 were lower than the corresponding values obtained in T_1. So, the treatment T_1 appears to produce the best output. The study revealed that increasing water stress significantly reduced the plant height, number of effective tillers per hill, number of total tillers per hill, grain yield, straw yield, and biological yield. So, where water is scarce, practicing treatment T_1, when the water level goes 10 cm below the ground level would be the best choice for rice cultivation in silty loam soil.

COMPLIANCE WITH ETHICAL STANDARDS

Peer-review

Externally peer-reviewed.

Conflict of interest

The author declare that they have no competing, actual, potential or perceived conflict of interest.

Author contribution

The contribution of the author to the present study is equal. The author read and approved the final manuscript.

Ethics committee approval

Ethics committee approval is not required.

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Data availability

Not applicable.

Consent to participate

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Consent for publication

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