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Automated Alternate Wetting and Drying Irrigation for Sustainable Rice Production in Bangladesh

Pierre Dubois[1*], Marc Lefevre[2], Claire Moreau[1], Julien Martin[3], Thomas Dupont[4]

Abstract

Rice ranks among the crops with the highest water consumption in farming, requiring a considerable amount of water each year for its growth in Bangladesh. To manage this large water demand, the International Rice Research Institute (IRRI) developed the alternate wetting and drying (AWD) irrigation technique. This technique requires frequent manual checks to maintain the correct water levels in the field. To reduce this manual work, research was conducted at Bangabandhu Sheikh Mujibur Rahman Agricultural University. The research focused on designing an automated version of the AWD irrigation system, examining its influence on plant development and yield-related traits, and analyzing water-use efficiency using that automated system. The automated AWD setup included water-level controllers, solenoid valves, and water-level detection probes to maintain water levels in the paddy field. The trial was structured using a Randomized Complete Block Design (RCBD) involving three treatments: T1 (Conventional Irrigation - CI), T2 (AWD), and T3 (Automated Alternate Wetting and Drying - AAWD), with each treatment repeated four times. Results revealed only slight differences in the growth and development aspects of rice plants between the CI and AWD treatments. Similarly, yield-related factors showed no significant differences between the treatments. Importantly, the automated alternate wetting and drying (AAWD) treatment (T3) recorded the highest water use efficiency (WUE) of 65.20 kg/ha/cm. In contrast, the lowest WUE of 52.56 kg/ha/cm was recorded under the conventional irrigation (CI) treatment (T1). These outcomes clearly demonstrate the benefits of using an automated AWD system, resulting in a 20% reduction in irrigation water consumption compared with the traditional method. This change further reduces the need for physically demanding work in Bangladesh's paddy fields, highlighting opportunities for more productive, eco-friendly rice farming methods.

Keywords Yield, Rice, Automated irrigation, AWD, Controller, Water use efficiency

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Introduction

Water is a fundamental need for growing crops in the farming industry. Among all crops, rice (*Oryza sativa* L.) is known for its particularly high water requirements. In the past, continuous flooding through irrigation has been the standard practice in numerous nations for growing rice, driven by environmental and climatic factors [1]. Yet this approach creates multiple problems, such as high water usage, losses from leaching and surface runoff, the release of methane into the air, and contamination of water supplies by farm chemicals within agricultural ecosystems [2].

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On average, nearly 2500 liters of water (from rainfall and/or irrigation) are required to produce 1 kilogram of rough rice, accounting for evapotranspiration, seepage, and percolation [3]. As freshwater supplies for farming become scarcer and global food needs continue to grow, boosting food output while using less water is increasingly urgent. Because rice is grown on more irrigated land than any other crop worldwide, reducing water waste in rice paddies is essential.

Many investigations have recommended several irrigation techniques, such as zero-grade fields, alternate wetting and drying [4, 5], multiple inlets and furrows [6], pivot irrigation [7], and drip irrigation [8-10]. Of these options, the alternate wetting and drying (AWD) approach was created especially for rice production. It is considered an effective water-conserving irrigation strategy and a key part of climate-smart agriculture that supports global food security [11, 12].

Applying alternate wetting and drying (AWD) does not affect rice yield but reduces methane gas emissions during paddy farming [13]. With AWD, the soil does not remain flooded continuously; instead, it is left to dry for 1 or more days after surface water vanishes before reflooding [14, 15]. Originally tested as a water-saving approach in the Philippines during 2002, AWD was first introduced in Bangladesh in 2005 through the Bangladesh Rice Research Institute (BRRI) [15].

Moreover, AWD technology has been widely adopted across multiple developing nations, including India [16], Nepal [17], Indonesia [18], China [19], Vietnam [20], and the United States of America [13, 21]. Research indicates that AWD technology reduces water requirements by 15% to 30% compared with continuously flooded fields [3, 22]. In addition, the method can lower greenhouse gas (GHG) emissions (methane plus nitrous oxide) by 45% to 90% [2, 23, 24], and reduce arsenic levels in rice grains by 50% [23, 25-27].

Still, the alternate wetting and drying (AWD) technique needs ongoing human checks to observe water levels in the field [28]. Farmers often rely on a measuring tape or ruler to check water depth inside the AWD pipe during their visits, a task that becomes difficult, especially during extreme weather events. Setting the right irrigation schedule can also be hard for farmers when water drops below a set point or must be started again. To resolve these issues, modern technologies are being added to the AWD system to provide practical solutions. For example, an IoT-based platform was developed to monitor water levels, surrounding conditions, and irrigation operations across broad AWD fields [1, 20]. At a smaller scale, AWD automation using various sensors has been used to control irrigation timing and reduce soil moisture shortages and plant stress during dry periods [1].

Even with advances in rice irrigation methods, no prior work has examined the development of accurate irrigation systems specifically for Bangladesh. As a result, the current study aims to develop an automated AWD irrigation system by attaching a water-level controller and probes to a water pipe installed in the paddy field. The purpose is to reduce water consumption, reduce labor needs, and limit greenhouse gas (GHG) emissions from standing water in rice paddies. This study includes the design and implementation of an automated irrigation system based on the AWD principle, enabling automatic management of water levels in the paddy field without human involvement. The setup adds water when levels fall below a defined limit and halts once the target irrigation depth is reached. This is carried out using a water-level controller, a solenoid valve, and water-level detection probes.

Materials and Methods

Components for developing an automated AWD

Automatic water level controller

A 12 V water level controller module served to regulate the operation of a pump or solenoid valve and to handle filling or emptying a water tank **(Figure 1)**. The attached sensor probe senses both high and low water levels in the tank. If the water drops below the bottom limit inside the tank, the module starts up and sends out a 12 V DC signal. On the other hand, once the water reaches the top mark, the module shuts down automatically and provides no output signal.

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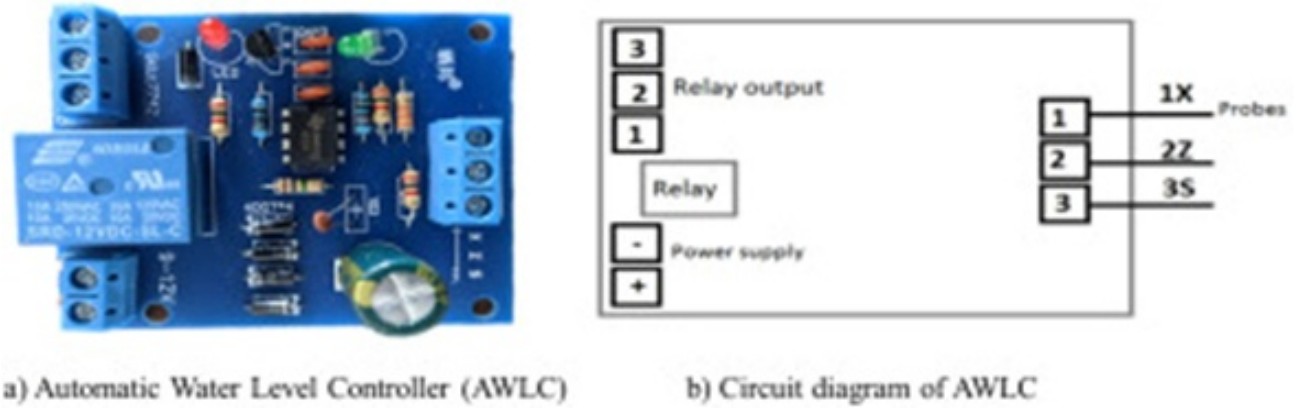

Figure 1. Automatic water level controller (AWLC) and its circuit diagram (1X, 2Z, and 3S indicate the lower level, medium (sink) immersed probe, and the upper level).

Solenoid valve

A solenoid valve is an electromechanical device that controls the flow of liquid in a pipe. In this trial, a normally closed model powered by 220 V AC was selected **(Figure 2)**. Without electricity, the valve stays shut. When electricity is applied, the plunger moves and opens the valve, allowing water to pass freely.

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Figure 2. Solenoid valve for controlling water flow.

Alternate wetting and drying (AWD) pipe

PVC pipes were used to make AWD pipes, with each pipe cut to 30 cm **(Figure 3)**. Each AWD pipe consisted of a 10 cm top section without holes and a 20 cm bottom section with perforations. The perforated 20 cm section was pushed into the ground from the surface, allowing water to enter the pipe through the openings. The top 10 cm portion extended above the ground level. For automated field tracking of water levels, sensor probes were connected to the water-level controller and positioned within the AWD pipe.

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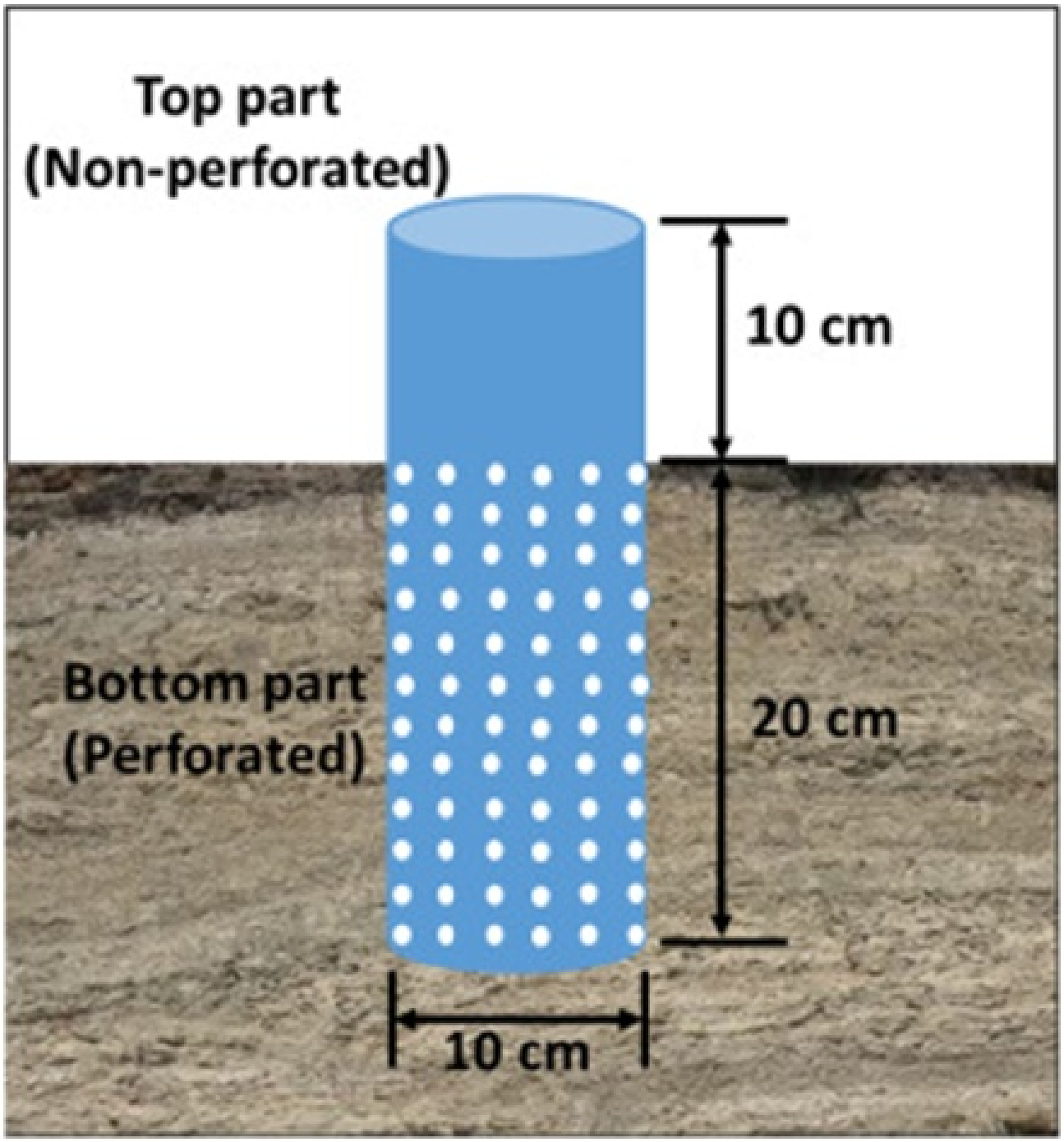

Figure 3. Alternate wetting and drying (ADW) pipe.

Water level indicator scale

A thin pipe of nearly 1.5 cm diameter received centimeter markings and was inserted into the AWD pipe. This thin pipe served to display the water depth within the AWD pipe and to verify water presence across the trial plots. Sensor probes linked to the water level controller were firmly fixed inside the AWD pipe—the controller controlled water flow independently by operating the solenoid valve. Placement included the lower-level probe (1X) at 10 cm below the soil surface and the upper-level probe (3S) at 3 cm above the soil surface. The central 2Z probe worked as the reference probe and sat between the upper and lower probes **(Figure 4)**.

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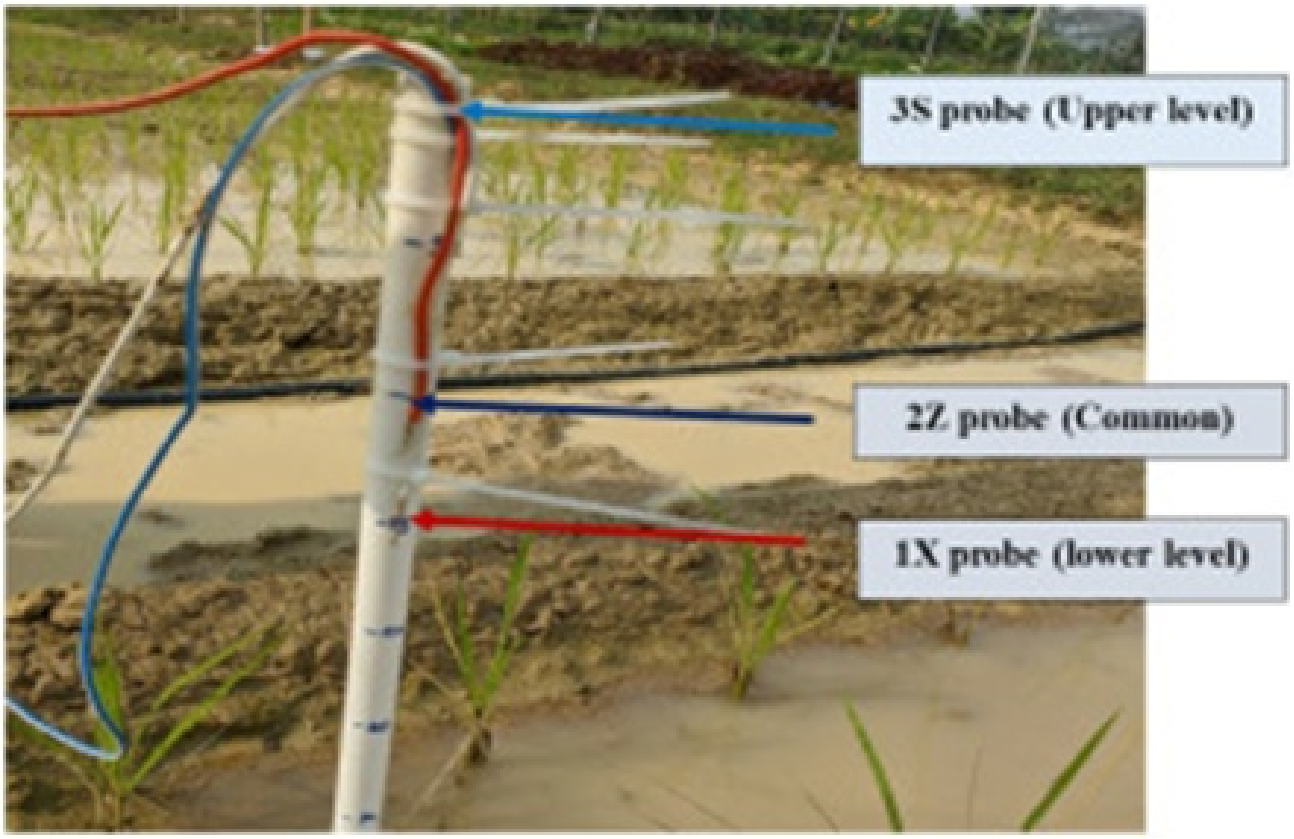

Figure 4. Water level indicator scale.

Other electrical and mechanical accessories

A magnetic contactor is an electrically controlled switch used to handle power circuits. It usually runs on a much weaker circuit than the one it oversees. During this trial, the 12 V DC water-level controller controlled the 220 V AC solenoid valve via the magnetic contactor. The setup relied on 12 V 2A AC-to-DC adapters because the automated water level controller demanded a 12 V DC supply. A circuit breaker was added for protection and emergency use. Reliable electricity throughout the trial held great importance. A power supply board was installed at the test location to provide continuous power for the experiment. Water reached the site via a ¾-inch hosepipe running from the source to the trial area. Connections used Tee connectors and clamps for a proper fit. Plastic boxes enclosed the entire circuit setup, making field installation straightforward while protecting electrical components from adverse weather, including rain, storms, and other natural disruptions. Solenoid valves were also kept inside these boxes for reliable attachment to the circuit setups.

Development of an automated irrigation system for rice using the AWD method

Three sensor probes (1X, 2Z, and 3S) connect to the automatic controller within the automatic water level controller, allowing it to adjust water levels. Probes 1X and 3S pick up the lower and upper water levels in the AWD pipe, with 2Z acting as the shared probe placed between 1X and 3S **(Figure 5)**. Probe 3S sits close to 3 cm above the soil surface to keep a 3 cm depth of standing water in the soil-embedded AWD pipe. Probe 1X sits nearly 10 cm beneath the soil surface inside the AWD pipe [29]. As soon as water falls below 10 cm from ground level, the sensor probes notice the drop and alert the automatic controller, which then opens the solenoid valve. Through the magnetic contactor, 220 V power is supplied to the solenoid valve immediately to initiate operation. Water travels across the field until the probes inside the AWD pipe sense the upper water level. At that point, shown by probe 3S at 3 cm above the soil, the controller signals the solenoid valve to close and halt water movement. In the same manner, while water stays between probes 3S and 1X and

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the valve needs to remain shut, the field dries out down to the lower level. This process allows effective automatic control over water delivery in the field.

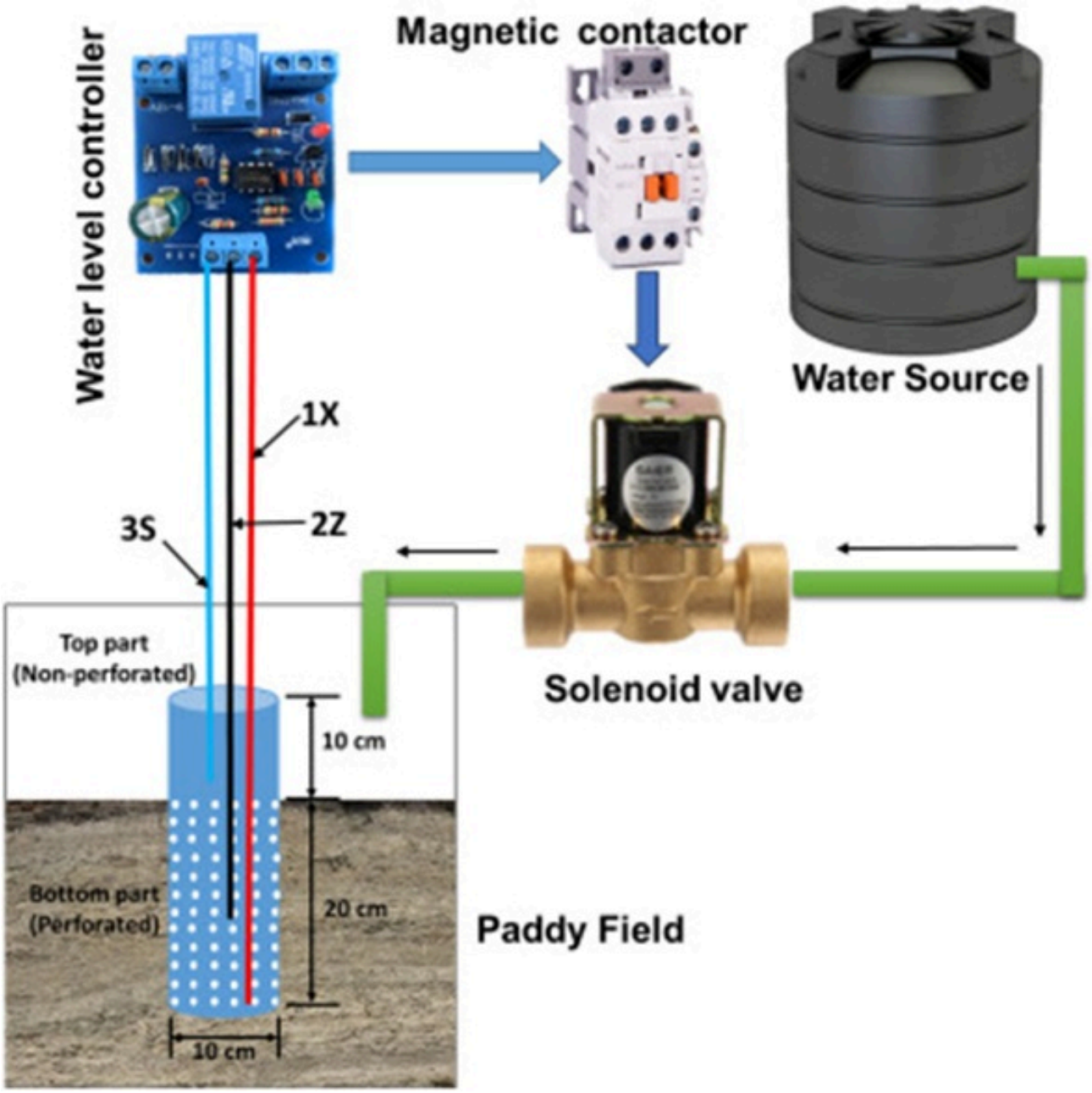

Figure 5. A schematic diagram of an automated irrigation system using the AWD method.

Evaluation of an automated AWD irrigation system

Experimental design

A Randomized Complete Block Design (RCBD) framework guided the research trial **(Figure 6)**. Three separate treatments formed part of the study: T1 - Conventional flood irrigation (CI), T2 - Alternate wetting and drying irrigation (AWD), and T3 - Automated alternate wetting and drying irrigation (AAWD). Conventional flood irrigation involved applying water every 3–4 days while keeping standing water around 2–4 cm deep. This went on until the ripening phase, which followed common farmer practices. In the AWD approach, water level regulation was achieved through a perforated PVC

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pipe **(Figure 3)**. By comparison, the automated version combined a water level controller with the AWD technique for hands-free water level management. Four blocks divided the experimental field, allowing three replications per treatment. Buffer zones of about 1.0 m separated neighboring blocks to allow easy movement inside the plots. Every block is split further into three treatment plots measuring 4 m × 3 m each **(Figure 7)**.

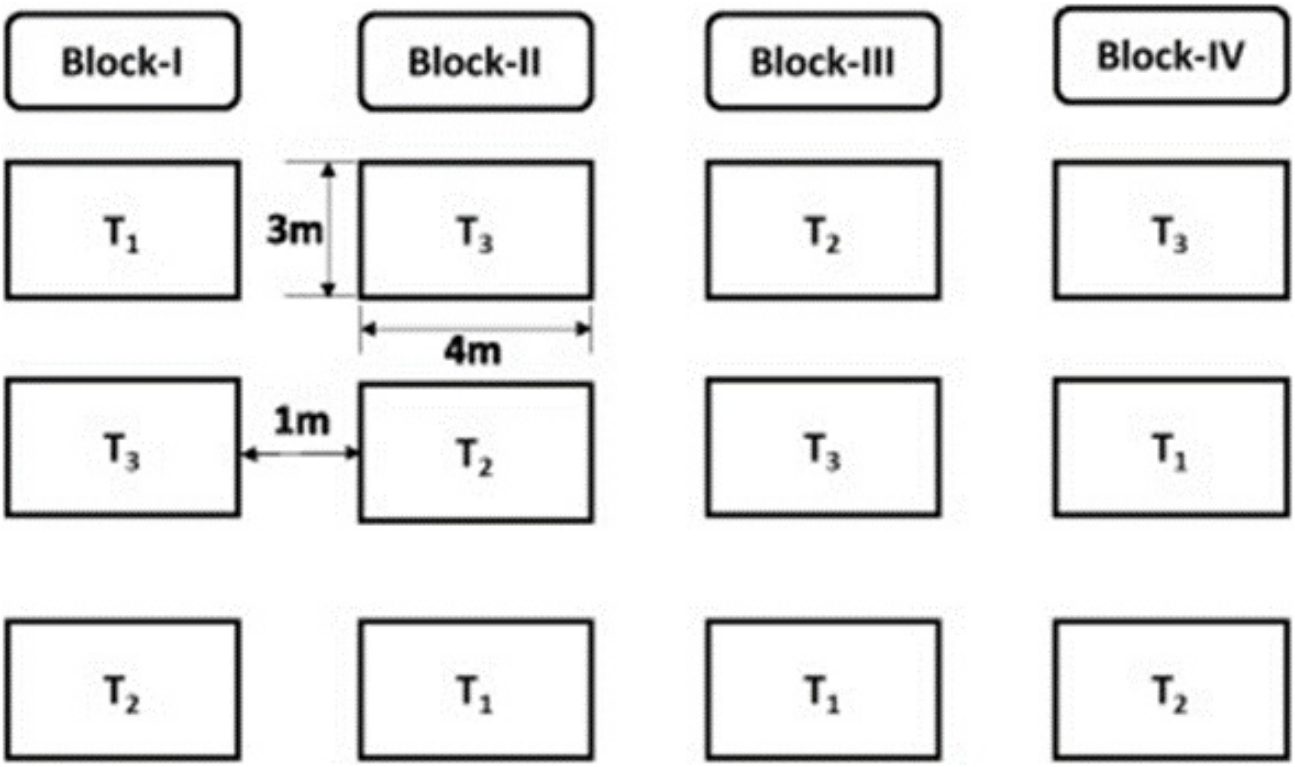

Figure 6. Experimental layout (RCBD).



Figure 7. Research field of the agricultural engineering department at Bangabandhu Sheikh Mujibur Rahman Agricultural University.

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Experimentation

Work was conducted at the experimental field belonging to the Agricultural Engineering department at Bangabandhu Sheikh Mujibur Rahman Agricultural University in Salna, Gazipur **(Figure 7)**. The period covered was from February 2021 to June 2021. The site lies 8.4 m above mean sea level, at latitude 24°09′ N and longitude 90°26′ E. The soil at the experimental field falls under the silty clay loam or red-brown terrace of the Salna series. A subtropical climate defined the location, bringing fairly high summer temperatures paired with heavy rainfall and fairly low winter temperatures with little rainfall. Local weather records during the trial — monthly rainfall amounts, highest and lowest air temperatures, relative humidity, and evaporation rates — were obtained from the BSMRAU weather station to provide a complete view of conditions.

Power tiller preparation and leveling prepared the experimental field soil before moving seedlings. The area was cleaned to remove weeds, leftover stubble, and other plant debris. Recommended quantities of urea, TSP, and MoP from the Bangladesh Rice Research Institute (BRRI) went into the field. The chosen rice type was BRRI Dhan 84. On February 3, 2021, seedlings aged 35–40 days **(Figure 8)** were transplanted at the site. The layout used 2/3 seedlings per bundle, 25 cm between rows, and 20 cm between individual plants. Spare seedlings waited near the field to fill any empty spots that developed in the plots.



Figure 8. Field layout and transplanting of seedlings for the experiment.

Careful removal of unwanted plants avoided damage to surrounding ones. The first weeding occurred at 30 days after transplanting (DAT), and the second at 60 DAT. Even though BRRI Dhan 84 shows strong insect resistance, a preventive insecticide was applied before flowering as a safeguard. Herbicides also helped manage weeds across the experimental field.

Each block **(Figure 6)** received the three irrigation treatments, which were maintained until one week before flowering. From flowering onward, standing water remained in every plot until two weeks before harvest. Paddy harvest occurred on April 29, 2021. Data on plant traits and yield factors were collected from a 1.0 m^2 marked area within each plot. Harvested plants received bundling and separate tagging per plot. Recorded measurements covered plant height (cm), tillers per hill, panicle length (cm), 1000-grain weight (g), grain yield (t/ha), straw yield (t/ha), biological yield (t/ha), harvest index (%), and water use efficiency (kg/m^3). The analysis used ANOVA in R and RStudio. The least significant difference (LSD) test at $p < 0.05$ was used to compare mean values.

Results and Discussion

Impact of AAWD on plant growth and yield-contributing characters

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Table 1 presents the broad influence of the irrigation treatments on plant growth and yield-related factors. Treatment T2 (AWD) produced a plant height of 115.46 cm, which was slightly taller than the 113.96 cm from treatment T3 (AAWD). Treatment T1 (CI) achieved a plant height of 115.45 cm, which was not statistically different from that of treatment T2 (AWD). This matched earlier reports [29] noting that greater water stress leads to clear drops in plant height. Plant height showed only a limited association with yield, as taller plants sometimes outperformed shorter ones. Findings confirmed that AAWD plant heights lacked notable differences from the rest of the irrigation options. Lower tiller counts per hill are tied directly to lower yields. T3 (AAWD) reached the top tiller count per hill at 15.47, with T2 (AWD) at the bottom with 15.42. Variations in tiller numbers stayed small and showed no meaningful gap from other treatments. Restricted irrigation, therefore, exerted little influence on tiller counts per hill, limiting its overall impact on paddy yield.

Table 1. Impact of irrigation treatments on plant growth and yield contribution.

Treatments	Harvesting index (%)	Biological yield (t/ha)	Straw yield (t/ha)	Grain yield (t/ha)	1000 grain weight (g)	Panicle length (cm)	No. of tiller/hill	Plant height (cm)
T_1	37.48	17.53	10.96	6.57	21.67	30.05	15.47	115.45
T_2	37.19	17.37	10.91	6.46	21.71	30.12	15.42	115.46
T_3	37.51	17.51	10.85	6.52	21.95	30.13	15.47	113.96
CV(%)	0.39	0.40	0.41	0.69	0.57	0.12	0.15	0.61
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Abbreviations: NS = Non-significant; T1 = Conventional flood irrigation (CI); T2 = Alternate wetting and drying irrigation (AWD); T3 = Automated alternate wetting and drying irrigation (AAWD).

Panicle length, another crucial component of paddy yield, is also discussed.

Greater panicle length directly correlates with higher output levels. Treatment T3 (AAWD) delivered the maximum panicle length (30.125 cm), in contrast to the minimum length (30.05 cm) noted under treatment T1 (CI). Treatment T2 registered a middle-range panicle length of 30.11 cm. Crucially, no substantial drop in panicle length occurred, and the possibility of reduced paddy output due to restricted irrigation remained low across treatments. These observations correspond closely with the figures reported by Rahman and Bulbul [27].

Thousand-grain weight (1000-grain weight) primarily reflects the test weight of the target crop while indicating both elevated mass or output and overall grain quality. Analysis indicated no meaningful differences across the irrigation treatments **(Table 1)**. Application of the AAWD irrigation approach had no notable effect on paddy grain quality, as indicated by statistical equivalence across all treatments. Although grain yield is a primary focus in agronomic investigations, the treatments showed no meaningful differences, despite minor fluctuations in the grain yield values listed in **Table 1**. Treatment T1 (CI) recorded the highest grain yield (6.57 t/ha) and was statistically comparable to the remaining treatments. By comparison, the minimum grain yield was 6.46 t/ha in T2 (AWD), and treatment T3 yielded an intermediate 6.52 t/ha. The outcomes correspond with earlier studies [1, 17] showing that AWD techniques exert only modest effects on grain yield. Consequently, introducing the AAWD irrigation system into paddy farming avoids any output decline compared with other strategies.

Straw yield is another key factor in paddy farming because it has commercial value. Consistent with prior measures, the treatments showed no meaningful differences, as summarized in **Table 1**. Treatment T1 (CI) attained the maximum straw yield (10.96 t/ha), remaining statistically similar to the rest. By comparison, treatment T3 (AAWD) generated the minimum straw yield at 10.85 t/ha. These observations establish that the AAWD irrigation system leaves straw yield unaffected

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throughout paddy production. Biological yield, formed by the sum of grain and straw yields, functions as an essential indicator during agronomic reviews. Treatment T1 (CI) obtained the highest average biological yield (17.53 t/ha), whereas treatment T2 (AWD) recorded the lowest (17.37 t/ha). Such results highlight the statistical alignment of biological yields when applying the AAWD irrigation method alongside other irrigation strategies, thereby eliminating concerns about output losses.

Harvest index is another vital measure that expresses the proportion of grain yield to biological yield. Treatment T3 (AAWD) achieved the maximum harvest index (37.51%), while treatment T2 (AWD) showed the minimum index (37.19%). Given the statistical alignment across all irrigation treatments, **Table 1** confirms that the AAWD irrigation method does not affect harvest index.

Impact of AAWD on water use efficiency (kg/m3)

Water use efficiency (WUE) acts as a fundamental benchmark when assessing irrigation strategies. Details regarding total water consumption, total grain yield, and water use efficiency (WUE) receive clear illustration within the study **(Table 2; Figure 9)**. Findings identified the maximum water use efficiency (WUE) reaching 65.20 kg/ha/cm under treatment T3 (AAWD), against the minimum WUE of 52.56 kg/ha/cm under treatment T1 (CI). Treatment T2 (AWD) achieved the second-highest WUE level (61.52 kg/ha/cm). Treatment T1 (CI) displayed the greatest average total water consumption (125 cm) by the crops, which corresponded to the greatest grain yield of 6.57 t/ha. Conversely, treatment T3 (AAWD) showed the smallest total water consumption (100 cm) after treatment T2 (AWD), while still achieving a grain yield of 6.52 t/ha, approaching the peak value. Notably, treatment T3 (AAWD) preserved around 20% and 5% of irrigation water relative to treatment T1 (CI) and T2 (AWD), respectively. Treatment T2 (AWD) preserved around 16% of irrigation water compared with T1. These observations align with previous published research [3, 15, 30] that likewise highlighted opportunities for water conservation through alternative irrigation methods. The present study emphasizes that continuous standing water is not the exclusive route to optimal rice output [29]. Employing the irrigation strategy from treatment T3 (AAWD) promises approximately 25 cm of water savings, in line with the literature [29].

Table 2. Effect of different treatments on water use efficiency.

Treatment	Total field irrigation requirement (cm)	Effective rainfall (cm)	Water savings compared to conventional irrigation (%)	Water use efficiency (kg/ha/cm)	Total water used (cm)
T_1	105	20	–	52.56	125
T_2	85		16	61.52	105
T_3	80		20	65.20	100

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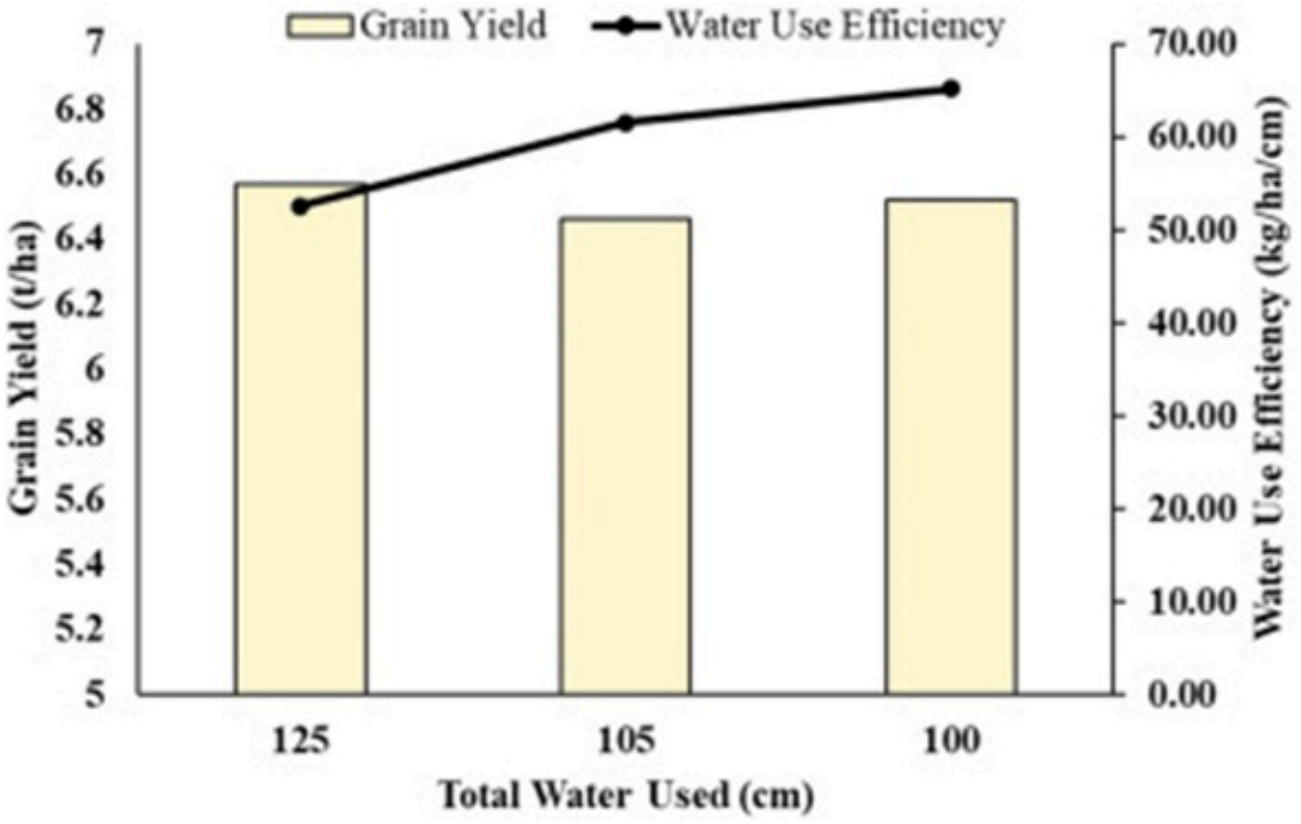

Figure 9. Relation between total water used and grain yield and water use efficiency.

The outcomes further establish that AAWD treatment is a highly effective option for both water conservation and water-use efficiency, with strong promise for major water-preservation efforts across the irrigation field. In addition, automation (AAWD) applied to standard irrigation arrangements can reduce the need for repeated human involvement in irrigation oversight, thereby trimming labor costs. Additionally, an individual AAWD module constitutes a notably compact arrangement that offers straightforward installation and relocation, with minimal maintenance costs.

Water level under AWD and AAWD

AAWD demonstrates its primary usefulness by maintaining the recommended water level within the perforated pipe. The AAWD arrangement described in this manuscript maintained irrigation timing precisely when needed. Crop establishment took nearly 21 days, during which the standing water level remained around 3 cm. Intermittent irrigation (AWD) began at 21 DAT as soon as the water level descended 10 cm beneath the ground surface **(Figure 10)**. Irrigation ceased upon the water level inside the perforated AWD pipe attaining roughly 3 cm above the ground surface. This regular pattern of decline and restoration occurred automatically for treatment T3 (AAWD) and was manually adjusted for treatment T2 (AWD). Furthermore, the AAWD system involved one fewer irrigation cycle than the AWD system. The variation arises because the automatic water level controller in the AWD tube maintained the designated water level across the field with high accuracy. On the contrary, the AWD system counts on direct visual assessment plus operator choice for its operation.

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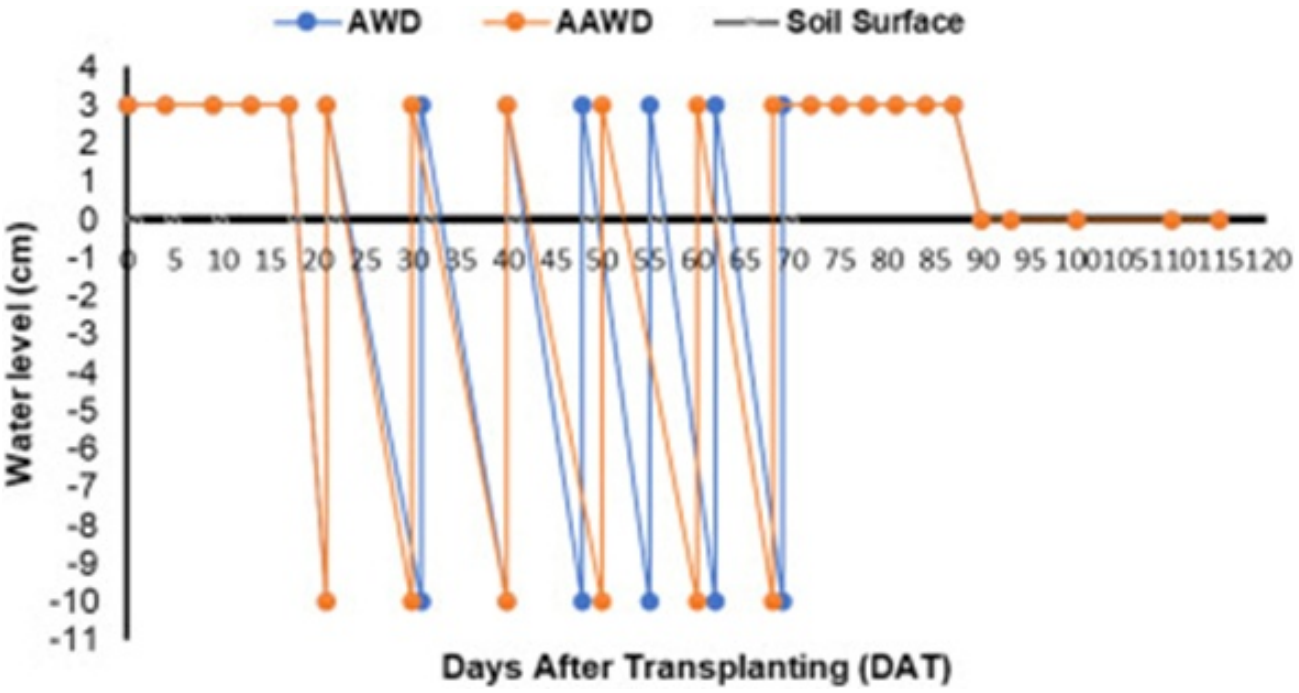

Figure 10. Irrigation events in treatments of AWD and AAWD.

Economic use of the AAWD irrigation system

Calculations estimated the cost of establishing one unit of the AAWD irrigation system across a 0.025 ha field area at BDT 6050 **(Table 3)**. Expenses linked to agronomic operations and irrigation water fees remained uniform across all treatments, as shown in **Table 4**, owing to identical land dimensions and the shared rice variety (BRRIdhan 84).

Table 3. Approximate cost of electronics used in a single unit AAWD installation.

Items	Total cost
Automatic water level controller	500
Magnetic contractor	550
Solenoid valve (diameter: 1 inch)	3500
Electric cable	1000
Circuit board	150
Circuit box	250
Adopter	100
Total cost (BDT)	6050

Table 4. Comparative analysis of the benefits and costs of different irrigation systems.

Cost components	T3 (AAWD)	T2 (AWD)	T1 (CI)
Expenses associated with the water delivery system	12,000	12,000	12,000

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AWD pipe installation cost	120	120	–
Cost of controllers and electrical accessories	12,100	–	–
Total fixed expenses (subtotal, a)	**30,170**	**12,120**	**12,000**
Amortization coefficient	0.277	0.277	1.12
Yearly depreciation and interest expenses	8369.45	3362.21	13,440
Production input expenditure*	71,060	71,060	71,060
Irrigation water fees	17,952	18,849.6	22,440
Labor expenditures	3900	4550	13,650
Total variable expenses (subtotal, b)	**21,852**	**23,399.6**	**36,090**
Overall annual cost per hectare (a + b)	**101,281**	**97,822**	**120,590**
Crop yield (t/ha)	6.52	6.46	6.57
Gross income per hectare	163,000	161,500	164,250
Net income	61,719	63,678	43,660
Benefit–cost ratio	1.609	1.651	1.362

† All the figures are in Bangladeshi currency (BDT) per hectare unless specified otherwise.

∗ includes the cost of seed, tillage, transplanting, fertilizing, weeding, mulching, spraying, and harvesting.

A clear supplementary advantage of AAWD adoption is substantially reduced labor costs compared with conventional flood irrigation. Overall production input expenses remained comparable across all treatments shown in **Table 4**, providing an economic review scaled to a far larger field (one hectare). Traditional flood-irrigated rice farming registered a benefit-cost ratio of 1.362, whereas the AWD treatment reached 1.651. The elevated BCR under AWD was not due to higher output but to lower irrigation and labor expenses **(Table 4)**. Under AAWD conditions, the BCR appeared marginally below the AWD level yet exceeded flood irrigation. Such information suggests that AAWD delivers favorable economic benefits to rice cultivators across Bangladesh.

Conclusion

This research presents an Automated Alternate Wetting and Drying (AAWD) irrigation system engineered to control field water levels independently of manual monitoring. The system incorporates water-level probes connected to a water-level controller housed within the alternate wetting and drying (AWD) pipe. Deployment of the AAWD system did not have any meaningful detrimental effects on plant development or yield-associated traits. In particular, indicators such as plant height, tiller count, and panicle length showed no significant differences among irrigation treatments. Likewise, primary yield components, including 1000-grain weight, grain yield, straw yield, and biological yield, showed no notable differences among treatments. The AAWD irrigation system distinguishes itself by achieving outstanding water-use efficiency (WUE) compared to competing irrigation strategies. Moreover, the system conserves roughly 20% of irrigation water compared with conventional irrigation (CI) practices in paddy farming. This research constitutes the first documented account of paddy farming using an automated alternate wetting and drying (AAWD) irrigation system in Bangladesh. Drawing on these observations, the AAWD irrigation system qualifies as a reliable, precise, secure, and ecologically sound approach for advancing paddy production across Bangladesh.

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Conflict of interest

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Ethics statement

None

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