Improving water use for dry season agriculture by marginal and tenant farmers in the Eastern Gangetic Plains

Technological interventions for improving water use efficiency in the northwest region of Bangladesh

Working Paper

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Executive Summary

The Eastern Gangetic Plains, which include the Nepal Tarai, Bihar and West Bengal of India and northern part of Bangladesh, is one of the most densely populated, poverty-stricken belts in South Asia. Behind this persisting poverty are deeply entrenched social structures of class and caste, with a high incidence of inequitable landlord-tenant relations. This is combined with poor access to irrigation water in the dry season, limited irrigation capacity and low agricultural innovation. A project: **"Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains (LWR/2012/079)"** was undertaken during July 2015 to June 2019, funded by ACIAR, Australia. At present technical, social and economic constraints have limited the effective use of groundwater and ponds for irrigation, and large areas of land remain fallow during the dry months. Access to year-round water for irrigation would significantly promote the productivity of agriculture, improving incomes and food security. Marginal and tenant farmers, youth and women are the target set of farmers who could benefit from a new approach to irrigation provision. This research is crucial to the long-term sustainability of small-scale agriculture in the Eastern Gangetic Plains. Among the project sites northwest part of Bangladesh is highly developed and well managed and access to irrigation water and thus this area become a food granary of Bangladesh. The overall aim of the project is to improve the livelihood of woman, marginal and tenant farmers in the Eastern Gangetic Plains, through improved water use and increased dry season agricultural production. Rice is the major crops (about 73%) grown in the region along with wheat, maize, potato, pulses and oilseeds and rice is the major water used crop and groundwater is the only source for irrigation. Therefore, this study was undertaken for improving the water and land productivity in northwest region of Bangladesh by technological interventions. The selected study sites were Pabna, Bogura, Rangpur and Thakurgaon.

Most of the irrigation water was distributed through earthen canal and due to light textured soil about 30-40% water was lost by conveyance. For reducing this conveyance loss, polythene pipe distribution systems were tested in the selected STWs. The tested results showed that by introducing polythene pipe for water distribution it could be saved about 20-25% conveyance water compared to earthen canal with the reduction of same percent irrigation time. But due to priming problem of STW, farmers were reluctant to use polythene pipe in water distribution. For overcoming that problem, a check valve was used in STW, which became easier for polythene pipe use. Now, farmers were interested to use the check valve in their STW. Groundwater level in the study areas were the main concern for STW operation. The study results showed that in most of the study areas groundwater level was below the suction limit except Bogura (about 8.8 m). There was no problem in STW running in Pabna, Rangpur and Thakurgaon, whereas deep set STW is needed for Bogura. High yielding newly released Boro varieties performed well in the selected locations and the farmers were chosen the different tested varieties based on yield and growth duration. The yield advantage would influence the improving water and land productivity of those locations.

Field scale water loss was another concern for increasing irrigation cost and reducing water productivity. AWD water management was the best approach for increasing water saved, reducing irrigation cost and improving water productivity. In this method about 14 - 18% irrigation water would be saved irrespective of variety and locations, which ultimate reduced the groundwater pumping. Water productivity mainly depends on rice yield and water applied. Overall water productivity of FP varied from 0.69 to 0.73 kg/m^3 and that of AWD varied from 0.81 to 0.83 kg/m^3. AWD irrigation method would be reduced 160 kg CO_2/ha emission and also reduced 23-36% methane flux emission from rice field compared to continuous flooding. Mass adoption of these technology in the northern region of Bangladesh will be helpful to cope with the water scarcity and sustainable agriculture and also improved environment.

1. Introduction

Background

Rice is one of the most widely grown crops in the world and used as staple food by more than 3.5 billion people (FAOSTAT, 2016). Globally, over 478 million tons of milled rice was produced in 2014/15 of which over 90% was used directly for human consumption (USDA, 2016) and Asian people are the major consumer of that rice (IRRI, 2016). While the population of Asian countries is growing steadily, land and fresh water availability for rice production are on decline trend, raising concerns about food security, and potentially on a longer term, political stability. Rice is also essential for ensuring global food security, traditional rice cultivation, practiced in flooded paddy soils, demands higher water inputs than other cereal crops (Pimentel et al., 2004). Although fresh water availability for agriculture is declining in many Asian countries (Postal, 1997) including Bangladesh and its demand for rice is increasing (Pingali *et al.*, 1997). Approximately 50% of the fresh water is used for rice production in Asia (Guerra *et al.*, 1998). In Bangladesh, water demand for house-hold, agriculture and industry are increasing very fast (Bindraban, 2001). According to OECD (2012), global water demand will be increased 55% by 2050, of which mainly for industry and domestic purposes. The projections show that feeding a world population of 9.1 billion people in 2050 would require raising overall food production by some 70 percent between 2005 and 2050. Ninety percent of the growth in crop production globally (80 percent in developing countries) is expected to come from higher yields and increased cropping intensity, with the remainder coming from land expansion, while the irrigated land will be increased by 17% by 2050 (FAO, 2009). Population of Bangladesh will be reached by 215.4 million and the corresponding rice demand will be 44.6 million tons by 2050 (Kabir et al, 2015). As a result, regulation of water allocation is one of the burning issues for the policy makers for sustainable rice production. With the increasing threat of water scarcity currently affecting 4 billion people around the globe (Mekonnen and Hoekstra, 2016), it is crucial to develop agronomic practices with the potential to reduce water use while maintaining or increasing yields to support a growing population.

Bangladesh has made remarkable development in agriculture over the last few decades and gained self-sufficiency in rice production. With the population of 76 million in 1977, total production of rice was 11.6 million tonnes (152 kg/capita). Now in 2015, with the population of 160 million, the total production of rice has increased to 34.83 million tonnes (222 kg/capita) (Kabir et al., 2015). It is not only rice, there is significant increase in production of other crops such as wheat, maize, vegetables and fruits over the last few decades. Agriculture is a leading contributor to poverty reduction in Bangladesh since 2000 (World Bank, 2016).

Production increases have resulted from a substantial intensification of agriculture rather than from increases in land area available for cultivation. The overall cropping intensity for the country has increased from 148.9% in 1977 to 193% in 2015 with an increasing proportion of land being double- or triple- cropped (BBS, 2016). This growth in intensity was driven by increased cultivation during the dry season due to the development of irrigation facilities. Based on this facility diversified crops like *Boro* rice, wheat, maize, potato, tomato, vegetables, pulses and oilseeds etc. can be grown in the dry season. Within these crops *Boro* rice alone contributed more than 55% of the total rice production of the country from about 42% of the total cultivated area of rice (BBS, 2016). *Aman* rice is the predominant crop (48% of total cultivated area) in the wet season mainly depends on rainfall. Aus is also pre-monsoon rainfed crop, but it covers only 8% of total cultivated area (BBS, 2016).

Rice fields have been identified as an important source of atmospheric methane (CH4), one of the major potent greenhouse gases (GHG), and contribute approximately 15–20% of global anthropogenic CH4 emissions (Aulakh, et al., 2001; Yan et al., 2005). Nitrous oxide (N2O), another potent GHG, may be emitted from rice fields as a combined effect of nitrogen (N) fertilization and water management (Zou et al., 2007; Shan and Yan, 2013; Li et al., 2014).

After the privatization of irrigation sector during 1982, a substantial growth of irrigation development over the last 3 decades. Total irrigated area has increased from 1.52 million ha in 1983 (18% of the net cultivable area) to 5.4 million ha in 2015, (63% of the net cultivable area). This growth was driven by the growing use of groundwater through rapid increase in the adoption of shallow tubewells. Groundwater covers about 80% of the total irrigated area of the country and is in increasing trend. The number of STWs has increased from 93 thousand to 1.53 million during this period. The number of deep tubewells (DTWs), which also pump groundwater, has increased from about 14 thousand to 35 thousand.

Northwest region has the highest percentage of net cultivable area irrigated in 2012-13 (around 85%) and has the most intensive use of groundwater; over 97% of the total area is irrigated (2012-13) by groundwater. The region produces 34% of the country's total rice, 60% of the total wheat, and more than 2/3 of the total production of potato and maize. This region is considered as the food basket of Bangladesh. Groundwater is the main driver of this development.

These rapid expansion of irrigated area and crop production was done on the expense of groundwater resources in the northwest region. In recent years, there are serious concerns about the sustainability of groundwater use in the northwest region. Many studies (Samsudduha et al., 2009; Rahman and Mahbub, 2012; Aziz et al., 2015) show that groundwater levels are falling and that the use of shallow aquifers for irrigation in the area is unsustainable. For sustainable use of groundwater is need to improve the water losses from water distribution and field scale. In most of the cases, irrigation water was distributed by earthen canal and in this system water losses from 30-40% of conveyance water depending on soil texture and compactness of the earthen canal (Biswas et al., 1984). This conveyance loss can be minimized by many options like canal lining, polythene and plastic pipe used, buried pipe water distribution systems etc. On the other hand, there are various ways in which water can enter and leave a rice field. Inflow occurs through rainfall, irrigation, and capillary rise, and outflow through percolation, seepage underneath bunds, overbund flow, evaporation and transpiration. Transpiration is the only type of outflow that contributes to crop growth and is therefore termed 'productive water use'. In a series of fields, both seepage and over bund flow can contribute to adjoining farmers' fields before draining into ditches or the groundwater. Even after entering the groundwater, this water may remain reusable through pumping (Bouman et al., 2007).

The current (2015) population of Bangladesh is 160 million and is projected to increase to 215 million by 2050 (Kabir et al., 2015). To feed this extra population, Bangladesh must increase food production substantially (Mainuddin and Kirby 2015, Kabir et al., 2015) and this will require further intensification of production from the declined land due to urbanization and industrial development. Irrigation development and management is the only option to sustaining food production.

But, development of irrigation in the northwest part of Bangladesh is near to saturation and the irrigation cost is near to one-third of the total rice production. To reduce the irrigation cost and improved the water productivity a study was undertaken to reduce the conveyance loss and field scale water use.

2. Methodology

2.1 Site selection

To fulfil the objectives of the study some water management technologies were tested in the farmer's field for validation and wide scale adoption in the project areas. Three STW areas like Mithapukur, Rangpur; Sherpur, Bogura and Ishurdi, Pabna and one DTW area like Thakurgaon Sadar, Thakurgaon were selected (Fig. 2.1). The tested technologies were:

i. Use of polythene pipe in STWs for reducing conveyance loss in water distribution
ii. Alternate wetting and drying (AWD) irrigation scheduling for improving the field scale water productivity

Among the technologies, polythene pipe distribution system was tested in three STW areas and AWD system was tested in all of the selected areas.

Fig. 2.1 Selected sites for technological interventions within the study areas.

2.2 Polythene pipe water distribution systems in STWs

Earthen canal water distribution system is common in all minor irrigation systems in Bangladesh. Generally, these canals are prepared by digging the land along the boundary levee of the plots. The excavated earth is used for constructing embankment of the canal. Normally, the bottom level of these canals remains below the land surface of the adjacent plots. For that reasons, some portion of pumped water was lost as dead storage in the canal. No lining measures were taken to reduce water losses through the bottom and bank of the canal. The conveyance losses in minor irrigation schemes ranges from 20-40 percent in Bangladesh depending on the soil texture (Biswas et al., 1984). These huge conveyance losses increased the pumping hours of STWs and consequently increased the irrigation cost and more pumping also lowering the groundwater level as well.

Now-a-days, through different projects awareness building program were initiated to improve the distribution systems of groundwater pumping. *Boro* rice area and productivity is in increasing trend of most of the areas, puts more pressure on groundwater resources for *Boro* rice production, especially in north-west region of Bangladesh (Aziz *et al.*, 2015). For that groundwater level in some particular areas goes below the suction limit of STWs at peak irrigation season. For reducing the conveyance losses and lowering the irrigation cost now-a-days polythene pipe water distribution system become popularised. Low cost polythene pipe water distribution system was a common practice for non-rice crops. But farmers were highly interested to use the polythene pipe in rice irrigation in limited scale. Though polythene pipe was beneficial, but most of the farmers were reluctant to use it due to fitting problem. Therefore, BRRI designed a check valve and it was tested in the selected STWs to overcome the priming facilities and also reduce the drudgery of STW operation. It also facilitated the polythene pipe fittings and easiness of improving the distribution systems. However, only government managed DTWs have buried pipe irrigation systems under BMDA and BADC.

To evaluate the performance of low-cost polythene pipe water distribution system, six STWs were selected in different study sites (Table 2.1). In the study STWs, required diameter (depends on the outlet diameter of STW) and about 90-100 m length of polythene pipes were used. In each replication, two rice plots were selected at similar area with same distance. Measured amount of water was applied by polythene pipe and earthen canal and then compared the efficiency of polythene pipe over earthen canal. Table 2.1 shows the number of demonstrations on polythene pipe distribution system in each site with the irrigation schemes and existing distribution system.

Table 2.1 Number of demonstrations on polythene pipe distribution system in each site with the irrigation schemes and existing distribution system during the Boro season 2016-17.

Site	Number of demonstration	Irrigation schemes	Existing distribution system
Bogura	2	STW with diesel engine	Earthen canal
Pabna	1	STW with electricity	Earthen canal
Rangpur	3	STW with diesel engine	Earthen canal
Total	6		

Five irrigation wells were selected for demonstrations in 3 different sites during Boro season 2017-18. Among the five wells 3 were in Rangpur, 1 in Pabna and 1 in Bogura. Similar procedure was applied for selecting the plots as 2016-17.

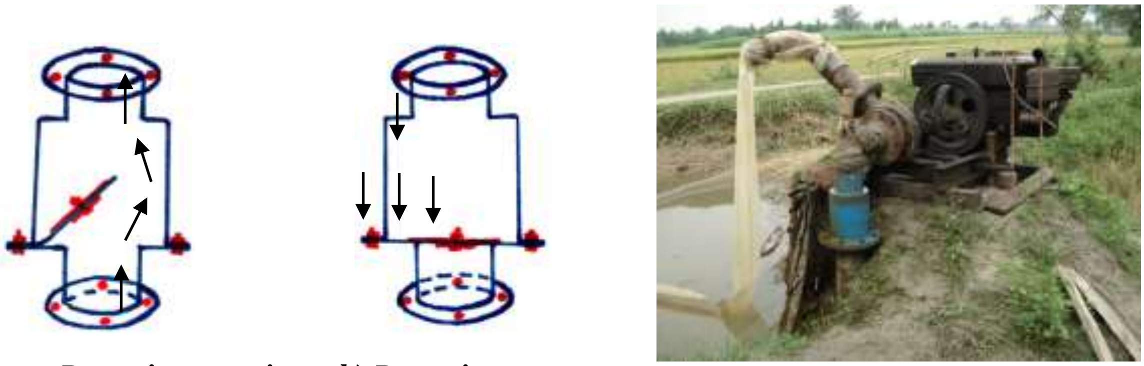
Table 2.2 shows the number of demonstrations on polythene pipe distribution system in each site with the irrigation schemes and existing distribution system during Boro season 2017-18.

Table 2.2 Number of demonstrations on polythene pipe distribution system in each site with the irrigation schemes and existing distribution system during Boro season 2017-18.

Site	Number of demonstration	Irrigation schemes	Existing distribution system
Bogra	1	STW with diesel engine	Earthen canal
Pabna	1	STW with electricity	Lined and earthen canal
Rangpur	3	STW with diesel engine	Earthen canal
Total	5		

2.3 Use of check-valve for improving priming and reducing drudgery of STW operation

During operation of STW, farmers faced the priming problem in every time of STW stating, which was troublesome and bothering work. To make STW operation easier by solving priming problem a check valve was developed in BRRI. For construction of a check valve, a rubber valve was set on a GI pipe of same diameter of the suction pipe of STW (Fig. 2.2). A pipe greater then minimum 50 mm diameter of the suction pipe and minimum 150 mm in length was fitted on the valve with flange joint, which was air tight and facilitate to free movement of the valve. Then it was fitted with the tubewell suction side before pump. It was keeping water up to delivery pipe of STW and thus overcoming the priming problem of STW. It also facilitated and easier to polythene pipe fittings to the STW outlets.



a) Pump in operation *b) Pump in stop* *c) Check valve in STW operation*

Fig. 2.2 Check valve design and operation of STW.

Boro season 2016-17:
Two check valves were installed in 2 STWs of Rangpur and Pabna districts during Boro season 2016-17. One check valve was installed in a STW running with electric motor in Rangpur. The another check valve was installed in a STW running with diesel engine In Pabna. A survey was conducted on owner’s feelings about the effectiveness of the check valve. They were asked about their perceptions on operation of the pumps before and after installation of the check valve. They were also asked about the easiness in use of polythene pipe for irrigation water distribution.

Boro season 2017-18:
Eight check valves were supplied in the project sites during Boro season 2017-18. Among these eight 3 were supplied in Rangpur, 3 were in Pabna and 2 were in Bogura. Six check valves were installed in Rangpur and Pabna districts.

Two check valves supplied in Bogura were not installed as pump owners were afraid of clogging in their wells. In Rangpur, 1 check valve was installed in STWs running with electric motor and 2 check valves were in STWs running with diesel engines. In Pabna, 1 check valve was installed in a STWs running with electric motor and another 2 in STWs running with diesel engines. A survey was conducted on owner's feelings about the effectiveness of the check valve.

2.4 Discharge measurement of the irrigation unit

Discharge of both STWs and DTWs were measured several times during the cropping season. The measurements were taken during initial (1st week of January), mid-season (1st week of March) and late season (2nd week of April). Discharge of STWs were measured using volumetric method. PVC containers having more than 100 lit capacity were used. After running for some time the initial reading of the meter was taken. Then flow was allowed for certain period and the time was counted with a stop-watch. The final meter reading was taken. The discharge was calculated using the following equation.

$$Q = \frac{Final\ reading - \quad Initial\ reading}{Time\ in\ Sec}$$

Flow meter method was also used for STW discharge and polythene pipe water distribution systems discharge measurement (Fig. 2.3). Steady state discharge was taken for unit time. The procedure was repeated at least for three times for accuracy of the measurements.

Fig. 2.3 Measurement of STW discharge by flow meter.

Due to lack of high capacity flow meter, the discharge of DTWs were measured by cut-throat flume (Figure 2.4). A straight canal section having a gentle slope was selected in an outlet which is closed to the DTW outlet. The flume was placed in the canal. The levelling was done by using a spirit level. The sides of the canal outside the flume were closed well by soil as water only flows through the flume. Water was allowed to flow through the canal and flume. After few minutes, when a steady-state condition in the flow was achieved, then measurements were taken. The elevation of water in the inlet and outlet of the flume were measured.

The relationship between flow rate Q and upstream depth of flow h_a in a cut-throat flume under free flow conditions is given by the following experimental relationship:

$Q = C_1 h_a^{n1}$

In which

Q= flow rate

C_1= free flow coefficient, which is the value of Q when h_a is 1.0 foot, which is the slope of the free flow rating curve when plotted on logarithmic paper.

n1= exponent, whose value depends only on the flume length L.

The value of n1 is a constant for all cut-throat flumes of the same length, regardless of the throat width W.

The cut-throat flume can be operated either as a free or a submerged flow structure. Under free flow conditions, critical depth occurs in the vicinity of minimum width, w, which is called the flume throat or the flume neck. The attainment of critical depth makes it possible to determine the flow rate, knowing only an upstream depth, h_a. This is possible because whenever critical depth occurs in the flume upstream depth, h_a, is not affected by changes in the downstream depth, h_b. For free flow, the ratio of inlet flow depth h_a to flume length should preferably be less than 0.4.

Fig. 2.4 Measurement of DTW discharge by cut-throat flume.

2.5 Evapotranspiration, seepage and percolation losses measurement

Evapotranspiration (ET), seepage and percolation (S&P) losses from irrigated plots were measured in each site. Ponded field, open bottom plastic container and closed bottom plastic container were used for the study. Three slopping gauges were installed inside the containers and the rice-field to measure ponded water levels daily (Fig. 2.5). Readings were taken at a specified time within 6-8 am. Daily rainfall data were recorded using a portable rain gauge.

Evapotranspiration rate was obtained from the water level data of a closed bottom container. This container prevents water losses by seepage and percolation. Evapotranspiration rate is-

$$ET = \frac{WL_t - WL_{t+1}}{RT} \times 24 \times 10 - Rf$$

Where,

ET= Evapotranspiration rate (mm/day)

WL_t= Initial water level in the container at time t (cm)
WL_{t+1}= Final water level in the container at time t+1 (cm)
R= Ratio between inclined and vertical side of the slopping gauge (here, 5)
T = Time difference between initial and final reading of water levels (hrs)
Rf= Rainfall recorded during last 24 hours (mm)

In open bottom plastic container water is lost through evapotranspiration and percolation. No seepage is occurring here. Evapotranspiration and percolation loss are calculated from the following formula:

$$ET + P = \frac{WL_{t-} WL_{t+1}}{RT} + R_f$$

Where,
ET= Evapotranspiration rate (mm/day)
P =Percolation rate (mm/day)
WL_t= Initial water level in the container at time t (cm)
WL_{t+1}= Final water level in the container at time t+1 (cm)
R= Ratio between inclined and vertical side of the slopping gauge (here, 5
T = Time difference between initial and final reading of water levels (hrs)
R_f= Rainfall recorded during last 24 hours (mm)

From the open field, water is lost through evapotranspiration, seepage and percolation. Water level data of the slopping gauge comprises all the three items. Evapotranspiration, seepage and percolation loss is calculated from the following formula.

$$ET + S + P = \frac{WL_{t-} WL_{t+1}}{RT} + R_f$$

Where,
ET= Evapotranspiration rate (mm/day)
S = Seepage rate (mm/day)
P =Percolation rate (mm/day)
WL_t= Initial water level in the container at time t (cm)
WL_{t+1}= Final water level in the container at time t+1 (cm)
R= Ratio between inclined and vertical side of the slopping gauge (here, 5
T = Time difference between initial and final reading of water levels (hrs)
R_f= Rainfall recorded during last 24 hours (mm)

To calculate seepage, daily loss of water from open bottom container is subtracted from the loss in the open field. To calculate percolation, daily loss of water from the closed bottom container is subtracted from the loss in the open bottom container. Evapotranspiration is obtained from closed bottom container when there is no rainfall. Plotted the water level data of both the closed bottom and open bottom container in excel sheet and for calculating the S&P data only used those data which were follow chronological trend. The average of S&P calculated data for each location was considered as mean S&P rate and used for any water balance calculation.

Fig. 2.5 Evapotranspiration, seepage and percolation rate measurement by using tank and slopping gauge.

2.6 Measurement of daily rainfall

A portable rain-gauge was installed in each site to measure the daily rainfall. A Taylor's rain-gauge was installed in an open area of the house. Amount of rainfall was measured every day at 6:00 am and recorded properly. If rainfall occurred, the cylinder is removed from the pole and measurement was taken. The rain water is removed from the gauge after measurement and the gauge placed in the pole again. The cylinder was graduated in inch. The unit was converted to millimetre using standard conversion. The recorded daily data was used to calculate monthly rainfall.

2.7 Groundwater level fluctuations monitoring

Four observation wells were installed in project sites at Pabna, Bogura, Dinajpur and Rangpur. The depth of the observation wells was 37m in Pabna, 24m in Bogura, 14m in Dinajpur and 23m in Rangpur. Weekly groundwater level was measured throughout the year. Water level meter was used to locate the distance from the well top. Measuring tape was used to measure the depth of water table. Measurement was taken in the morning to avoid the influence of irrigation wells. There was regular groundwater level monitoring program by BMDA in Rajshahi and Thakurgaon. They take fortnightly measurements. So, no observation wells were installed in these project sites. Groundwater level data were collected from BMDA in these two sites. Technological interventions were conducted at four project sites in Pabna, Bogura, Rangpur and Thakurgaon. So, measurements were taken in Pabna, Bogura, Rangpur and data were collected from BMDA in Thakurgaon. These data were plotted against time to present groundwater level fluctuations.

2.8 Introduction of newly released suitable rice varieties

A study was conducted to understand the preferences of the farmers of the study areas regarding rice varieties of Boro season. Based on the farmers choice and availability of seeds from reliable source 4 varieties were selected for demonstrations as- BRRI dhan63, BRRI dhan68, BRRI dhan74 and BRRI hybriddhan5. Some characteristics of these varieties are given in Table 2.3.

Table 2.3 Characteristics of the new rice varieties selected for performance demonstration.

Variety	Growth duration (days)	Grain type	Yield (t/ha)	Year of release
BRRI dhan63	146	Fine and long, Basmati type	6.5	2014
BRRI dhan68	149	Medium bold & white	7.3	2014
BRRI dhan74	147	Medium bold & white, Zn enriched	7.1	2015
BRRI hybriddhan5	145	Medium fine, long and white	9.0	2017

Seeds of the 4 varieties were supplied to the farmers of each site along with management instructions on cultivation practices. Farmers management practices were monitored and documented regularly.

2.9 Alternate wetting and drying (AWD) irrigation scheduling for Boro rice

There are mainly 3 rice seasons in Bangladesh. They are- Aus (pre-monsoon), Aman (monsoon) and Boro (winter). Aus and Aman are rainfed but Boro is fully dependent on irrigation. Supplementary irrigation is given to Aus and Aman if drought occurs. The traditional practice for Boro irrigation is to maintain continuous standing water in the rice field. Generally, 5-8 cm standing water is applied to the field and re-irrigate when water table reached about 1 cm. Maintaining continuous standing water helps application of fertilizers easier as well as control of weeds. A huge quantity of irrigation water 600-1300 mm is needed based on crop duration, planting time, soil texture and rainfall occurrence (Ref.------).

Mainly two types of losses encountered from rice field. These were evapotranspiration and seepage and percolation. Evapotranspiration was driven by climatic demand and varied from location to location. On the other hand, seepage and percolation loss mainly depends on soil textures and depths of standing water levels. Research findings showed that always standing water was not necessary for rice production. But to obtain optimum yield of rice, maintaining standing water is not mandatory. Intermittent irrigation in rice field can save irrigation water without hampering the yield. Alternate wetting and drying (AWD) irrigation scheduling have been proven as a water saving technology for Boro rice production. In this technology, rice field is allowed to be dried and flooded simultaneously during its mid vegetative phase to early reproductive phase and late at ripening phase.

The drying limit of the field is indicated by the perched water table. To monitor the perched water table a perforated PVC pipe is used. Generally, a PVC pipe of 7-10 cm diameter and 25 cm length is taken. The pipe has perforation at the lower 15 cm. The pipe is installed within 4 hills at the representative area of the plot (Fig. 2.6). The soil inside the pipe is removed up to its bottom so that water can easily move between the pipe and the field. A low ponding depth (1-2 cm) of water in the field is maintained up to 10-12 days after transplantation of paddy seedlings for easier establishment of the seedlings. After establishment during 12-15 days after transplanting, the 1st split of urea fertilizer is top dressed and weeding is done if required. Then a re-irrigation up to 5-7 cm standing water is applied. The water level in the field declines with time and at one stage surface of the field becomes dry but water remains visible in the pipe.

When the water level in the pipe touches its bottom and mud becomes visible then re-irrigation up to 5-7 cm is applied. This process continues up to booting stage of the crop. During initiation of heading the field is flooded again with 5 cm water without considering the level of the perched water in the pipe. Re-irrigation is applied when the flooding water level reaches 1 cm. This process continues for at least 15 days (up to milk stage). After milk stage the AWD irrigation is applied again up to the maturity of the crop. Generally, irrigation ceases two weeks before harvest of the crop if standing water is available in the field.

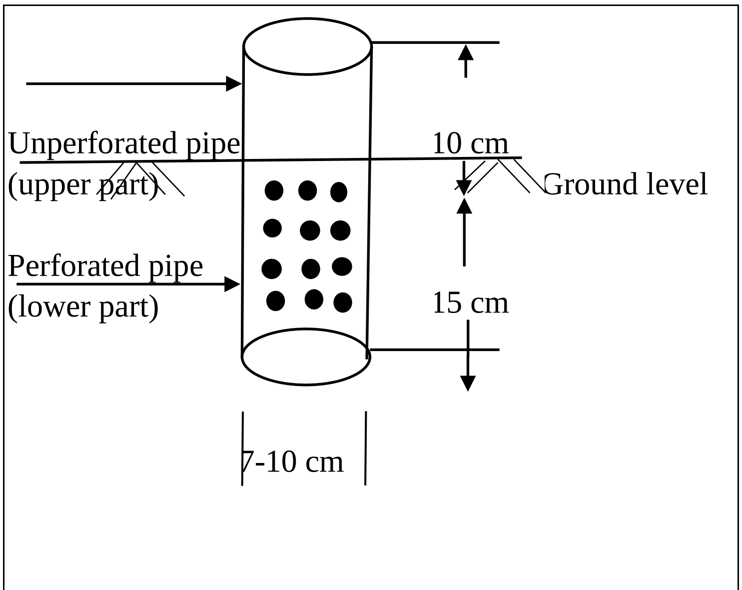


Fig. AWD Pipe

Fig. 2.6 AWD pipe and its installation in rice field.

During Boro season 2016-17 a total of 15 trial was conducted in the farmers' field of the study sites. The number of trials in Bogra, Pabna, Rangpur and Thakurgaon were 4, 3, 5 and 3, respectively. Similarly, during Boro season 2017-17, 20 trials were conducted in the selected locatons (Table 2.2).

As has been stated by Linquist et al. (2015), though many studies have examined potential benefits of water-saving irrigation, the consequences are rarely evaluated concomitantly. Water management in rice farming has several environmental implications, aside from the challenge of water scarcity. Rice farming emits approximately four times as much greenhouse gas as wheat or maize and therefore has significant potential in terms of mitigating agricultural greenhouse gas contributions (Linquist et al., 2012). Reducing the amount of time, the soil is kept under flooded anaerobic conditions has been found to decrease emissions of the strong greenhouse gas methane. However, the conversion to aerobic conditions instead leads to increased microbial activity and increased soil organic matter (SOM) decomposition and CO_2 emissions (Sahrawat, 2005; Haque et al., 2016a). SOM has great importance for soil health and agricultural sustainability. The conversion to more aerobic conditions may therefore have significant implications for long-term soil fertility and rice farming sustainability. Furthermore, the implementation of water-saving irrigation has also been found to affect nutrient availability in the soil, as well as losses of fertilizers through surface runoff and seepage (Sahrawat, 2005; Yang et al., 2015). Hence, the implementation of water-saving irrigation has many implications that should be considered in addition to the challenges of water scarcity.

A total of 15 trials were conducted in the farmers' field of the study sites during Boro season 2016-17. Number of trials in different sites are given in Table 2.4 along with used varieties and types of irrigation schemes.

Table 2.4 Number of demonstrations in each site with the irrigation systems and popular rice varieties.

Site	Number of demonstration	Irrigation scheme	Popular rice varieties
Bogra	4	STW with diesel engine	Minikit
Pabna	3	STW with electricity	BRRI dhan29, Minikit
Rangpur	5	STW with diesel engine STW with electricity	BRRI dhan28, Hybrid Heera
Thakurgaon	3	DTW with electricity	BRRI dhan28, BRRI dhan29
Total	15		

A total of thirteen demonstrations on AWD irrigation scheduling were conducted in 4 study sites during Boro season 2017-18. Among the demonstrations 3 were in Rangpur, 4 in Pabna, 3 in Thakurgaon and 3 in Bogura. Table 2.5 shows the number of demonstrations in different sites during Boro season 2017-18.

Table 2.5 Number of demonstrations in project sites with the irrigation systems and popular rice varieties during Boro season 2017-18.

Site	Number of demonstration	Irrigation scheme	Popular rice varieties
Bogra	3	STW with diesel engine	Minikit, Kajol lota
Pabna	4	STW with electricity	BRRI dhan28, BRRI dhan63, Minikit, Hybrid Surma
Rangpur	3	STW with diesel engine STW with electricity	BRRI dhan28, Hybrid Surma
Thakurgaon	3	DTW with electricity	BRRI dhan29
Total	13		

3. Results and Discussion

3.1 Demonstration on polythene pipe irrigation water distribution system for reducing the conveyance losses

3.1.1 Boro season 2016-17

Selected irrigation schemes

The performance of polythene pipe distribution system was tested in 6 STWs of 3 sites. Out of these 6 STWs, 3 were in Rangpur, 2 were in Bogra and 1 in Pabna. Table 3.1 shows the features of the selected STWs. Among the 6 tubewells 3 have well diameter of 10.0 cm, two have well diameter of 12.5 cm and one have well diameter of 15.0 cm. Total depth of the tubewells varied from 24-49 m. Among the pumps, 3 were with 7.5 cm and 3 were with 10.0 cm diameter of the delivery. Among the STWs 5 were operated by diesel engine and the rest one with electric motor. Prime mover capacity of the pumps also varies. Table 3.1 shows the features of the selected tubewells and pumps.

Table 3.1 Selected STWs with owner's name, tubewell features, prime movers' capacity and command area during Boro season 2016-17.

STW	Owners name	Well		Diameter of pump delivery (cm)	Prime mover	Prime mover's capacity (kW)	Year of install-ation	Command area (ha)
		diameter (cm)	Total depth (m)					
Pabna-1	Atiqul Mowla	15.0	48.8	10.0	Electric motor	6.45	2007	3.51
Bogra-1	Shafiqul Islam	10.0	24.4	7.5	Diesel engine	4.48	2017	2.97
Bogra-2	Abdul Latif	10.0	24.4	7.5	Diesel engine	4.48	2014	1.00
Rangpur-1	Sumon Ranjan	12.5	26	10.0	Diesel engine	4.48	2001	2.02
Rangpur-2	Fulu Mia	10.0	26	7.5	Diesel engine	2.94	2013	0.61
Rangpur-3	Golam Mustofa	12.5	28	10.0	Diesel engine	4.48	2013	2.49

Table 3.2 shows the area of the selected plots along with canal/pipe lengths and number of irrigations applied during Boro season 2016-17. The water loss was measured in similar length of polythene pipe and earthen canal. The applied number of irrigations were same for both earthen canal and polythene pipe. Number of irrigations varies from 9-18 in different STWs and locations. Highest number of irrigations was 18 in Pabna. The number of irrigations were lower in Bogura and Rangpur.

Table 3.2 Selected STWs with owner's name, plot size, canal/pipe length and number of irrigations during Boro season 2016-17.

Site	STW	Owner of the pump	Earthen canal			Polythene pipe		
			Area of the plot (decimal)	Canal length (m)	Number of irrigation	Area of the plot (decimal)	Pipe length (m)	Number of irrigation
Pabna	P-1	Atiqul Mowla	41.0	61	18	33.0	61	18
Bogura	B-1	Shafiqul Islam	37.0	67	10	39.5	67	10
	B-2	Abdul Latif	31.0	55	11	31.4	55	11
Rangpur	R-1	Sumon Ranjan	45.0	96	9	45.0	96	9
	R-2	Fulu Mia	25.0	67	10	30.0	67	10
	R-3	Golam Mustofa	45.0	100	10	45.0	100	10

Irrigation water saving:

Table 3.3 showed that the irrigation depth applied by polythene pipe and earthen canal distribution systems in different sites. The amount of irrigation water by polythene pipe and earthen canal varied from location to location depends upon the soil texture. The highest water supplied in polythene pipe and earthen canal water distribution systems in Pabna were 719 and 847 mm, respectively in silt-loam soil. Whereas, the lowest water supplied in Bogura by polythene pipe and earthen canal distribution systems were 408 and 515 mm, respectively in clay loam soil. Rangpur soil was in between those location and its water supplied was also within the range of previous both the locations. These amounts of irrigations were accounted for both land preparation and growing duration. The irrigation water saving varied from 15-22% irrespective of locations and soil type with an average of 20% compare to earthen canal. The study results indicated that use of polythene pipe reduces irrigation water pumping which may increase the command area of STWs. Sen et al. (2018) conducted a study on the irrigation water losses in earthen canal and found that under natural condition earthen canal conveyance losses varied from 35-40%. Belal et al. (2016) and Maniruzzaman et al. (2000) showed that plastic pipe distribution system successfully minimized 91.6-95.0% water loss that occurred in earthen canal.

Table 3.3 Irrigation water and irrigation time saving by Polythene pipe compared to earthen canal irrigation water distribution system at different STWs.

STW	Water supplied (mm)		Water saved (%)	Sp. irrigation time (min/decimal)		Irrigation time saved (%)
	Earthen canal (mm)	Polythene pipe (mm)		Earthen canal	Polythene pipe	
Pabna-1	847	719	15.2	19.8	16.7	15.3
Mean Pabna	**847**	**719**	**15.2**	**19.8**	**16.7**	**15.3**
Bogra-1	512	409	21.5	31.6	25.4	19.7
Bogra-2	518	407	21.3	36.7	28.8	21.5
Mean Bogura	**515**	**408**	**21.4**	**34.2**	**27.1**	**20.6**
Rangpur-1	534	426	20.2	38.2	30.4	20.2
Rangpur-2	645	505	21.7	41.2	33.0	20.1
Rangpur -3	743	576	22.5	35.6	27.3	23.3
Mean Rangpur	**640.7**	**502.3**	**21.5**	**38.3**	**30.2**	**21.2**
Mean all sites	**634.6**	**506.9**	**20.4**	**33.8**	**26.9**	**20.0**

Irrigation time saving:

Table 3.3 showed that time required for applying irrigation water per unit area up to 5 cm depth of each irrigation by polythene pipe and earthen canal distribution systems in different schemes. The time requirement for irrigation by polythene pipe and earthen canal distribution system were varied from location to location based on the tubewell discharge and soil texture. In this study, the highest time saving was found in Rangpur (21.2%) area and the lowest in Pabna (15.3%) with an average of 20.0% for all locations.

The above result shows that polythene pipe irrigation water distribution system not only saves irrigation water but also irrigation time compared to the earthen canal. The reduction in irrigation time as well as saving of irrigation water may help to increase the command area of the irrigation scheme.

3.1.2 Boro season 2017-18

The study was repeated in Boro season 2017-18 in 5 irrigation wells at 3 different sites at Pabna, Bogura and Rangpur. Table 3.4 showed the location of pumps along with the experimental plots size and length of canal or pipes used for irrigation and the number of irrigations for both earthen canal and polythene pipe.

Table 3.4 Pump owner's, area of demonstration plots, length of water distribution systems and number of irrigations applied by earthen canal and polythene pipe in different study sites during Boro season 2017-18.

Site	STW	Owner of the pump	Earthen canal			Polythene pipe		
			Area of the plot (decimal)	Canal length (ft)	Number of irrigations	Area of the plot (decimal)	Pipe length (ft)	Number of irrigations
Pabna	1	Md. Badsha Mondal	25.0	150	12	33.0	75	11
Bogura	1	Md. Yasin Ali	68.0	229	10	67.5	264	9
Rangpur	1	Sazu Mia	25.0	288	10	20.0	154	9
	2	Titu Mia	20.0	355	14	34.0	220	12
	3	Md. Saiful Islam	35.0	324	13	50.0	222	12

Table 3.5 shows a comparison of average discharge, total irrigation time, volume of irrigation water and depth of irrigation water for both earthen canal and polythene pipe. The average discharge rate was similar for both earthen canal and polythene pipe at pump delivery. Irrespective of pump the total depth of irrigation is lower for polythene pipe compared to earthen canal. The average irrigation depth for earthen canal and polythene pipe was 689 and 513 mm, respectively.

Table 3.5 Comparison of average discharge, total irrigation time, volume of irrigation water and depth of irrigation water for both earthen canal and polythene pipe during Boro season 2017-18.

STW	Earthen canal				Polythene pipe			
	Average discharge (lps)	Total irrigation time, Tc (min)	Total volume supplied by canal(lit)	Total depth of irrigation by canal, Idc (mm)	Average discharge (lps)	Total irrigation time, Tp (min)	Total volume supplied by pipe (lit)	Total depth of irrigation by pipe, Idp (mm)
P-1	29.3	375	658980	650.8	29.3	360	634524	474.8
B-1	14.9	1753	1560780	566.7	14.8	1395	1231740	450.6
R-1	12.0	845	610620	603.1	12.1	515	375720	463.9
R-2	9.7	1125	654570	808.1	9.8	1330	782190	568.0
R-3	11.5	1675	1159440	817.9	11.6	1780	1233420	609.1
	Average			689.3	15.52			513.3

Table 3.6 shows a comparison of specific irrigation volume, specific irrigation time, irrigation water saving and irrigation time saving between earthen canal and polythene pipe distribution system. Irrespective of irrigation scheme, the specific irrigation water volume is higher for earthen canal compared to polythene pipe. The average specific irrigation water volume for earthen canal and polythene pipe was 27919 and 20787 lit/decimal, respectively. The irrigation water saving by polythene pipe ranges from 20.5-29.7 percent over the earthen canal. It indicates that the average water saving by polythene pipe is 25.2%. The average specific time of irrigation for earthen canal and polythene pipe was 35.8 and 26.4 min/decimal, respectively. The irrigation time saving by polythene pipe ranges from 19.8-30.5 percent over the earthen canal with an average of 26.4%.

Table 3.6 Comparison of specific irrigation volume, specific irrigation time, irrigation water saving and irrigation time saving for both earthen canal and polythene pipe distribution system during Boro season 2017-18.

STW	Owner of the pump	Volume for unit area by earthen canal (lit/dec)	Volume for unit area by poly pipe (lit/dec)	Water saved by poly pipe (%)	Sp. Time of irrigation, Tc (min/dec)	Sp. Time of irrigation, Tp (min/dec)	Irrigation time saved by poly pipe (%)
Pabna-1	Md. Badsha Mondal	26359	19228	27.05	15.0	10.9	27.27
Bogura-1	Md. Yasin Ali	22953	18248	20.50	25.8	20.7	19.83
Rangpur-1	Sazu Mia	24425	18786	23.09	33.8	25.8	23.82
Rangpur-2	Titu Mia	32729	23006	29.71	56.3	39.1	30.46
Rangour-3	Md. Saiful Islam	33127	24668	25.53	47.9	35.6	25.61
	Average	27918.6	20787.2	25.18	35.76	26.42	25.4

Statistical and economic analysis:

Table 3.7 shows statistical analysis of the irrigation water pumped and specific irrigation time for both earthen canal and polythene pipe during boro season 2016-17 and 2017-18. The mean irrigation water pumped for earthen canal and polythene pipe were 635 mm and 507 mm, respectively for Boro season 2016-17.

It indicates that there is no significant difference between the mean irrigation depth by polythene pipe and earthen canal though polythene pipe saves more than 20 percent irrigation. The mean irrigation water pumped for earthen canal and polythene pipe were 689 mm and 513 mm, respectively for Boro season 2017-18. Statistical analysis shows that there is significant difference between the mean irrigation depth by polythene pipe and earthen canal as polythene pipe pipe saves more than 25 percent irrigation water compared to earthen canal water distribution systems.

Table 3.7 also shows the mean specific irrigation time for both earthen canal and polythene pipe. The mean specific irrigation time for earthen canal and polythene pipe were 33.85 min/decimal and 26.94 min/decimal, respectively for Boro season 2016-17. Statistical analysis shows no significant difference between the mean specific irrigation time for polythene pipe and earthen canal though polythene pipe saves more than 20 percent irrigation time. The mean specific irrigation time for earthen canal and polythene pipe were 35.76 min/decimal and 26.42 min/decimal, respectively for Boro season 2017-18. Statistical analysis shows that there is no significant difference between the mean specific irrigation time for polythene pipe and earthen canal though polythene pipe saves more than 25 percent irrigation time. Maniruzzaman et al. (2000, 2002) reported that about 47-55% irrigation time was saved in hope pipe irrigation compared to earthen canal in STW.

In both study years, on an average 22.5% irrigation water and about 23.2% irrigation applied time saved by polythene pipe used instead of earthen canal, which may increase the irrigation command area. The lower amount of water withdrawal from groundwater reserve also reduce the fuel cost as well as irrigation cost of the farmers. It also reduced the less fuel burning as well as reduce the greenhouse gas emission.

Table 3.7 Statistical analysis for comparison irrigation water pumped and specific irrigation time for both earthen canal and polythene pipe distribution system.

Variable	**2016-17**	Earthen canal (n=6)	Polythene pipe (n=6)	t-value	prob	LSD -value
Irrigation applied (mm)	Mean SD	634.7 136.8	507.0 123.2	1.699	0.121	167.71
Specific irrigation time (min/decimal)	Mean SD	33.85 7.6	26.94 2.3	1.794	0.106	8.69
	2017-18	Earthen canal (n=5)	Polythene pipe (n=5)	t-value	prob	LSD -value
Irrigation applied (mm)	Mean SD	689.3 116.8	513.3 70.7	2.882	0.025	146.29
Specific irrigation time (min/decimal)	Mean SD	35.76 16.6	26.42 11.4	1.037	0.334	21.25

3.2 Use of check valve to eliminate drudgery of STW operation

3.2.1 Boro season 2016-17

Two check valves were supplied for installation in 2 STWs of Rangpur and Pabna districts during Boro season 2016-17. Table 3.8 showed the list of STWs selected for installation of check valves with their prime mover and size. In Rangpur, a check valve was installed in a STW running with electric motor at the end of the Boro season. Owner's was asked to describe his feelings about the effectiveness of the check valve. Therefore, only trial operation was conducted in this pump.

Table 3.8 List of the STWs with their key features during 2016-17.

Unit	Location	Owner	Energy source	Pump suction	Pump delivery	Engine/ motor capacity (HP)
1	Rangpur	Md. Sazu Mia	Electric motor	10.2 cm	10.2 cm	5
2	Pabna	Md. Awlad Sardar	Diesel engine	7.6 cm	7.6 cm	4

The installation of check valve provides easier operation of the STW. Now only one person can easily start the pump. Pump owner's reaction is given below-

Impact/ Pump owner's reaction:

- The equipment has reduced drudgery of the farmers
- They are convinced that check valve did not reduce the discharge of the pump
- It also provides the opportunity to use Polythene pipe for reducing water loss

Advantages:

- Easy to install below the pump
- Saves labour and reduces human drudgery
- Offers uninterrupted operation while using plastic pipe for water distribution
- Helps wider adoption of polythene pipe distribution systems

Some other pump owners also requested to install the check valve in their pumps. Some more check valve will be installed in other pumps to demonstrate the performance.

3.2.2 Boro season 2017-18

Eight check valves were supplied in the project sites during Boro season 2017-18. Among the eight 3 were supplied in Rangpur, 3 were in Pabna and 2 were in Bogura. Two check valves supplied in Bogura were not installed as pump owners were afraid of clogging in their wells. In Rangpur, 3 check valves were installed in STWs running with electric motor and diesel engines. In Pabna, another 3 check valves were installed in 3 STWs running with electric motor and diesel engines. The installation of check valve provides easier operation of the STW. Now only one person can easily start the pump. According to the pump operator there was no reduction of discharge. After installation of the check valve, it becomes easy to use polythene pipe for irrigation water distribution. A survey was conducted on owner's feelings about the effectiveness of the check valve.

Table 3.9 shows some features of the STWs in which check valves were installed. Five pumps were with 10.2 cm suction and delivery size. The capacity of the engine/motor varies from 4-6 HP.

Table 3.9 List of the STWs with their key features during 2017-18.

Unit	Location	Owner	Energy source	Pump suction	Pump delivery	Engine/ motor capacity (HP)
1	Rangpur	Md. Sazu Mia	Electric motor	10.2 cm	10.2 cm	5
2	Rangpur	Md. Titu Mia	Diesel engine	7.6 cm	7.6 cm	4
3	Rangpur	Md. Saiful Islam	Diesel engine	10.2 cm	10.2 cm	6
4	Pabna	Md. Badsha Mondal	Diesel engine	10.2 cm	10.2 cm	4
5	Pabna	Md. Ejazul Islam	Electric motor	10.2 cm	10.2 cm	5
6	Pabna	Md. Azibar Rahman	Diesel engine	10.2 cm	7.6 cm	4

Table 3.10 showed a comparison between the hassel for starting pump before and after installation of the check valve. It shows that at least 2 persons were needed to start the pump before installation of check valve. Time required to start the pump was 5-15 minutes. But after installation of the check valve it requires only one person to start the pump each time. The time required to start the pump was 1-3 minutes only. So, it is clear that check valve has reduced human drudgery in operation of STWs.

Table 3.10 Persons and time required to start the STW every time.

Unit	Persons required to start pump		Time required to start the pump (min)	
	Before use of check valve	After use of check valve	Before use of check valve	After use of check valve
1	2	1	5 - 10 min	1 min
2	2	1	5 - 10 min	1-2 min
3	2	1	10 - 15 min	1-2 min
4	2	1	10-15 min	2 min
5	2	1	10-15 min	1 min
6	2	1	10-15 min	3 min

Table 3.11 shows a hypothetical analysis of labour requirement for starting STW without and with a check valve. If a pump operates for 100 days and on an average, it has to start 3 times daily, then the total number of times it has to start is 300. If the mean starting time is 10 minutes then it will take 3000 minutes i.e. 50 hours for 2 persons to start the pump. But if check valve is installed in the system and the average starting time is 2 minutes the total starting time will be 10 hours only. It indicates that time requirement for pump start reduces 90 percent whereas labour requirement reduces 50 percent.

Table 3.11 Cost saved by installation of check valve in STW.

Condition	Times start daily	Person needed to start	Time taken to start	Duration of operation (days)	Total time needed (min)	Total labour (man-hr)	Total wage (Tk)	Savings (%)
Before installation of check valve	3	2	10	100	3000	100	4000	
After installation of check valve	3	1	2	100	600	10	400	90

The farmers were asked about the requirement of priming activity for pumping operation. All most everyone said that it requires to prime the pump only once in the season, i.e. at the beginning of the pumping. After initial priming water always remains above the pump as well as water remains in the pump suction pipe. But before installation of the check valve it requires priming the pump each time of starting.

Problems in use of low-cost polythene pipe for irrigation water distribution was the main concerns for the farmers. Due to minimum loss in water distribution system, no requirement for canal construction and easier placement now-a-days polythene pipe water distribution system was preferred by the farmers. But due to interruption in pump operation and frequent starting farmers did not use these technologies. All the farmers said that it was very hard to use polythene pipe for distribution as they have to start the pump many times and for leakage, damage and change in alignment of the pipe. It was very hard to start the pump before installation of the check valve. Installation of check valve in STW provides an opportunity for using polythene pipe in water distribution systems. Almost all the pump owners informed that it become very convenient to use polythene pipe in distribution system as starting pump was easier now.

The overall impact

Impact/ Pump owner’s reaction:

- The check valve reduced drudgery of the farmers

- They were convinced that check valve did not reduce the discharge of the pump
- It also provided the opportunity to use polythene pipe very easily that reduced irrigation water loss significantly
- Some other pump owners requested to install the equipment in their pumps

Advantages:

- Easy to install
- Saves labour and reduced human drudgery
- Offered uninterrupted operation while using plastic/polythene pipe for water distribution
- Wide-scale adoption of polythene pipe distribution system was possible by installing check valve

3.3 Discharge measurement of the irrigation unit

Discharge rate varies with locations and capacity of the pumps. Table 3.12 showed the fortnightly discharge rate of the selected irrigation units of the study sites. Decreasing trends in discharges of the irrigation pumps with the progression of dry season were observed. Highest discharge rate was observed during the first measurement in late February 2017. Lowest discharge was found in late March and early April. Due to huge rainfall in late March, higher discharge rate was found in early and late April.

There was difference in the discharge rate among the pumps having same size and similar tubewell diameter. This is due to the aquifer properties and static water table depth. Discharge was higher in Rangpur compared to the discharge of Bogura.

Table 3.12 Fortnightly discharge of the irrigation pumps at different sites during the dry season 2016-17.

Irrigation unit	Owner's name	Diameter (cm)		Engine/ motor capacity (kW)	Late February	Early March	Late March	Early April	Late April
		Tubewell	Pump delivery						
	Bogura- Volumetric method								
STW-1	Mannan	10.0	7.5	4.5	10.21	9.84	9.49	10.1	10.34
STW-2	Abdul Latif	10.0	7.5	4.5	9.72	9.51	9.28	9.37	9.64
STW-3	Shafiqul Islam	10.0	7.5	4.5	11.11	10.85	10.26	9.17	9.38
	Rangpur- Volumetric method								
STW-1	Sazu Mia	12.5	10.0	5.0	16.53	14.82	13.71	12.90	11.40
STW-2	Titu Mia	10.0	7.5	3.0	12.11	11.44	10.55	9.31	8.89
STW-3	Saiful Islam			4.5	12.92	12.21	11.40	11.00	9.31
STW-4	Fulu Mia	10.0	7.5	4.5	11.50	10.71	9.54	8.37	7.62
STW-5	Mustafa	12.5	10.0	4.5	16.53	14.74	13.66	12.88	11.56
STW-6	Suman	12.5	10.0	4.5	11.01	10.65	9.91	8.87	7.69
	Pabna- Volumetric method								
STW-1	Ejajul Islam	15.0	10.0		25.59	25.18	24.84	23.04	
STW-2	Atiqul Mawla	15.0	10.0		29.45	29.14	28.68	28.56	
	Thakurgaon- Cut-throat flume								
DTW-1	BMDA	70.0	15.0		61.15	60.44	58.35	57.54	

3.4 Measurement of ET, seepage, percolation and rainfall in rice fields

Evapotranspiration rate:

Decadal crop evapotranspiration rates were measured from February to April. A temporal change in crop evapotranspiration rates were observed. Crop evapotranspiration rates was lowest after transplanting. Then it starts to increase and continues up to flowering stage. After flowering stage, it starts to decline. Crop evapotranspiration rate varied from location to location and also for crop stages (Fig. 3.1). In Bogura and Pabna, crop evapotranspiration rate increased over time gradually, whereas in Rangpur, it increased sharply after middle of March and for Thakurgaon, it sharply increased after transplanting and declined after 1st decade of April. Almost all of the locations, the highest crop evapotranspiration rate was obtained during April.

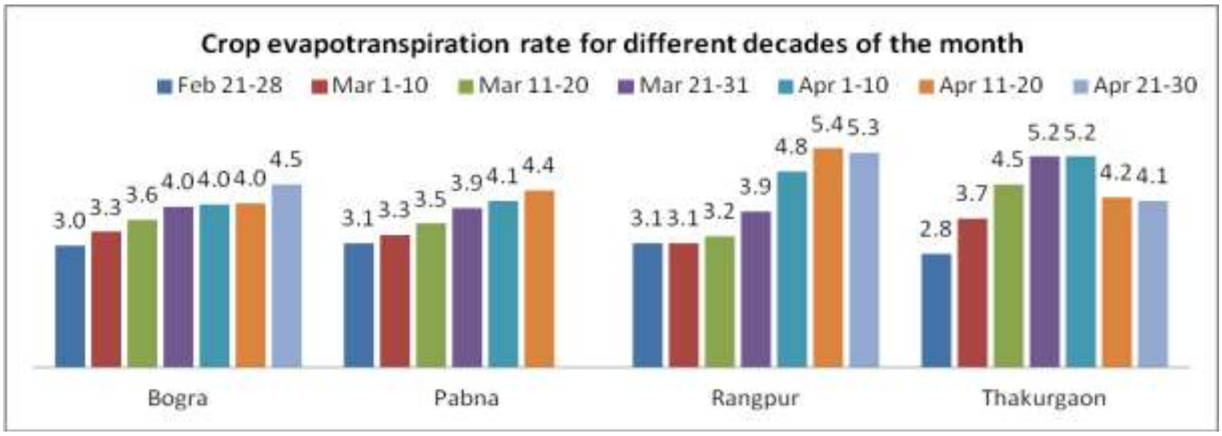


Fig. 3.1 Decadal average daily crop evepotranspiration in Bogura, Pabna, Rangpur and Thakurgaon from February-April, 2017.

Seepage and percolation rate:

Seepage and percolation rate vary with the depth of ponding. Seepage and percolation rate were higher for higher depth of ponding. Figure 3.2 shows the average seepage and percolation rate in different sites. The average seepage rate in Bogura, Pabna, Rangpur and Thakurgaon were 2.43, 2.45, 2.50 and 2.43 mm/day, respectively. The average percolation rate in Bogra, Pabna, Rangpur and Thakurgaon were 2.04, 2.63, 2.50 and 2.20 mm/day, respectively.

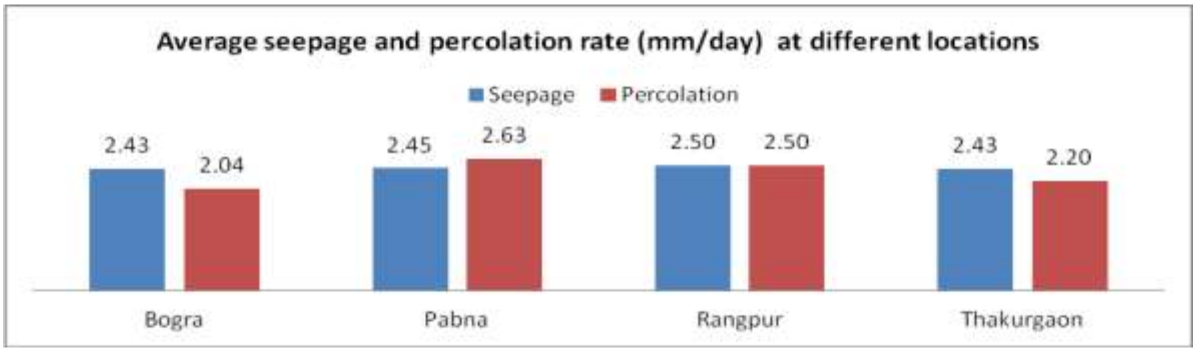


Fig. 3.2 Average daily seepage and percolation rate in Bogra, Pabna, Rangpur and Thakurgaon from February-April, 2017.

3.5 Measurement of rainfall during dry season

Rainfall is an important component of water balance analysis for crop production. Amount of rainfall and it's distribution pattern influenced the amount of irrigation water needed for crop production. The early and middle part of Boro season is about rainless in Bangladesh. Generally considerable amount of rainfall occurs at the later part of the Boro season. Amount of rainfall during March-April reduces the amount of irrigation and thus saves the pumping, which is congenial for rice growth and also reduce the irrigation cost. This is very much beneficial as this is the time for peak water demand as well as time for peak water scarcity. Fig. 3.3 showed the amount of monthly rainfall (mm) during Jan-June 2018 in Rangpur, Pabna, Bogura and Thakurgaon and the corresponding rainfall was 250, 240, 170 and 140mm, respectively. These rainfalls contribute a lot to meet the crop water demand during the peak time of crop growth in the study locations.

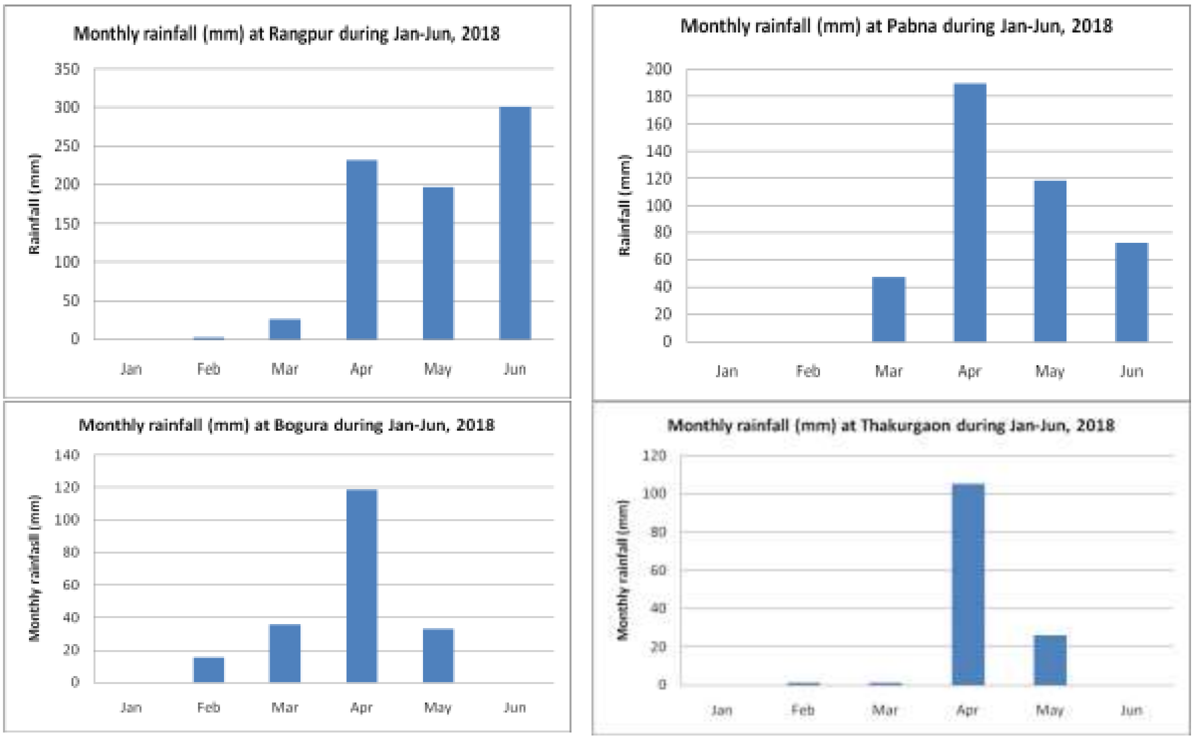


Fig. 3.3 Monthly rainfall in different study locations during Jan-Jun 2018.

3.6 Monitoring of groundwater level fluctuations in the project sites

Observation wells were installed at project sites of Rangpur, Dinajpur, Bogura, and Pabna to study the groundwater level dynamics. Weekly groundwater level was recorded in each site. Height of the top of the well from ground surface (parapet) was deducted from the recorded value to calculate the water table depth from the ground surface. Average of the readings taken in a month was considered as the groundwater level for the month. Groundwater level data were collected from BMDA in Thakurgaon area.

Fig. 3.4 shows the average monthly groundwater level fluctuations at Mithapukur, Rangpur during 2016-18. It showed a common pattern that groundwater level declined highest during April-May and reach the peak during September-October. The highest groundwater level declination during the study period was below 5.0 m which is above the suction limit of STW.

Similar trend was also followed in Ishurdi, Pabna during 2016-18 (Fig. 3.5). The highest groundwater level declination during the study period was above 7.0 m which is close to the suction limit of STW. The groundwater trend in Sherpur, Bogura during the same period (2016-18) was also the similar with Mithapukur and Ishurdi, but the highest groundwater level declination during the study period was above 8.0 m which is below the suction limit of STW (Fig. 3.6).

Fig.3.7 showed the average monthly groundwater level fluctuations at Thakurgaon Sadar, Thakurgaon during 2016-18. It showed a common pattern that groundwater level declined highest during May-June and reach the peak during September-October. The highest groundwater level declination during the study period was around 5.0 m which is above the suction limit of STW.

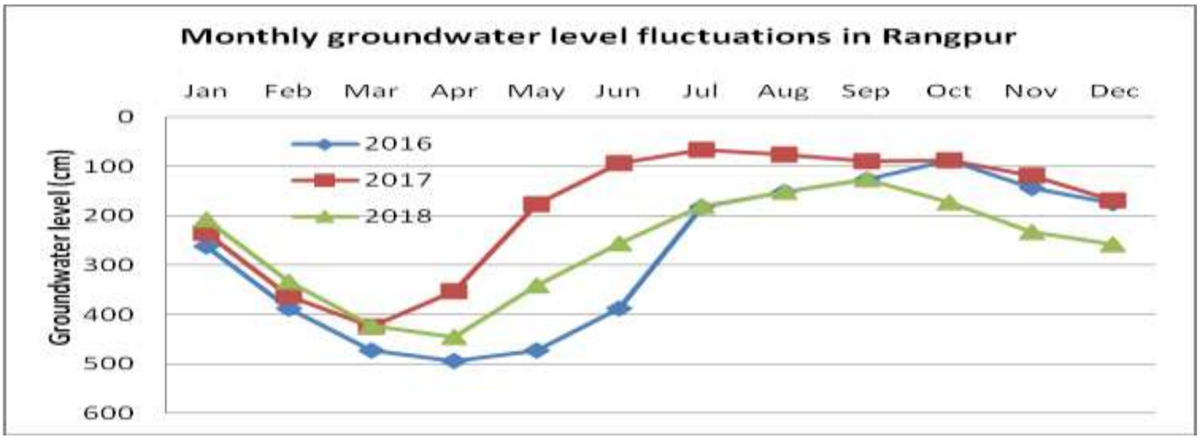


Fig. 3.4 Monthly average groundwater level in Mithapukur, Rangpur.

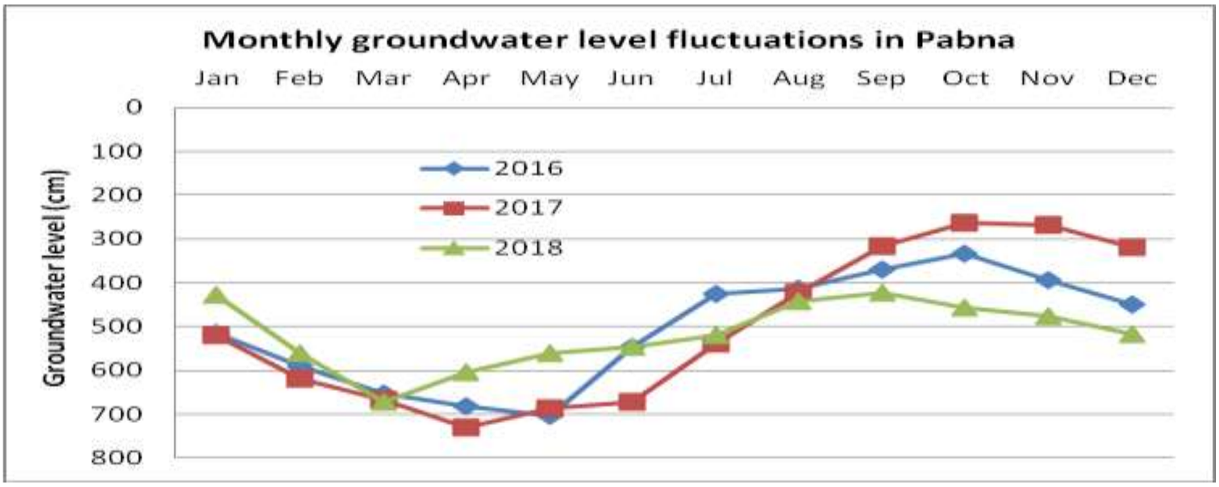


Fig. 3.5 Monthly average groundwater level in Ishurdi, Pabna.

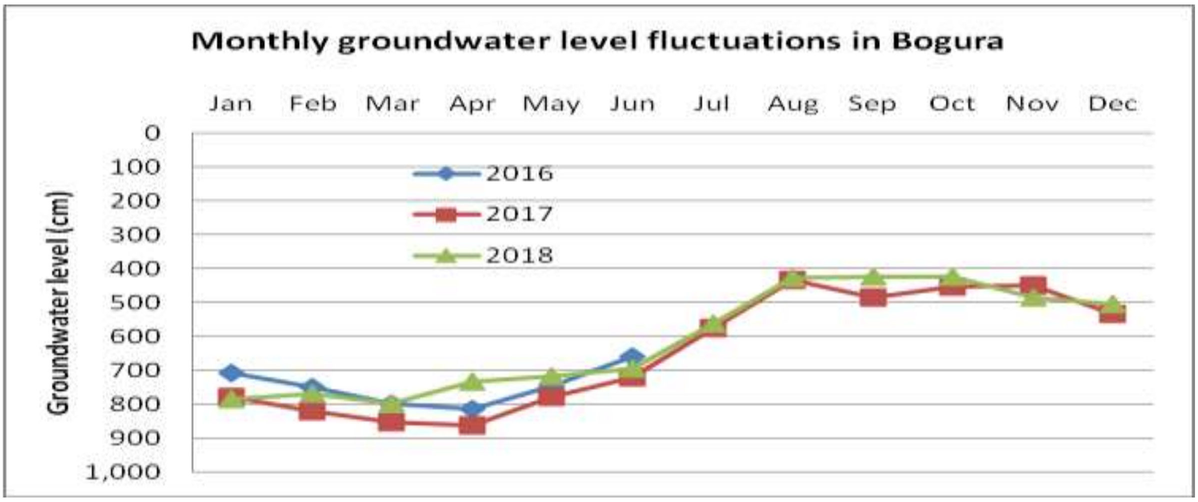


Fig. 3.6 Monthly average groundwater level in Sherpur, Bogura.

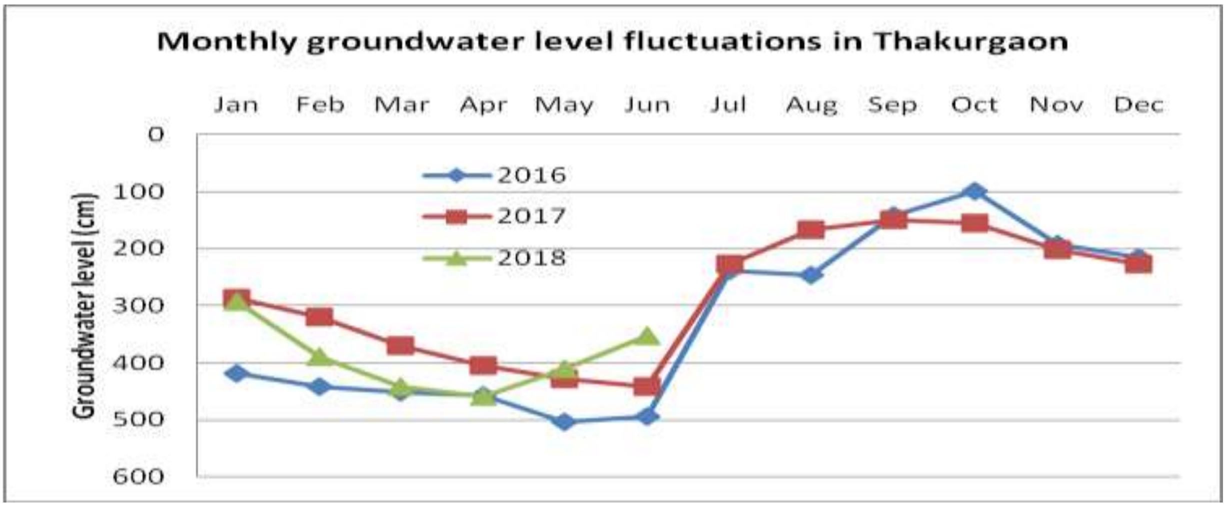


Fig. 3.7 Monthly average groundwater level in Thakurgaon sadar, Thakurgaon.

It indicated that there is no problem in STW operation in Mithapukur, Ishurdi and Thakurgaon, but in Sherpur area sometimes water level goes below the suction limit and then deep set STW was the solution option for irrigation in peak irrigation period of March and April. But, the irrigation in Thakurgaon mainly supplied by DTW. In our short-term study, it was not able to find the groundwater declination, but Azia et al. (2015) reported that in long-term study groundwater level was declining in Rajshahi region.

3.7 Performance evaluation of newly released Boro varieties

Through farmers group discussions regarding suitable varieties of the project sites, they indicated their demand for increasing rice production and sustained food security farmers needed:

- High yielding variety with comparatively shorter duration
- Variety with tolerance to environmental stresses

- Variety with less pest infestation
- Variety having higher market price

Table 3.13 showed some important characteristics of 4 newly released varieties. Growth duration is a very important characteristics as it influences the cropping pattern. Growth duration of BRRI dhan63 (146 days), BRRI dhan68 (149 days), BRRI dhan74 (147 days) and BRRI hybriddhan5 (145 days) are comparatively shorter with respect to their potential yield. Besides, these varieties had some other important characteristics that can attract the farmers. BRRI dhan63 has fine long grain which possessed higher market price than the other varieties. BRRI dhan68 has medium bold grain and higher potential yield (7.3 t/ha). Though medium bold grain, BRRI dhan74 is Zinc enriched and has higher yield potential. It was helpful for the children who suffer from malnutrition. BRRI hybriddhan5 has highest yield potential with shorter growth duration.

Table 3.13 Characteristics of the selected new rice varieties released by BRRI.

Variety	Growth duration (days)	Grain type	Yield (t/ha)	Year of release
BRRI dhan63	146	Fine and long, Basmati type	6.5	2014
BRRI dhan68	149	Medium bold & white	7.3	2014
BRRI dhan74	147	Medium bold & white, Zn enriched	7.1	2015
BRRI hybriddhan5	145	Medium fine, long and white	9.0	2017

Seeds were supplied to 12 farmers along with the production package. Among the farmers 11 reported the performance. One farmer in Bogura didn't report as he cultivated 2 varieties outside the project area.

Fig. 3.4.1 shows the comparative yield of BRRI dhan63 at different locations. Highest yield was obtained in Bogura (6285 kg/ha) followed by Pabna (5679 kg/ha), Rangpur (5644 kg/ha) and Thakurgaon (4527kg/ha), respectively. The average yield was 5332 kg/ha, which was lower than the potential yield. The study results indicated that this variety is suitable for Borgura and Pabna as farmers of these areas prefer and cultivate fine rice. Presently they cultivate Minikit and average yield is around 5.0 t/ha. Therefore, cultivation of BRRIdhan63 will increase the productivity as well as income of the farmers. Farmers of Rangpur prefer BRRI dhan28 which can be replaced by BRRI dhan63. Due to cultivation of over aged seedlings the yield was not satisfactory in Thakurgaon. The yield trials may be repeated in Thakurgaon with proper seedling age and proper transplanting time.

Fig. 3.8 showed the comparative yield of BRRI dhan68 at different locations. Highest yield was obtained in Thakurgaon (9877 kg/ha) followed by Rangpur (6914 kg/ha), Pabna (5975 kg/ha), and Bogura (5864 kg/ha), respectively. The average yield was 7158 kg/ha, which was similar to the potential yield. The yield obtained in Thakurgaon (9877 kg/ha) was higher than the potential yield (7.30 t/ha) this may be due to the fertility of the land. Cowdung was applied in the land before cultivation. The yield obtained in Rangpur (6914 kg/ha) was closer to the potential yield.

The study results indicated that this variety is suitable for Thakurgaon and Rangpur as farmers of these areas prefer hybrid rice varieties which has medium bold grain like this variety. Cultivation of this variety will provide them availability of seeds at lower costs. The performance of these variety in Pabna and Bogura was not satisfactory. Therefore, cultivation of BRRI dhan68 will increase the productivity as well as income of the farmers.

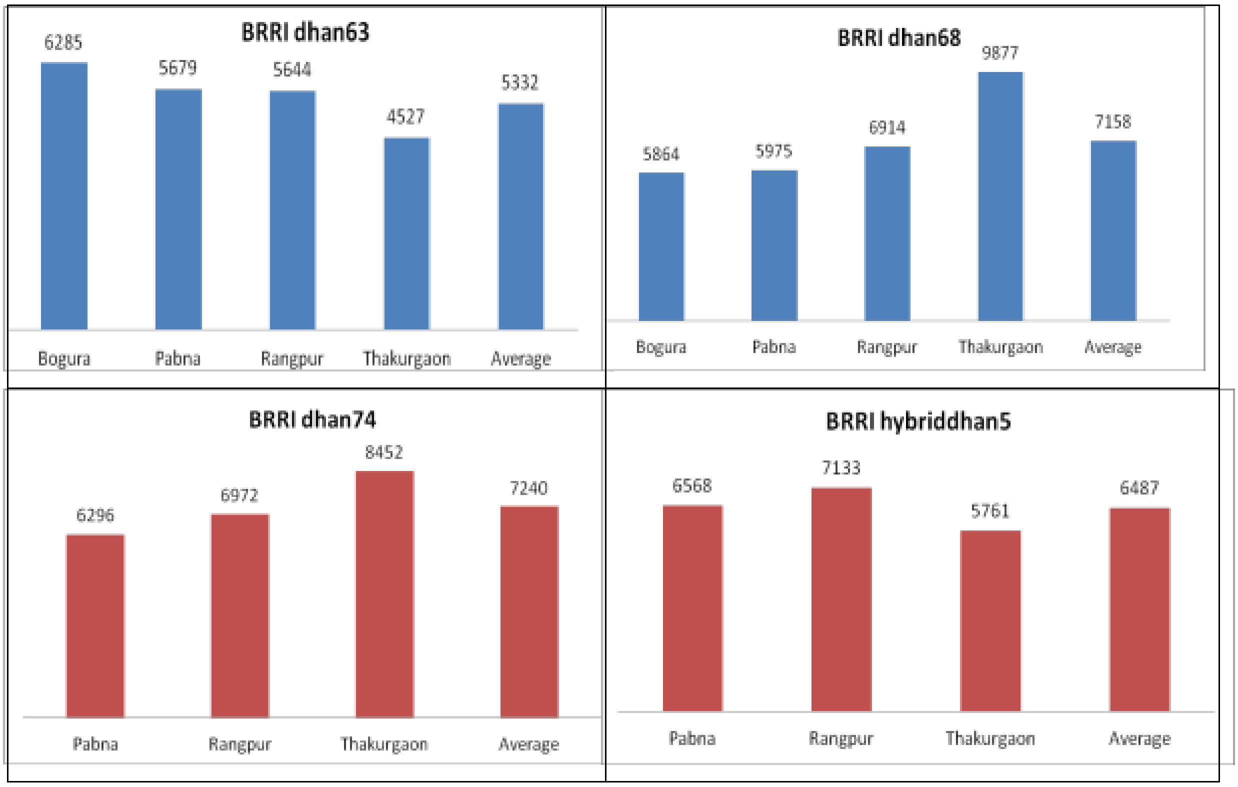


Fig. 3.8 Yields of different varieties in the study sites during Boro season 2017-18.

Fig. 3.8 showed the comparative yield of BRRI dhan74 at different locations. Highest yield was obtained in Thakurgaon (8452 kg/ha) followed by Rangpur (6972 kg/ha) and Pabna (6296 kg/ha), respectively. The average yield was 7240 kg/ha, which was similar to the potential yield (7.10 t/ha). The yield obtained in Thakurgaon (8452 kg/ha) was higher than the potential yield (7.10 t/ha) this may be due to the fertility of the land. Cowdung was applied in the land before cultivation. The yield obtained in Rangpur (6.97 t/ha) was closer to the potential yield. Though the yield obtained at Pabna was lower than the potential yield but it was satisfactory considering farmers' field. The study results indicated that this variety is suitable for Thakurgaon and Rangpur as farmers of these areas prefer hybrid rice varieties which has medium bold grain like this variety. Cultivation and consumption of this variety will provide the people better nutritional security. Therefore, cultivation of BRRI dhan74 will increase the productivity as well as income of the farmers.

Fig. 3.8 showed the comparative yield of BRRI hybriddhan5 at different locations. Highest yield was obtained in Rangpur (7133 kg/ha) followed by Pabna (6568 kg/ha) and Thakurgaon (5761 kg/ha) respectively. The average yield was 6487 kg/ha, which was much lower than the potential yield (9.00 t/ha). The yield obtained in Rangpur (7.13 t/ha) was lower than the potential yield (9.00 t/ha) this may be due to the delay in planting and over aged seedlings. The yield obtained in Pabna (6.57 t/ha) was higher than the preferred variety Minikit.

Due to medium fine grain quality this variety will get higher market price. Therefore, cultivation of BRRI hybriddhan5 will increase the productivity as well as income of the farmers.

Farmers' reaction about the new varieties

Farmers were asked to point out positive and negative sides of the varieties. They were also asked whether they would like to cultivate the varieties further.

BRRI dhan63

Farmers' identified fine grain quality, taste of cooked rice and shorter growth duration as the positive sides of BRRI dhan63. They have pointed out less yield as negative side of the variety (Table 3.14). Except Thakurgaon, farmers of other 3 sites want to cultivate the variety again.

Table 3.14 Farmer's reaction about the merits and demerits of BRRI dhan63.

Site	Positive side	Negative side	Like to cultivate further
Rangpur	Grain quality and cooked rice very good	Less yield	Yes
Pabna	Grain quality and cooked rice very good, short duration	No	Yes
Bogura	Grain quality and cooked rice very good, short duration	No	Yes
Thakurgaon	Grain quality and cooked rice very good	Less yield	No

BRRI dhan68

Farmers' identified higher yield and shorter growth duration as the positive sides of BRRI dhan68. The have pointed out bold grain and less yield as negative sides of the variety (Table 3.15). Farmers of Rangpur and Thakurgaon sites want to cultivate the variety again.

Table 3.15 Farmer's reaction about the merits and demerits of BRRI dhan68.

Site	Positive side	Negative side	Like to cultivate further
Rangpur	Higher yield and shorter duration	Bold grain, market price is less	Yes
Pabna	Shorter duration	Less yield and bold grain	No
Bogura	Shorter duration	Less yield and bold grain	No
Thakurgaon	Higher yield and shorter duration	No	Yes

BRRI dhan74

Farmers' identified higher yield and shorter growth duration as the positive sides of BRRI dhan74. The have pointed out bold grain as negative side of the variety (Table 3.16). Farmers of Rangpur and Thakurgaon sites want to cultivate the variety again.

Table 3.16 Farmer's reaction about the merits and demerits of BRRI dhan74.

Site	Positive side	Negative side	Like to cultivate further
Rangpur	Higher yield and short duration	Not fine	Yes
Pabna	Short duration	Not fine	No
Thakurgaon	Higher yield and short duration	Not fine	Yes

BRRI hybriddhan5

Farmers' identified higher yield, fine grain and shorter growth duration as the positive sides of BRRI hybriddhan5. The have pointed out lack of availability of seed as negative side of the variety (Table 3.17). Farmers of Rangpur and Pabna sites want to cultivate the variety again if the seed was available.

Table 3.17 Farmer's reaction about the merits and demerits of BRRI hybriddhan5.

Site	Positive side	Negative side	Like to cultivate further
Rangpur	Higher yield, short duration, fine grain	Seed not available in market	Yes
Pabna	Higher yield, short duration, fine grain	Seed not available in market	Yes
Thakurgaon	Short duration, fine grain	Comparatively less yield	No

Problems for cultivation of the new varieties

Farmers were asked to point out the reasons why they are not adopting new varieties. They have identified 5 main reasons as given below:

a) Lack of information about the newly released varieties
b) Lack of availability of seeds in the local market
c) Lack of knowledge about the production package
d) As unknown to the farmers and rice traders, so lack of market demand
e) Lack of practice in seed production and preservation for the next season

Possible remedies to solve the problem

The farmers were also asked to point out the ways to solve the problems for rapid expansion of the newly released rice varieties. They have suggested the following measures for rapid adoption of good varieties:

a) Mass scale performance demonstration of the newly released varieties
b) Seed production by GOs and NGOs for supplying to the farmers
c) Conduct seed production and preservation program at farmers level
d) Farmer to farmer seed exchange program
e) Facilitate seed preservation practice through supply of plastic containers

3.8 Demonstration on AWD irrigation scheduling

3.8.1 Performance of AWD

Performance of AWD irrigation was demonstrated in the farmers' field of Bogura, Pabna, Rangpur and Thakurgaon. Comparison was made between AWD irrigation scheduling and farmers' practice (maintaining continuous standing water in the rice field). Amount of irrigation needed and crop yield was measured for both the irrigation scheduling to compare irrigation water saving and crop yield advantage. A total of 16 demonstrations were conducted in the 4 project sites with locally popular rice cultivars.Table 3.18 showed the farmer's name, varieties of rice cultivated with dates of seeding and transplanting.

Among the 16 demonstration trials 2 were with BRRI dhan28, 4 were with BRRI dhan29, 3 were with hybrid Heera and 7 were with Minikit. The seeding and transplanting date were same for both Farmers practice (FP) and AWD practice. The seeding was done within 15th November to 15th December 2016. The transplanting was done between 26th January to 19th February 2017. Seedling age varies from 48 to 71 days. Higher aged seedlings were used for the longer duration varieties. Growth duration of BRRI dhan28, BRRI dhan29, Hybrid Heera and Minikit ranges from 149-155 days, 152-170 days, 155-165 days and 136-151 days, respectively. Growth duration of a specific variety varies few days and earlier seeding gives higher growth duration compared to late seeding. This is due to prolong lower temperature during the vegetative phase of the varieties. The growth duration was similar for both AWD and FP.

Table 3.18 Details information of farmer's, varieties under different water regimes and study sites during 2016-17.

Trial	Farmer's Name	Variety	Date of seeding	Date of trans planting	Seed-ing age (days)	Date of maturity		Growth duration (days)	
						FP	AWD	FP	AWD
Rangpur									
1	Titu Mia	BRRI dhan29	5 Nov 16	6 Jan 17	71	9 Apr 17	9 Apr 17	164	164
2	Saiful Islam	Hybrid Heera	8 Dec 16	8 Feb 17	61	8 May 17	8 May 17	160	160
3	Golam Mostofa	Hybrid Heera	5 Dec 16	5 Feb 17	51	0 May 17	0 May 17	155	155
4	Sazu Mia	BRRI dhan28	5 Dec 16	8 Feb 17	64	1 May 17	1 May 17	155	155
5	Nazmul Islam	Hybrid Heera	8 Dec 16	8 Feb 17	61	3 May 17	3 May 17	165	165
Pabna									
1	Atiqul Mawla	Minikit	3 Dec 16	0 Jan 17	57	3 May 17	5 May 17	149	151
2	Atiqul Mawla	Minikit	3 Dec 16	0 Jan 17	57	0 Apr 17	3 May 17	145	149
3	Abdul Hakim	Minikit	3 Dec 16	4 Feb 17	61	2 May 17	4 May 17	148	150
4	Ejajul Islam	BRRI dhan29	4 Dec 16	3 Feb 17	59	4 May 17	5 May 17	169	170
Thakurgaon									
1	Gojen Roy	BRRI dhan29	9 Dec 16	9 Feb 17	71	5 May 17	6 May 17	155	156
2	Molindra Roy	BRRI dhan28	2 Dec 16	5 Feb 17	64	2 May 17	3 May 17	149	149
3	Dijendra Roy	BRRI dhan29	9 Dec 16	8 Feb 17	70	2 May 17	3 May 17	152	153
Bogura									
1	Md. Amir Hosen	Minikit	9 Dec 16	7 Jan 17	48	7 Apr 17	7 Apr 17	137	137
2	Abdul Latif	Minikit	5 Dec 16	6 Jan 17	51	4 Apr 17	4 Apr 17	136	136
3	Shafiqul Islam	Minikit	0 Dec 16	8 Jan 17	48	7 Apr 17	7 Apr 17	136	136
4	Jabed Ali	Minikit	9 Dec 16	1 Jan 17	52	7 Apr 17	7 Apr 17	137	137

Thirteen demonstrations on AWD were conducted in 4 study sites during Boro season 2017-18. Among the demonstrations 3 were in Rangpur, 4 in Pabna, 3 in Thakurgaon and 3 in Bogura. Table 3.19 showed the farmer's name, variety used, planting dates and growth duration of each demonstration in the study sites. BRRI dhan28, BRRI dhan29, BRRI dhan63, Minikit, Hybrid Surma and Kajollota were the selected study varieties. Sowings were done between 1-21 December 2017 and transplanting was done between 28 Jan - 20 Feb 2018. Seedlings age varies from 41-74 days. Younger seedlings were used in Bogura and oldest seedlings were used in Thakurgaon. This is due to cultivation of shorter and longer duration varieties in the sites. Crops matured in late April and early May of 2018. Growth duration was similar for both AWD and farmer's practice but AWD plots was matured 1-2 days earlier in most of the cases.

Table 3.19 Details information of farmer's, varieties under different water regimes and study sites during Boro season 2017-18.

Trial	Farmer's Name	Variety	Date of seeding	Date of trans-planting	Seedling age (days)	Date of maturity		Growth duration (days)	
						FP	AWD	FP	AWD
Rangpur									
R-1	Titu Mia	BRRI dhan28	5–Dec-17	28-Jan-18	53	24-Apr-18	23-Apr-18	140	139
R-2	Anarul Islam	BRRI dhan28	17-Dec-17	2-Feb-18	46	9-May-18	8-May-18	142	141
R-3	Sazu Mia	Hybrid Surma	5–Dec-17	29-Jan-18	54	11-May-18	9-May-18	160	158
Pabna									
P-1	M. Atiqul Mawla	Minikit	3-Dec-17	5-Feb-18	58	30-Apr-18	29-Apr-18	148	147
P-2	M. Atiqul Mawla	Minikit	3-Dec-17	1-Feb-18	54	30-Apr-18	29-Apr-18	148	147
P-3	M. Atiqul Mawla	BRRI dhan63	3-Dec-17	3-Feb-18	56	8-May-18	7-May-18	156	155
P-4	Mojibor Rahman	BRRI dhan28	3-Dec-17	29-Jan-18	51	29-Apr-18	28-Apr-18	147	146
Thakurgaon									
T-1	Arun Roy	BRRI dhan29	1-Dec-17	14-Feb-18	74	15-May-18	14-May-18	164	163
T-2	Arun Roy	BRRI dhan29	1-Dec-17	14-Feb-18	74	15-May-18	14-May-18	164	163
T-3	Rajoni Kant	BRRI dhan29	9-Dec-17	20-Feb-18	72	20-May-18	20-May-18	161	161
Bogura									
B-1	Md. Yasin Ali	Minikit	21-Dec-17	1-Feb-18	41	8-May-18	8-May-18	137	137
B-2	Md. Yasin Ali	Kajol lota	21-Dec-17	1-Feb-18	41	8-May-18	8-May-18	137	137
B-3	Md. Babu Mia	Kajol lota	20-Dec-17	2-Feb-18	42	8-May-18	7-May-18	138	137

3.8.2 Water used and water saved

Table 3.20 showed size of plots, the number and amount of irrigation water applied, amount rainfall received and total water used for both AWD and FP. Results showed that irrespective of sites and demonstrations the number of irrigations for AWD is less than that of FP. Experimental data showed that AWD practice reduced the total number of irrigations compared to the farmers' practice. The average number of irrigations for AWD and farmers' practice were 11.6 and 13.8 in Rangpur, 12.0 and 16.0 in Pabna, 9.3 and 11.7 in Thakurgaon and 8.3 and 10.3 in Bogura areas, respectively. The average number of irrigations for AWD and farmers' practice of all the sites were 10.4 and 13.1, respectively. The above results indicated that AWD practice can save 2-4 irrigations compared to farmers' practice. The reduction of irrigation number by AWD practice has saved time of pump operation and amount of water pumping. This ultimately saves fuel for pump operation which has contribution in reducing greenhouse gas emission. Though not accounted in this experiment there will be some reduction of irrigation water loss in earthen channel distribution system due to less wetted time compared to farmers' practice.

Irrespective of demonstrations and locations, the amount of total irrigation water applied were also less in AWD treatments than the FP. Table 3.20 showed that AWD practice saves 9.7% to 24.2% of irrigation water compared to FP.

The average total depth of irrigation for AWD and farmers' practice were 635 mm and 811 mm in Pabna, 635 mm and 756 mm in Rangpur, 541 mm and 651 mm in Thakurgaon and 338 mm and 398 mm in Bogura areas, respectively. The average depth of irrigation for all the sites under AWD and farmers' practice were 543 mm and 661 mm, respectively.

The average irrigation water saving was 16.8, 21.6, 16.8 and 15.0 percent in Rangpur, Pabna, Thakurgaon and Bogra, respectively. The above results indicated that safe AWD practice can save 15-22 percent irrigation water compared to farmers' practice. The average saving for all the sites is 17.6 percent. Total water used by the crop in different plots was calculated by addition of rainfall with the amount of irrigation water. Table 3.19 also showed that amount of total water used for farmers' practice and AWD were varied from 589 mm to 1326 mm and from 528 mm to 1147 mm, respectively.

Table 3.20 Water used and water saved by AWD method over Farmers practice during Boro season 2016-17.

Trial	Variety	Area of plot (decimal)		Number of irrigations		Irrigation applied (mm)		Rainfall received (mm)	Total water used (mm)		Water saving by AWD (%)
		FP	AWD	FP	AWD	FP	AWD		FP	AWD	
1	BRRI dhan29	10	10	15	13	744	671	248	1109	1031	9.73
2	Hybrid Heera	11	14	16	13	881	702	445	1326	1147	20.28
3	Hybrid Heera	12	13	13	11	621	481	384	1005	866	17.64
4	BRRI dhan28	12	13	11	9	768	660	323	1091	985	22.47
5	Hybrid Heera	8.5	8.5	14	12	768	660	484	1252	1145	14.00
Avg.	**Rangpur**			**13.8**	**11.6**	**756**	**635**	**377**	**1133**	**1012**	**16.82**
1	Minikit	50	50	16	12	836	665	237	1073	902	20.44
2	Minikit	17	41	16	12	825	626	283	1108	909	24.16
3	Minikit	17	40	16	12	868	667	215	1083	882	23.15
4	BRRI dhan29	33	17	16	12	717	582	283	1000	865	18.75
Avg.	**Pabna**			**16.0**	**12.0**	**812**	**635**	**328**	**1066**	**890**	**21.63**
1	BRRI dhan29	25	25	13	11	715	627	209	924	836	12.28
2	BRRI dhan28	15	15	10	8	528	446	188	716	634	15.51
3	BRRI dhan29	25	25	12	9	710	549	209	919	758	22.72
Avg.	**Thakurgaon**			**11.7**	**9.3**	**651**	**541**	**202**	**853**	**743**	**16.84**
1	Minikit	32.8	32.7	10	8	400	341	196	596	538	14.72
2	Minikit	25.3	31.0	10	8	404	332	196	600	528	17.80
3	Minikit	31.4	29.5	11	9	394	335	196	590	531	14.87
4	Minikit	37.9	35.9	10	8	393	343	196	589	539	12.59
Avg.	**Bogra**			**10.3**	**8.3**	**398**	**338**	**196**	**594**	**534**	**15.00**
Avg.	**Overall**			**13.0**	**10.3**	**654**	**537**	**277**	**929**	**811**	**17.57**

Table 3.21 showed the area, number of irrigations applied, depth of irrigation and depth of rainfall received in the demonstration plots for both AWD and FP. The plot sizes for farmer's practice were varied from 10 - 50 decimal whereas those for AWD practice were varied from 15-50 decimal. The average area of all plots for both FP and AWD were 31.8 and 30.1 decimal, respectively.

Irrespective of demonstrations the total number of irrigations were higher for FP compared to AWD. The total number of irrigations for FP were varied from 10-18 and for AWD varied from 8-15.

The average of total number of irrigations for FP and AWD were 13.5 and 11.1, respectively. It indicated that AWD practice can save more than 2 irrigations compared to FP. The depth of irrigation water was calculated by using pump discharge and time of irrigation. Irrespective of demonstrations the total depth of irrigation and total water used was lower in AWD compared to FP. The average total depth of irrigation was lowest in Thakurgaon, followed by Bogura, Rangpur and Pabna. The average depth of irrigation for AWD and FP were 609 mm and 708 mm, respectively. The average depth of total water applied was lowest in Thakurgaon followed by Bogura, Pabna and Rangpur. The amount of irrigation water saved by AWD compared to FP varies from 10 to 21 percent. Average irrigation water saving was highest in Rangpur followed by Bogura, Thakurgaon and Pabna. The overall average irrigation water saving in AWD was 14 percent compared to the FP. Carrijo et at. (2017) reported that mild AWD or field water level did not drop below 15 cm from the soil surface, yields were not significantly reduced in most circumstances and the water saved about 23.4% relative to continuous flooding.

Table 3.21 Water used and water saved by AWD method over Farmers practice during Boro season 2017-18.

Trial	Variety	Area (decimal)		Number of irrigations		Irrigation applied (mm)		Rainfall received (mm)	Total water used (mm)		Water saved by AWD method (%)
		FP	AWD	FP	AWD	FP	AWD		FP	AWD	
R-1	BRRI dhan28	20	15	16	13	846	745	186	1032	931	11.94
R-2	BRRI dhan28	10	20	16	12	807	638	366	1173	1004	20.94
R-3	Hybrid Surma	42	32	14	11	728	613	419	1147	1032	15.80
Avg.	**Rangpur**	**24**	**22.3**	**15.3**	**12.0**	**794**	**665**	**243**	**1117**	**989**	**16.23**
P-1	Minikit	33	17	15	13	765	672	236	1001	908	12.15
P-2	Minikit	50	50	18	15	861	757	236	1097	993	12.07
P-3	BRRI dhan63	25	30	16	14	795	715	268	1063	983	10.11
P-4	BRRI dhan28	50	50	16	13	832	721	236	1068	957	13.36
Avg.	**Pabna**	**41.6**	**43.3**	**16.3**	**13.8**	**813**	**716**	**244**	**1057**	**960**	**11.92**
T-1	BRRI dhan29	12.5	12.5	10	8	587	502	134	721	636	14.51
T-2	BRRI dhan29	25	25	10	8	564	486	134	698	620	13.72
T-3	BRRI dhan29	50	50	12	10	553	486	134	687	620	12.08
Avg.	**Thakurgaon**	**29.2**	**29.2**	**10.7**	**8.7**	**568**	**491**	**134**	**702**	**625**	**13.44**
B-1	Minikit	31.4	26	11	9	614	514	202	816	716	16.29
B-2	Kajol lota	31.6	30.4	11	9	620	522	202	822	724	15.81
B-3	Kajol lota	32.8	33.0	11	9	634	543	202	836	745	14.35
Avg.	**Bogura**	**31.9**	**29.8**	**11**	**9**	**623**	**526**	**202**	**825**	**728**	**15.48**
Avg.	**Overall**	**31.8**	**30.1**	**13.5**	**11.1**	**708**	**609**	**227**	**935**	**836**	**14.09**

3.8.3 Water productivity

Table 3.22 showed the grain yield, water productivity under AWD and Farmers' practice. Experimental data indicated that similar yield was obtained from AWD compared to farmers' practice.

The average yield for AWD and Farmers' practice were 4.68 and 4.54 t/ha in Bogura, 6.93 and 6.95 t/ha in Pabna, 6.25 and 6.16 t/ha in Rangpur, 8.10 and 7.66 t/ha in Thakurgaon, respectively. The average yield for AWD and Farmers' practice of all the sites were 6.40 and 6.23 t/ha, respectively. It indicated that safe AWD could able to maintain the rice yield at per continuous standing water over the locations. The yield advantage may be due to expansion of roots (Sandhu et al., 2017) and higher availability of some micro-nutrients like Zinc and Sulpher under unsaturated condition compared to continuous flooded condition (Ref---------). On the other hand, lower yield in some AWD plots may be due to inferior weed control cmpared to Farmers' practice plot.

Table 3.20 also showed that irrespective of trials, the total water productivity of AWD plots are higher than that of FP plots. The total water productivity for FP were ranges from 0.46 to 0.97 kg/m^3 and for AWD practice were ranges from 0.51 to 1.25 kg/m^3, respectively. Water productivities were highest in Thakurgaon followed by Bogura, Pabna and Rangpur, respectively. The 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.

Reverse water productivity (Amount of water needed to produce 1 kg of paddy) is a popular term to indicate water consumption for rice production. This is just reciprocal of the water productivity expressed in litres instead of m^3. Table 3.22 also revealed that the reverse water productivity for FP ranges from 1033 to 2176 lit/kg and for AWD ranges from 803 to 1950 lit/kg. Irrespective of trials lower reverse water productivity were found for AWD plots compared to the concerned FP plots.

Table 3.22 Grain yield and water productivity under AWD plots over FP in study locations during Boro season 2016-17.

Trial	Variety	Total water used (mm)		Grain yield (t/ha)		Change of yield in AWD plot (%)	Total water productivity (kg/m^3)		Reverse water productivity (lit/kg)	
		FP	AWD	FP	AWD		FP	AWD	FP	AWD
1	BRRI dhan29	1109	1031	6.67	6.79	1.85	0.60	0.66	1663	1517
2	Hybrid Heera	1326	1147	6.96	7.06	1.38	0.53	0.62	1904	1625
3	Hybrid Heera	1005	866	5.97	6.04	1.22	0.59	0.70	1684	1432
4	BRRI dhan28	1091	985	5.43	5.51	1.40	0.50	0.56	2008	1787
5	Hybrid Heera	1252	1145	5.75	5.87	2.02	0.46	0.51	2176	1950
Avg.	**Rangpur**	**1133**	**1012**	**6.16**	**6.25**	**1.57**	**0.54**	**0.61**	**1867**	**1642**
1	Minikit	1073	902	6.97	7.11	2.13	0.65	0.79	1541	1268
2	Minikit	1108	909	6.97	6.57	-5.84	0.63	0.72	1589	1384
3	Minikit	1083	882	6.68	6.79	1.63	0.62	0.77	1620	1298
4	BRRI dhan29	1000	865	7.19	7.26	1.10	0.72	0.84	1391	1191
Avg.	**Pabna**	**1066**	**890**	**6.95**	**6.93**	**-0.25**	**0.65**	**0.78**	**1530**	**1282**
1	BRRI dhan29	924	836	8.50	8.69	2.33	0.92	1.04	1087	962
2	BRRI dhan28	716	634	5.60	6.18	10.29	0.78	0.97	1279	1027
3	BRRI dhan29	919	758	8.89	9.44	6.11	0.97	1.25	1033	803

Avg.	**Thakurgaon**	**853**	**743**	**7.66**	**8.10**	**6.24**	**0.89**	**1.09**	**1124**	**920**
1	Minikit	596	538	4.52	4.83	6.99	0.76	0.90	1320	1112
2	Minikit	600	528	4.88	5.10	4.46	0.81	0.97	1230	1036
3	Minikit	590	531	4.33	4.19	-3.24	0.73	0.79	1364	1269
4	Minikit	589	539	4.43	4.61	4.02	0.75	0.85	1328	1170
Avg.	**Bogura**	**594**	**534**	**4.54**	**4.68**	**3.06**	**0.76**	**0.88**	**1309**	**1140**
Avg.	**Overall**	**929**	**811**	**6.33**	**6.49**	**2.37**	**0.69**	**0.81**	**1514**	**1302**

Table 3.23 showed the comparative yield performance of the demonstrations under AWD and FP along with respective total water productivity and reverse water productivity. Out of 13 demonstrations 8 AWD plots gave higher yield compared to FP. Highest yield was 7.95 t/ha and obtained by AWD practice for BRRI dhan29 and lowest yield was 5.72 t/ha and obtained by FP for Kajollota. Irrespective of sites and demonstrations, the mean yield for FP and AWD were 6.47 t/ha and 6.62 t/ha, respectively. Statistical analysis showed that the yield difference is statistically insignificant. It indicated that yield reduction did not hampered for AWD adoption in framers' field.

Water productivity was an important parameter to assess the efficiency in water use for crop production. Irrespective of demonstrations, higher water productivity was obtained for AWD compared to FP. Due to variation in yield and amount of irrigation, water productivity varied from plot to plot as well as from site to site. The highest water productivity for FP and AWD were 1.0977 kg/m^3 and 1.2823 kg/m^3, respectively. The lowest water productivity for FP and AWD were 0.5447 kg/m^3 and 0.5993 kg/m^3, respectively. The average water productivity for FP and AWD were 0.7254 kg/m^3 and 0.8342 kg/m^3, respectively. Similar findings were also found by Bouman and Toung (2001), which varied from 0.3 to 1.1 kg grain m^{-3} water productivity with continuous submergence regimes. It indicated that AWD practice gave higher amount of grain per unit volume of water compared to FP. The reverse water productivity indicated that how much (litres) water is needed to produce 1 kg of rice. Table 3.23 indicated that it requires 911 to 1836 litre of water to produce 1 kg of rice. The maximum water needed to produce 1 kg of rice under FP and AWD practice were 1836 lit and 1689 lit, respectively. The minimum amount of water needed to produce 1 kg of rice under FP and AWD were 911 and 780 litres, respectively. The average amount of water needed to produce 1 kg of Paddy under FP and AWD were 1475 and 1293 litres, respectively. The results revealed that about 182 litres irrigation water could be saved by adopting AWD practice for producing 1 kg of Paddy. This water could be used in irrigating additional lands.

Table 3.23 Grain yield in both Farmers practice and AWD plots with comparative yield change in AWD plots in demonstration trials during Boro season 2017-18.

Trial	Variety	Total water used (mm)		Grain yield (t/ha)		Change of yield in AWD plot (%)	Total water productivity (kg/m^3)		Reverse water productivity (lit/kg)	
		FP	AWD	FP	AWD		FP	AWD	FP	AWD
R-1	BRRI dhan28	1032	931	6.18	6.26	1.3	0.60	0.67	1671	1488
R-2	BRRI dhan28	1173	1004	6.42	6.92	7.8	0.56	0.69	1827	1452
R-3	Hybrid Surma	1147	1032	6.59	6.33	-3.9	0.57	0.61	1741	1631
Avg.	**Rangpur**	**1117.3**	**989.0**	**6.40**	**6.50**	**1.6**	**0.57**	**0.66**	**1746**	**1523**
P-1	Minikit	1001	908	5.99	5.96	-0.5	0.60	0.66	1671	1524

P-2	Minikit	1097	993	5.98	5.95	-0.5	0.55	0.60	1836	1669
P-3	BRRI dhan63	1063	983	6.32	6.09	-3.6	0.60	0.62	1681	1613
P-4	BRRI dhan28	1068	957	5.83	5.98	2.6	0.55	0.62	1833	1601
Avg.	**Pabna**	**1057.3**	**960.3**	**6.03**	**6.00**	**-0.5**	**0.57**	**0.63**	**1755**	**1602**
T-1	BRRI dhan29	721	636	7.90	7.81	-1.1	1.10	1.23	912	815
T-2	BRRI dhan29	698	620	7.66	7.95	3.8	1.10	1.28	911	780
T-3	BRRI dhan29	687	620	7.24	7.51	3.7	1.05	1.21	949	826
Avg.	**Thakurgaon**	**702.0**	**625.3**	**7.6**	**7.76**	**2.1**	**1.08**	**1.24**	**924**	**807**
B-1	Minikit	816	716	5.98	6.46	8.0	0.73	0.90	1365	1108
B-2	Kajol lota	822	724	6.25	6.83	9.3	0.76	0.94	1315	1061
B-3	Kajol lota	836	745	5.72	5.99	4.7	0.68	0.80	1461	1244
Avg.	**Bogura**	**825**	**728**	**5.98**	**6.43**	**7.5**	**0.73**	**0.88**	**1380**	**1138**
Avg.	**Overall**	**935**	**836**	**6.47**	**6.62**	**2.3**	**0.73**	**0.83**	**1475**	**1293**

Table 3.24 showed the statistical analysis of the experimental results. The mean yield for AWD was slightly higher than the FP for both the study periods. There was no significant difference between the mean grain yield under AWD and FP for both the years. Table 3.24 also revealed that the mean irrigation applied for AWD was significantly lower than that for FP. But there was no significant difference found in total water applied for both AWD and FP though total water applied for FP was higher than that for AWD.

Table 3.24 Statistical analysis of the experimental results obtained in 2016-17 and 2017-18.

Variable	**2016-17**	**AWD (n=16)**	**FP (n=16)**	**t-value**	**prob**	**LSD -value**
Yield (t/ha)	Mean SD	6.378 1.414	6.234 1.369	-0.292	0.772	1.005
Irrigation applied (mm)	Mean SD	542.94 140.63	660.75 179.55	2.066	0.048	116.73
Total water used (mm)	Mean SD	818.50 211.80	936.31 245.25	1.454	0.156	165.59
	2017-18	**AWD (n=13)**	**FP (n=13)**	**t-value**	**prob**	**LSD -value**
Yield (t/ha)	Mean SD	6.619 0.72585	6.466 0.70168	-0.544	0.591	0.578
Irrigation applied (mm)	Mean SD	608.77 104.75	708.15 115.58	2.297	0.031	89.33
Total water used (mm)	Mean SD	836.08 160.80	935.46 176.98	1.499	0.147	136.95

3.9 Environmental impact of water saving technologies

The study findings revealed that average water used was 824 mm in AWD and 932 mm in FP and average water saved was 16% (calculation based on Table 3.20 and 3.21). In this case about 108 mm water was saved by AWD over FP. Most of the STW discharge varied from 9.8 to 29.3 l/sec with an average discharge of 15.52 l/sec (Table 3.5). Considering this water saved and pump discharge about 16 liters diesel fuel was saved per hectare of land irrigation, which is equivalent to 160 kg CO_2 emission (Haque et al., 2017). On the other hand, if we considered the polythene pipe water saved about 25% compare to earthen canal (Table 3.6) and in earthen canal conveyance loss was 30-40% (Biswas et al., 1984), then the ultimate water saved was about 10% by polythene pipe. To consider the combined effect of polythene pipe and AWD water management about 30 liters of diesel fuel was saved, which is equivalent to 300 kg CO_2 emission.

Besides these, AWD irrigation was very effective to reduce seasonal CH_4 flux about 23-36% than continuous flooding (Hossain et al., 2019) and also reduce the GWP by 22-25% (Haque et al., 2016).

Other benefits of AWD irrigation practices:
Methane is the dominant GHG emitted from rice systems in terms of global warming potential (GWP). Several field studies have shown that the drainage of wetland rice once or several times during the growing season effectively reduces CH_4 emissions (Wassmann et al., 1993; Yagi et al., 1997; Lu et al., 2000; Towprayoon et al., 2005; Itoh et al., 2011). Through mid-season drainage (MD) and intermittent irrigation, the development of soil reductive conditions can be prevented, leading to reduced CH_4 emissions. MD can reduce the total CH_4 emission during the rice-growing period by 30.5% (Minamikawa et al., 2014). Additional benefits include the reduction of ineffective tillers, the removal of toxic substances and the prevention of root rot, leading to increased yields and reduced water use (Zou et al., 2005; Itoh et al., 2011).

4. Conclusions and Recommendations

a. Conclusions:

- Use of polythene pipe irrigation water distribution system was found effective in minimizing loss of irrigation water. It could save about 20-25% irrigation conveyance water and also saves irrigation time by 25% significantly. The thickness of the polythene pipe should be increased to ensure longevity of the pipe.

- Check valve installation offer reduction of drudgery in STW start and ensures uninterrupted operation of the pump. Installation of check valve in STWs will encourage the owners to use polythene pipe for water distribution.

- The yield of newly released high yielding varieties varied from 4.53 – 9.88 t/ha and the farmers' chosen the variety depends upon the yield, grain quality, growth duration and price of local market.

- AWD technique for irrigation scheduling was found effective for irrigation water saving about 14-18% in Boro rice cultivation. Mass adoption of this technology by the farmers will reduce significant amount of irrigation water consumption and fuel use for pumping water. It not only saved the irrigation water and also reduce the greenhouse gas emission and reduce the groundwater withdrawal.

b. Recommendations:

- Field level training and demonstration on Polythene pipe distribution system should be arranged to motivate the farmer for wide-scale adoption of the technology. Measures should be taken to improve the quality of the polythene pipe available in Bangladesh.

- Steps should be taken to demonstrate the use of check valve in STW of different regions. Availability of check valve should be ensured by large-scale production.

- Field level training and demonstration on AWD irrigation scheduling should be arranged to motivate the farmer for wide-scale adoption of the technology. AWD pipe should be provided without cost.

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