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

Report on the project of Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains (LWR/2012/079)

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Executive Summary

The report presents the results of technological interventions for improving water use efficiency in the northwest region of Bangladesh. The study was undertaken in collaboration with CSIRO and University of Southern Queensland of Australia as part of the project: **"Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains (LWR/2012/079)".** The project was funded by the Australian Centre for International Agricultural Research (ACIAR). The overall aim of the project was to improve the livelihood of woman, marginal and tenant farmers in the Eastern Gangetic Plains which includes northwest region of Bangladesh through improved water use and increased dry season agricultural production.

Northwest region is the most intensively cultivated and irrigated area of the country. About 85% of the net cultivable area is irrigated; 97% of which is by groundwater. Boro rice, which is fully irrigated, is the major crop grown in the dry season. Water use efficiency of Boro rice, in general, is good, however, there are scopes for further improvement. In this study, we discuss the results of some technological interventions such as the use of polythene pipe for water conveyance to the field, alternate wetting and drying (AWD), and introduction of new high yielding varieties to increase water use efficiency of rice in the region. The study was carried out during 2016-17 and 2018-19 crop season at 4 locations (Pabna, Bogra, Rangpur, and Thakurgaon districts) across the region. The key results are given below:

- Use of polythene pipe irrigation water distribution system was found effective in minimizing conveyance loss of irrigation water. It may reduce water supply by 20-25% and saves irrigation time by 25%. Thickness of polythene pipe should be used 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.
- Groundwater level in the study areas was the main concern for STW operation. There was no problem of STW operation in Pabna, Rangpur and Thakurgaon as the groundwater level did not drop below the suction limit. Only in Bogura water level fell below the suction limit (8.8 m) whereas deep set STW was needed for pumping of water.
- AWD technique for irrigation scheduling was found effective for reduction in irrigation water supply by about 14-18% in Boro rice cultivation. Overall water productivity in traditional farmers practice 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 reduces 160 kg CO2/ha emission and reduced 23-36% methane flux emission from rice field compared to continuous flooding. Mass adoption of this technology by the farmers will reduce significant amount of irrigation water pumping, fuel use and cost of irrigation in some areas. It will also reduce the greenhouse gas emission.
- The yield of newly released high yielding varieties varied from 4.53 – 9.88 t/ha and the farmers' choice of the variety depends upon the yield, grain quality, growth duration and price of local market.

The study recommends field level training and demonstration of Polythene pipe distribution system and AWD to motivate the farmer for wide-scale adoption of these technologies.

1. Introduction

1.1 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 (FAO, 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 declining 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 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 but water 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 household, agriculture and industry are increasing very fast (Bindraban, 2001). According to OECD (2012), global water demand will be increased 55% by 2050, which is 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 is projected to increase to 202 million (UN, 2017) and the corresponding rice demand will be 44.6 million tons by 2050 (Kabir et al, 2015, Mainuddin and Kirby, 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 (Mainuddin and Kirby, 2015). 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 190% in 2017 with an increasing proportion of land being double- or triple- cropped (BBS, 2018). 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, 2018).

After the privatization of irrigation sector during 1982, a substantial growth of irrigation development has taken place 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.

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. Over extraction may cause this unsustainability. 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, over bund 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.

Water use efficiency of rice depends on the amount of water supplied to the rice fields. Conveyance losses is part of the water supplied for irrigation to the field, reduction of which has the potential to improve water use efficiency of rice. To reduce the conveyance losses of irrigation water, buried pipe water distribution system is introduced in limited scale only in BMDA managed DTWs. For STW, irrigation delivery is done mainly through earthen canal, which needs to be addressed for minimizing irrigation cost. Alternate Wetting and Drying (AWD) technology can also reduce pumping of irrigation water thus improve water use efficiency as well as cost of irrigation though it has some debate whether it increases or decreases rice yield. However, safe AWD can maintain yield at per CSW (Bouman et al., 2007) or produce higher grain yield (Yang et al., 2017). Many researchers reported that AWD reduced water input by 20-25% (Bauman and Toung, 2001; Maniruzzaman, 2012). AWD also reduce the energy/fuel consumption in cases where irrigation is supplied by pumping (Nalley et al., 2015; Kurschner et al., 2010). Moreover, rice fields have been identified as an important source of atmospheric methane (CH_4), one of the major potent greenhouse gases (GHG) and contribute approximately 15–20% of global anthropogenic CH_4 emissions (Aulakh, et al., 2001; Yan et al., 2005; Yang et al., 2017). Nitrous oxide (N_2O), 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). Linguist et al. (2014) reported that AWD reduced global warming potential by 45 - 90% compared to continuously flooded systems.

In this study, we evaluate the performance of some technological interventions such as the use of polythene pipe for water conveyance to the field, alternate wetting and drying (AWD), and introduction of new high yielding varieties to increase water use efficiency of rice in the northwest region.

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) to set up the field experiments. The tested technologies were-

i. Use of polythene pipe in STWs for reducing conveyance loss in water distribution as well as cost of irrigation,
ii. Use of check-valve for reducing drudgery of STW operation and also facilitate the polythene pipe use in STW,
iii. Introduction of newly released suitable rice varieties for improving land productivity,
iv. Alternate wetting and drying (AWD) irrigation scheduling for reducing the cost of production, increase productivity of irrigation water and reduce greenhouse gas emission.

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

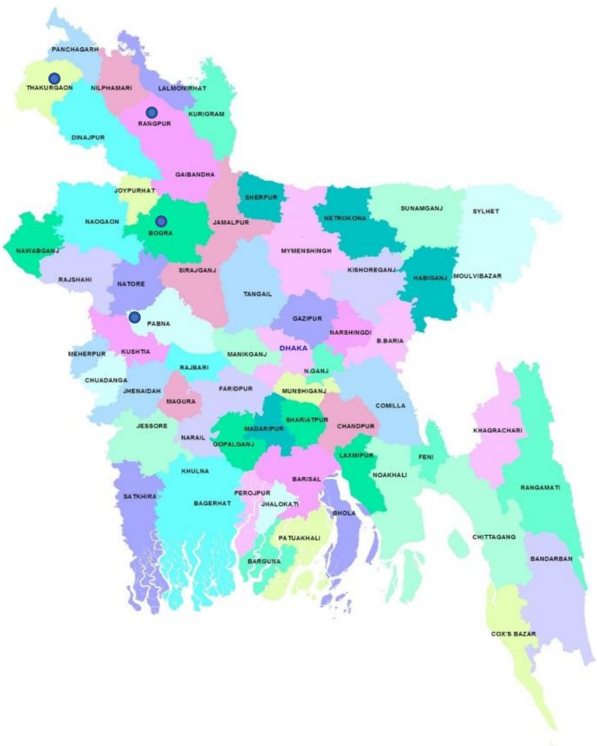


Fig. 2.1 Selected sites for technological interventions within the study areas.

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.

Now-a-days, through different projects, awareness building program was 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. For DTW water is mostly distributed through buried pipe irrigation systems particularly in the DTW managed by 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 selected STWs, about 90-100 m length of appropriate (depends on the outlet diameter of the STW) 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, 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		

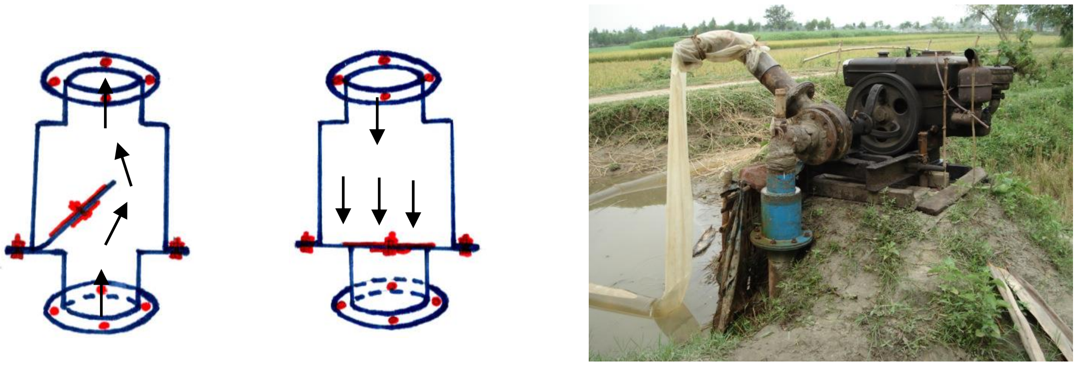
Five irrigation wells were selected for demonstrations in 3 different sites during Boro season 2017-18. Among the five wells 3 were in Rangpur, 1 in Pabna and 1 in Bogura. Similar procedure was applied for selecting the plots as 2016-17. Table 2.2 shows the number of demonstrations on polythene pipe 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, 2017-18.

Site	Number of demonstration	Irrigation schemes	Existing distribution system
Bogura	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 face the priming problem in every time of STW starting, which was troublesome and difficult 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 than minimum 50 mm diameter of the suction pipe and minimum 150 mm in length is fitted on the valve with flange joint, which is air tight and facilitate to free movement of the valve. Then it is fitted with the tubewell suction side before pump. It keeps water up to delivery pipe of STW and thus overcoming the priming problem of STW. It also facilitates easier fitting of polythene pipe 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 other 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.

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

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 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:

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

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.

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

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, 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 (Mainuddin et al. 2019).

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. Earlier studies (Li, 2001; Islam et al., 2005; BRRI, 2007; Yang, et al., 2017; Tan et al., 2013; Richards and Sanders, 2014; Sandhu et al., 2017) showed that continuous standing water was not necessary for rice production. 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 become 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.

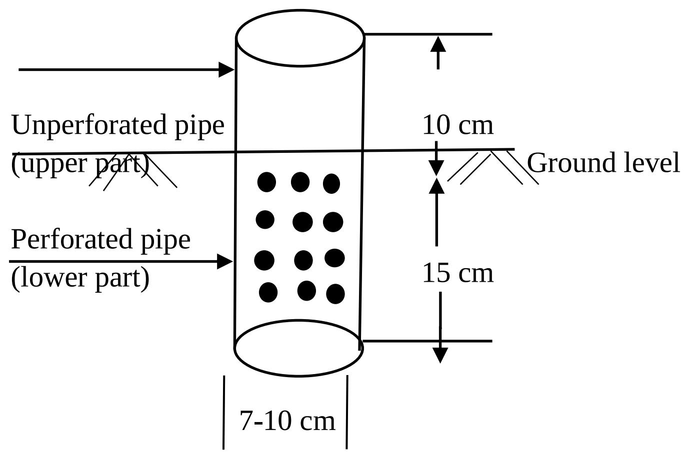


Fig. AWD Pipe

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 Bogura, Pabna, Rangpur and Thakurgaon were 4, 3, 5 and 3, respectively. Similarly, during Boro season 2017-17, 20 trials were conducted in the selected locations (Table 2.2).

It has been stated by Linquist et al. (2015), though many studies have examined potential benefits of water-saving irrigation, the environmental consequences (greenhouse gas like CH_4 and N_2O emission) 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 (Haque et al., 2016). 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 (Yang et al., 2017). Hence, the implementation of water-saving irrigation has many implications that should be considered in addition to the challenges of water scarcity. In addition, less pumping of water will require less burning of fuel or less use of electricity which will further reduce the environmental footprint of rice cultivation.

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 during Boro season 2016-17.

Site	Number of demonstration	Irrigation scheme	Popular rice varieties
Bogura	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
Bogura	3	STW with diesel engine	Minikit, Kajollota
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

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 installation	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
Bogura-1	Shafiqul Islam	10.0	24.4	7.5	Diesel engine	4.48	2017	2.97
Bogura-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. Irrigations were applied in both the plots on the same day. Therefore, the number of irrigations were same for both earthen canal and polythene pipe. The time required to irrigate up to the upper level of the indicator stick was counted for both the systems. 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 irrigations	Area of the plot (decimal)	Pipe length (m)	Number of irrigations
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 two locations. These amounts of irrigation were accounted for both land preparation and growing duration. The irrigation water saving in delivery 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 and consequently reduce the pumping cost. ~~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%. Hossain 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)		Reduction in water supply (%)	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 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 reduce pumping of irrigation water but also irrigation time compared to the earthen canal. The reduction in irrigation time as well as amount of irrigation water also helped to reduce the irrigation cost.

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 shows 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, 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 (m)	Number of irrigations	Area of the plot (decimal)	Pipe length (m)	Number of irrigations
Pabna	1	Md. Badsha Mondal	25.0	45.7	12	33.0	22.9	11
Bogura	1	Md. Yasin Ali	68.0	69.8	10	67.5	80.5	9
Rangpur	1	Sazu Mia	25.0	87.8	10	20.0	47.0	9
	2	Titu Mia	20.0	108.2	14	34.0	67.1	12
	3	Md. Saiful Islam	35.0	98.8	13	50.0	67.7	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, (min)	Total volume supplied by canal(lit)	Total depth of irrigation by canal, (mm)	Average discharge (lps)	Total irrigation time, (min)	Total volume supplied by pipe (lit)	Total depth of irrigation by pipe, (mm)
P-1	29.3	375	658,980	650.8	29.3	360	634,524	474.8
B-1	14.9	1753	1,560,780	566.7	14.8	1395	1,231,740	450.6
R-1	12.0	845	610,620	603.1	12.1	515	375,720	463.9
R-2	9.7	1125	654,570	808.1	9.8	1330	782,190	568.0
R-3	11.5	1675	1,159,440	817.9	11.6	1780	1,233,420	609.1
Avg.	15.5			689.3	15.5			513.3

Table 3.6 shows a comparison of specific irrigation volume, specific irrigation time, reduction in irrigation water supply and irrigation time saving between earthen canal and polythene pipe distribution system. Irrespective of irrigation scheme, irrigation water pumped for the plots with earthen canal was higher compared to the plots with polythene pipe. The average irrigation depth by earthen canal and polythene pipe was 698 and 520 mm, respectively. The reduction in irrigation water supply by polythene pipe ranges from 20.5-29.7 percent over the earthen canal; the average of which is 25.2%. The average 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 irrigation volume, irrigation time, reduction in irrigation water saving supply and irrigation time saving for both earthen canal and polythene pipe distribution system during Boro season 2017-18.

STW	Owner of the pump	Irrigation depth by earthen canal (mm)	Irrigation depth by poly pipe (mm)	Water saved by poly pipe (%)	Time of irrigation, (min/dec)	Time of irrigation, (min/dec)	Irrigation time saved by poly pipe (%)
Pabna-1	Md. Badsha Mondal	659	481	27.1	15.0	10.9	27.3
Bogura-1	Md. Yasin Ali	574	456	20.5	25.8	20.7	19.8
Rangpur-1	Sazu Mia	611	470	23.1	33.8	25.8	23.8
Rangpur-2	Titu Mia	818	575	29.7	56.3	39.1	30.5
Rangour-3	Md. Saiful Islam	828	617	25.5	47.9	35.6	25.6
	Average	698	520	25.2	35.76	26.42	25.4

Statistical and economic analysis:

Table 3.7 shows statistical analysis of the irrigation water pumped and 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 reduces more than 20 percent of pumping. 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 reduces more than 25 percent irrigation water pumping compared to earthen canal water distribution systems.

Table 3.7 also shows the mean 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 irrigation time for polythene pipe and earthen canal though polythene pipe saves more than 20 percent irrigation time. The mean 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 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 hose pipe irrigation compared to earthen canal in STW.

In both years, on an average 22.5% irrigation water pumping and about 23.2% irrigation application time saved by polythene pipe compared to earthen canal.

Table 3.7 Statistical analysis for comparison irrigation water pumped and 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
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
Irrigation time (min/decimal)	Mean SD	35.76 16.6	26.42 11.4	1.037	0.334	21.25

Economic analysis

The average water supplied by earthen canal and polythene pipe was 698 mm and 520 mm respectively and the reduction of water supplied by polythene pipe was 178 mm (Table 3.6). The lower amount of water withdrawal from groundwater reserve also reduce the fuel cost as wells irrigation cost of the farmers. It also reduces the less fuel burning as well as reduce the greenhouse gas emission. Based on the average discharge of the pumps (15.5 lps), to irrigate 178 mm water per hectare of land it is required about 32 hours. On an average, STW consumes 1 litre of diesel per hour and accordingly polythene pipe irrigation reduced 32 litre of diesel fuel, which cost is about BDT 2,073 (diesel cost @ BDT 65/lit.). Considering the maximum length (100 m) and 12.5 cm diameter of polythene pipe, the total weight of the pipe is about 10 kg and the cost is about 1500 BDT (polythene cost @ 150 BDT/kg). Therefore, it reduces the pumping cost of the pump owner. But there are different irrigation water pricing systems in Bangladesh. Most of the cases, in crop sharing pricing system, pump owner used the polythene pipe and all benefit goes to him. However, individual farmers have no benefit by using polythene pipe in irrigation distribution systems.

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. 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 hassle 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 by 90 percent whereas labour requirement reduces by 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. Almost 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 using 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 this technology. 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 as it requires at least 2 persons and 10-15 minutes of time. 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 in 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)	Discharge (lit/sec)				
		Tubewell	Pump delivery		Late February	Early March	Late March	Early April	Late April
	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	4.5	25.59	25.18	24.84	23.04	
STW-2	Atiqul Mawla	15.0	10.0	4.5	29.45	29.14	28.68	28.56	
	Thakurgaon- Cut-throat flume								
DTW-1	BMDA	35.0	15.0	35	61.15	60.44	58.35	57.54	

3.4 Measurement of ET, 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 rate was lowest after transplanting. Then it starts to increase and continues up to the 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.

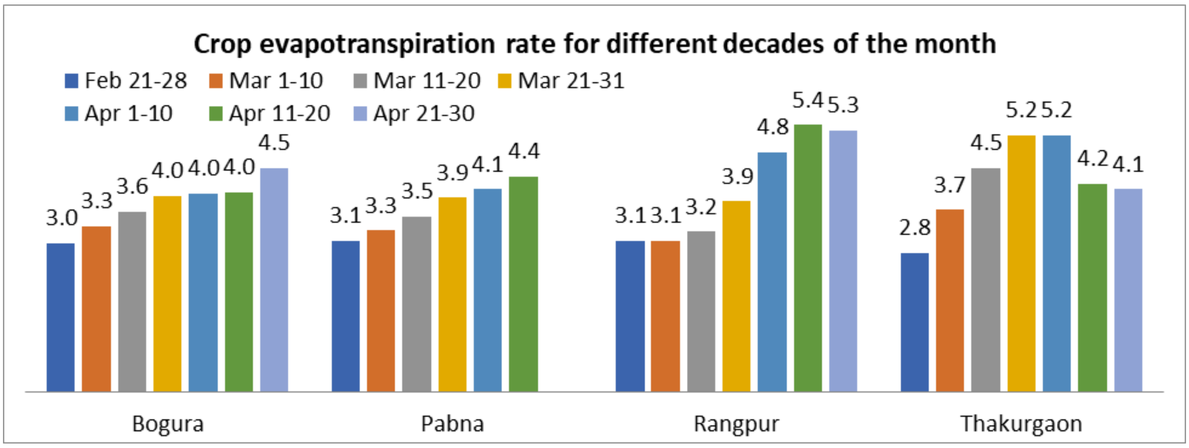


Fig. 3.1 Decadal average daily crop evepotranspiration in Bogura, Pabna, Rangpur and Thakurgaon from February-April, 2017.

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 percolation rate in Bogura, Pabna, Rangpur and Thakurgaon were 2.04, 2.63, 2.50 and 2.20 mm/day, respectively.

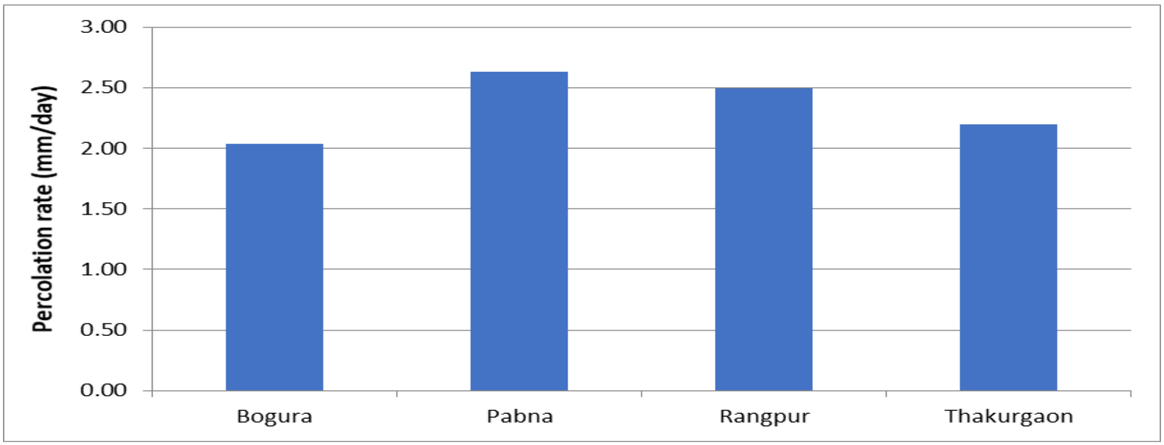


Fig. 3.2 Average daily percolation rate in Bogura, Pabna, Rangpur and Thakurgaon from February-April, 2017.

3.5 Measurement of rainfall during dry season

Rainfall is an important component of water balance analysis for crop production. Amount of rainfall and its 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.

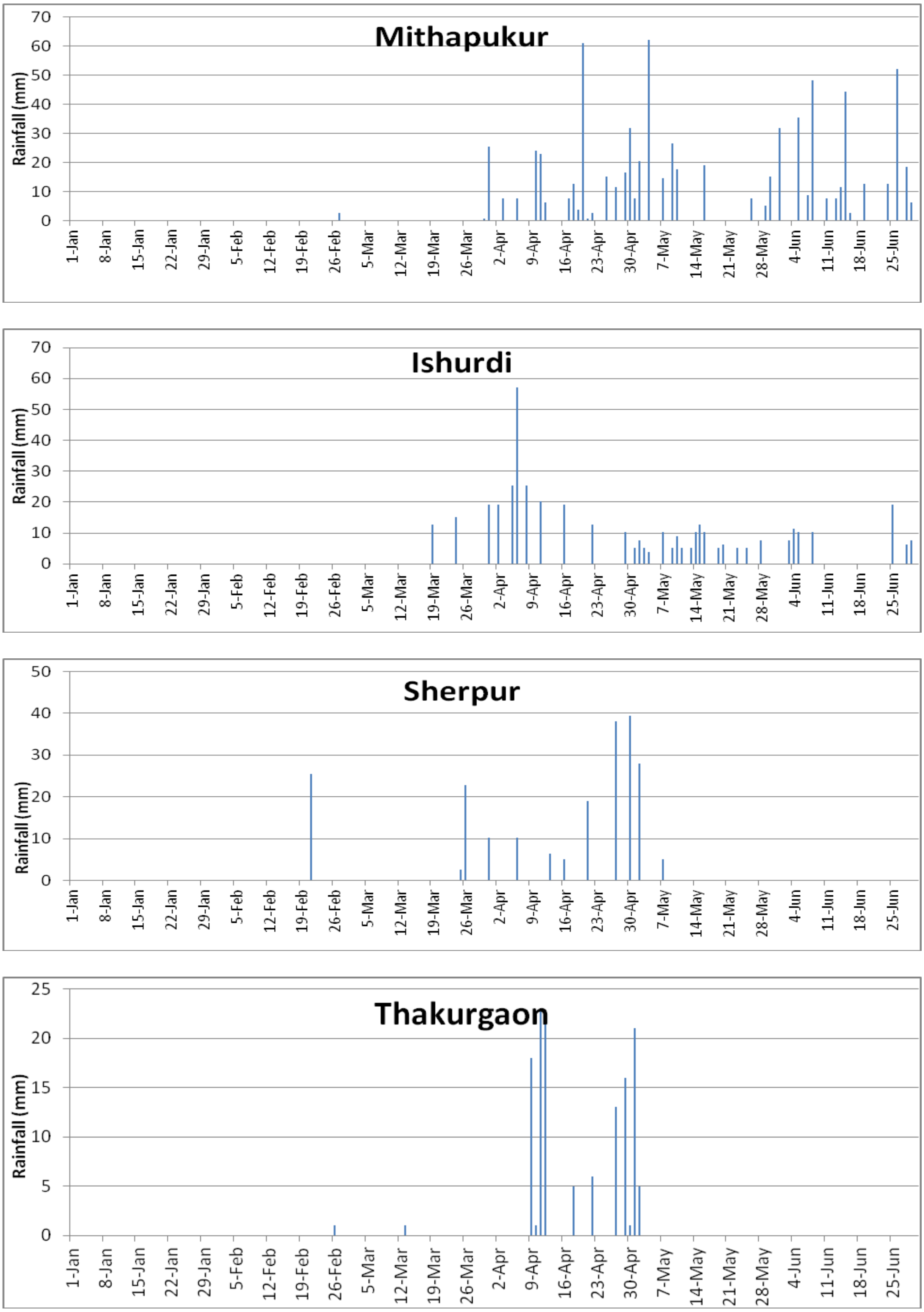


Fig. 3.3 Daily rainfall in different study locations during Jan-Jun 2018.

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). For that reason, all pump owner lowered their pump unit 1 m below the ground surface to capture groundwater at peak irrigation season.

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.

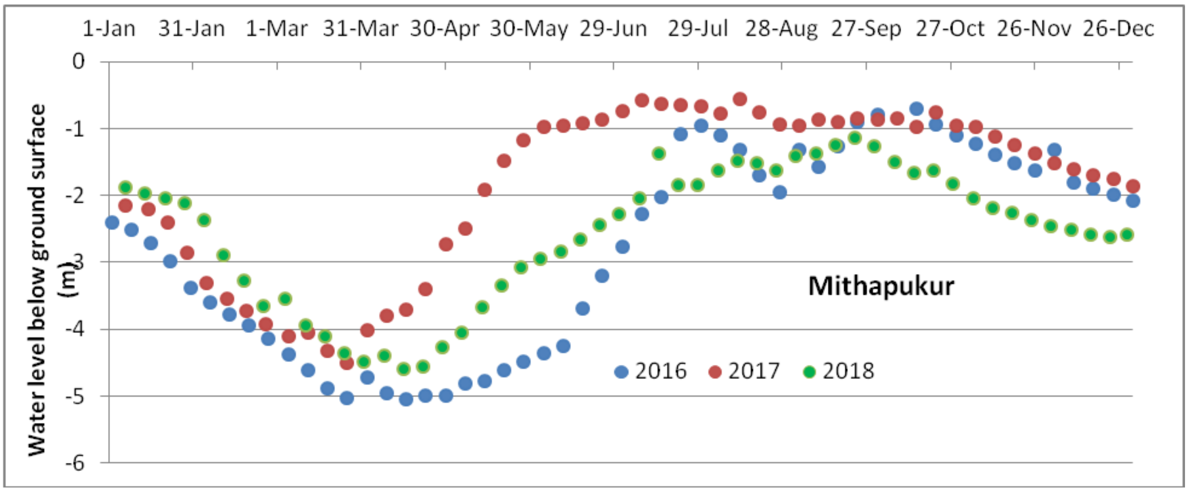


Fig. 3.4 Weekly groundwater level hydrograph of Mithapukur, Rangpur.

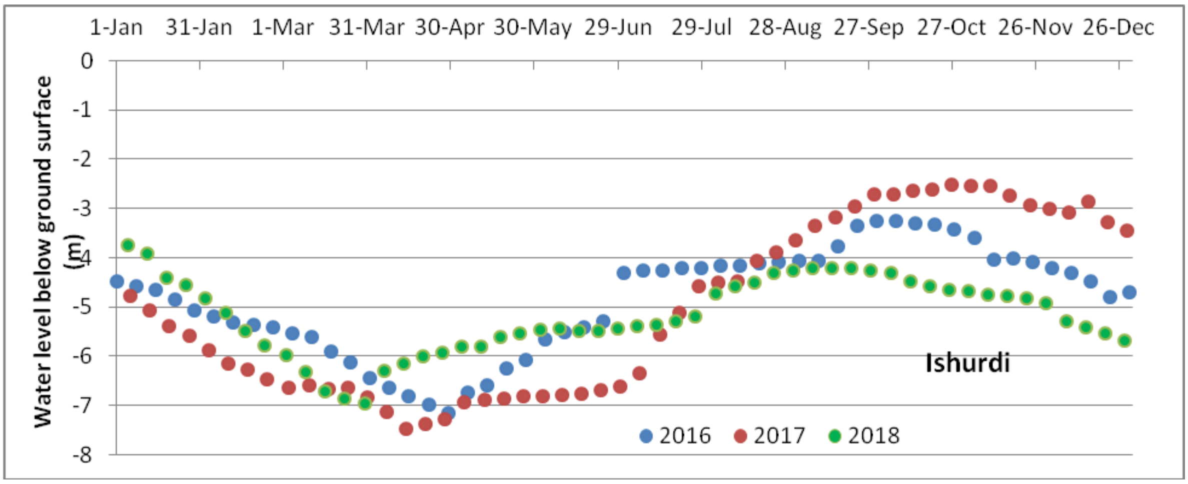


Fig. 3.5 Weekly groundwater level hydrograph of Ishurdi, Pabna.

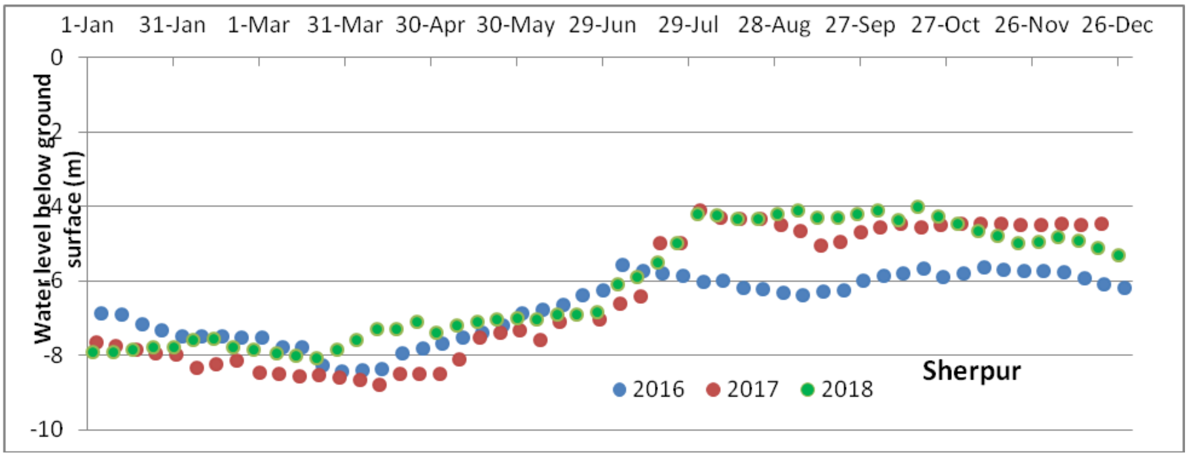


Fig. 3.6 Weekly groundwater level hydrograph of Sherpur, Bogura.

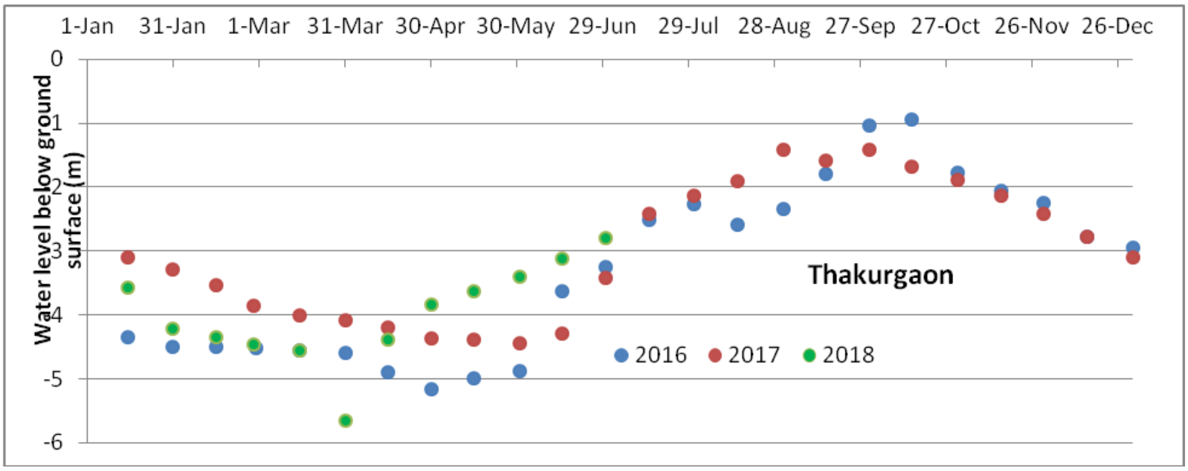
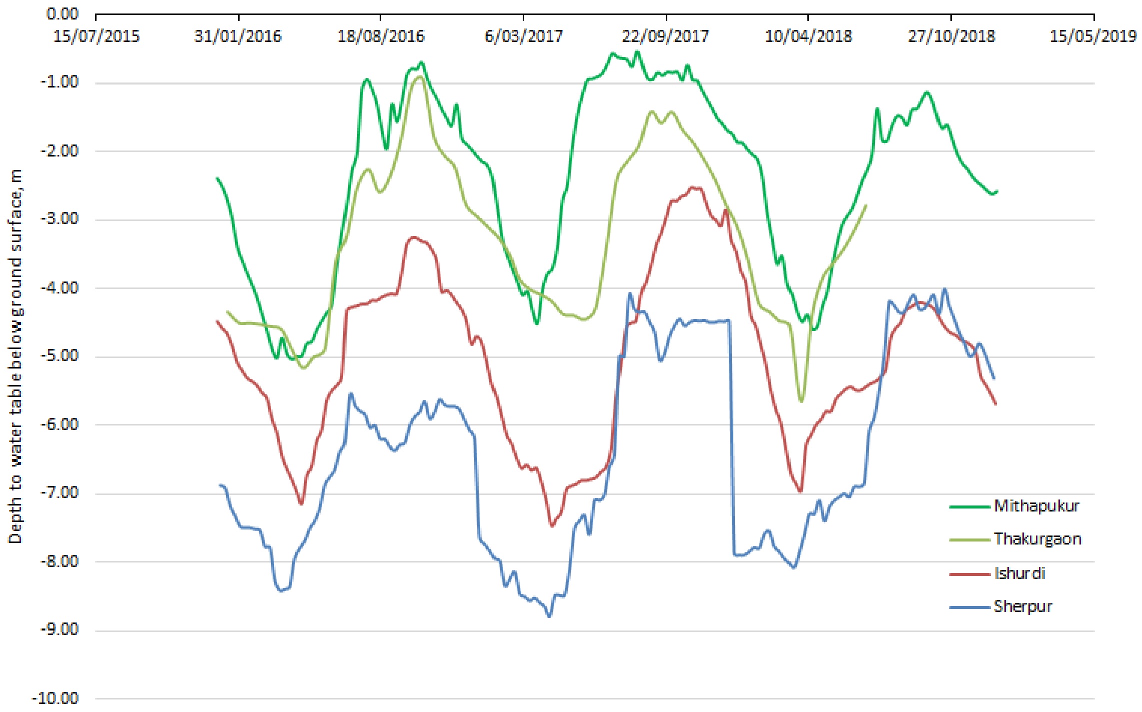


Fig. 3.7 Weekly groundwater level hydrograph of Thakurgaon Sadar, Thakurgaon.



It indicates that there was no problem in STW operation in Mithapukur, Ishurdi and Thakurgaon, but in Sherpur area sometimes water level dropped below the suction limit. So, farmers installed the STW below the ground level to pump water during peak irrigation period of March and April.

3.7 Performance evaluation of newly released Boro varieties

In the Focus Group Discussion (FGD) conducted in the selected sites, farmers wanted to get new better varieties of rice to increase their production. They specifically wanted varieties with following characteristics:

- 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 shows some important characteristics of 4 newly released varieties of BRRI. 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 have some other important characteristics that can attract the farmers. BRRI dhan63 is fine long grain which has higher market price than the other varieties. BRRI dhan68 is medium bold grain and with higher potential yield (7.3 t/ha). BRRI dhan74 is Zinc enriched, medium bold grain with higher yield potential. It is 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.

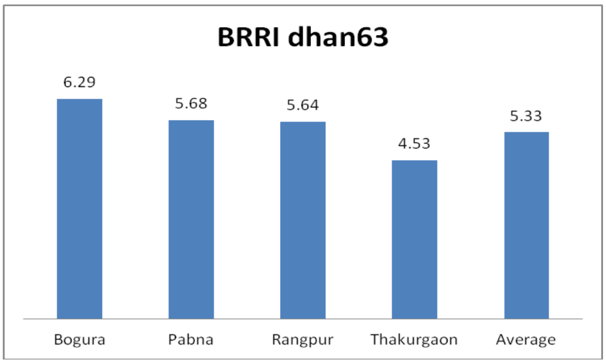
Variety	Growth duration (days)	Grain type	Yield (t/ha)	Year of release

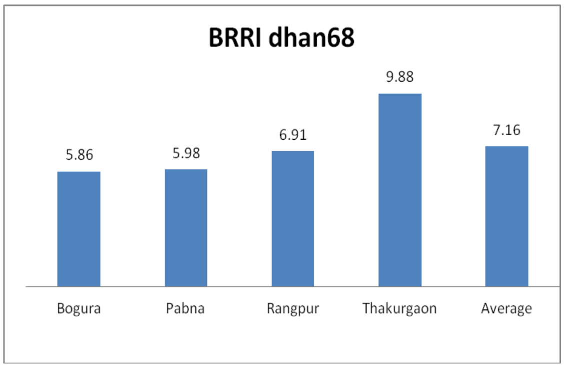
BRRI dhan63	146	Fine and long, Basmati type	6.5	2014
BRRI dhan68	149	Medium bold & white	7.3	2014
BRRI dhan74	147	Medium bold & white, Zn enriched	7.1	2015
BRRI hybriddhan5	145	Medium fine, long and white	9.0	2017

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. 3.8 shows the comparative yield of BRRI dhan63 at different locations. Highest yield was obtained in Bogura (6.3 t/ha) followed by Pabna (5.7 t/ha), Rangpur (5.6 t/ha) and Thakurgaon (4.5 t/ha), respectively. The average yield was 5.3 t/ha, which was lower than the potential yield. Presently they cultivate Minikit and average yield is around 5.0 t/ha. The results indicate that this variety is suitable for Bogura and Pabna as farmers of these areas prefer and cultivate fine rice. 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 (9.9 t/ha) followed by Rangpur (6.9 t/ha), Pabna (6.0 t/ha), and Bogura (5.9 t/ha), respectively. The average yield was 7.2 t/ha, which was similar to the potential yield. The yield obtained in Thakurgaon (9.9 t/ha) was higher than the potential yield (7.30 t/ha) this may be due to the fertility of the land and timely sowing and also for management. Cowdung was applied in the land before cultivation. The yield obtained in Rangpur (6.9 t/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.





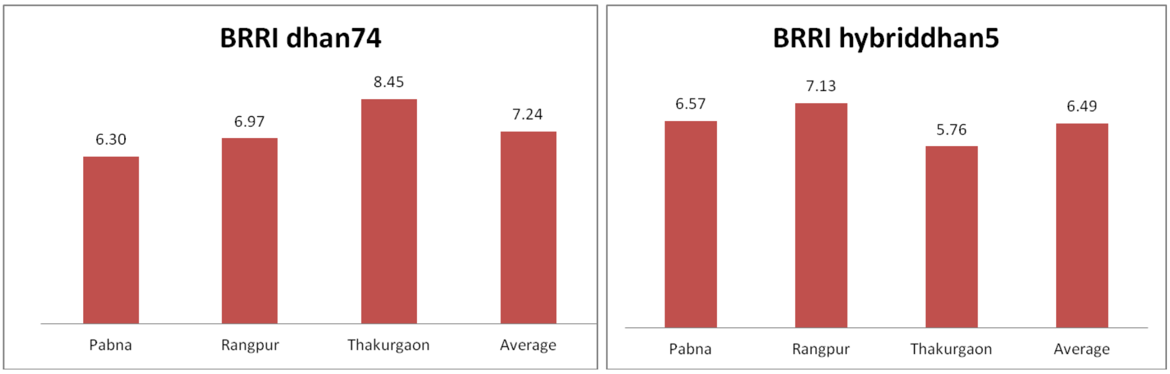


Fig. 3.8 Yields of different varieties in the study sites during Boro season 2017-18.

Fig. 3.8 showed the comparative yield of BRRI dhan74 at different locations. Highest yield was obtained in Thakurgaon (8.5 t/ha) followed by Rangpur (7.0 t/ha) and Pabna (6.3 t/ha), respectively. The average yield was 7.2 t/ha, which was similar to the potential yield (7.10 t/ha). The yield obtained in Thakurgaon (8.5 t/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 results indicate 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.

Fig. 3.8 showed the comparative yield of BRRI hybriddhan5 at different locations. Highest yield was obtained in Rangpur (7.1 t/ha) followed by Pabna (6.6 t/ha) and Thakurgaon (5.8 t/ha) respectively. The average yield was 6.5 t/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) 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 shows 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 rice 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-ling age (days)	Date of maturity		Growth duration (days)	
						FP	AWD	FP	AWD
Rangpur									
1	Titu Mia	BRRI dhan29	15 Nov 16	26 Jan 17	71	29 Apr 17	29 Apr 17	164	164
2	Saiful Islam	Hybrid Heera	08 Dec 16	08 Feb 17	61	18 May 17	18 May 17	160	160
3	Golam Mostofa	Hybrid Heera	15 Dec 16	05 Feb 17	51	20 May 17	20 May 17	155	155
4	Sazu Mia	BRRI dhan28	05 Dec 16	08 Feb 17	64	11 May 17	11 May 17	155	155
5	Nazmul Islam	Hybrid Heera	08 Dec 16	08 Feb 17	61	23 May 17	23 May 17	165	165

Pabna									
1	Atiqul Mawla	Minikit	03 Dec 16	30 Jan 17	57	03 May 17	05 May 17	149	151
2	Atiqul Mawla	Minikit	03 Dec 16	30 Jan 17	57	30 Apr 17	03 May 17	145	149
3	Abdul Hakim	Minikit	03 Dec 16	04 Feb 17	61	02 May 17	04 May 17	148	150
4	Ejajul Islam	BRRI dhan29	04 Dec 16	03 Feb 17	59	14 May 17	15 May 17	169	170
Thakurgaon									
1	Gojen Roy	BRRI dhan29	09 Dec 16	19 Feb 17	71	15 May 17	16 May 17	155	156
2	Molindra Roy	BRRI dhan28	12 Dec 16	15 Feb 17	64	12 May 17	13 May 17	149	149
3	Dijendra Roy	BRRI dhan29	09 Dec 16	18 Feb 17	70	12 May 17	13 May 17	152	153
Bogura									
1	Md. Amir Hosen	Minikit	09 Dec 16	27 Jan 17	48	27 Apr 17	27 Apr 17	137	137
2	Abdul Latif	Minikit	05 Dec 16	26 Jan 17	51	24 Apr 17	24 Apr 17	136	136
3	Shafiqul Islam	Minikit	10 Dec 16	28 Jan 17	48	27 Apr 17	27 Apr 17	136	136
4	Jabed Ali	Minikit	09 Dec 16	31 Jan 17	52	27 Apr 17	27 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 shows 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 rice 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 varied 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	Anwarul 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	Kajollota	21-Dec-17	1-Feb-18	41	8-May-18	8-May-18	137	137
B-3	Md. Babu Mia	Kajollota	20-Dec-17	2-Feb-18	42	8-May-18	7-May-18	138	137

3.8.2 Water supply for irrigation

Table 3.20 shows the size of plots, the number and amount of irrigation water applied, amount of rainfall received and total water supply 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. 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 results indicate 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 was also less in AWD treatments than the FP. Table 3.20 shows that AWD practice reduced irrigation water supply by 9.7% to 24.2% 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 reduction in irrigation water supply were 16.8, 21.6, 16.8 and 15.0 percent in Rangpur, Pabna, Thakurgaon and Bogura, respectively. This indicates that safe AWD practice can reduce 15-22 percent irrigation water supply compared to farmers' practice. The average reduction 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 shows that amount of total water used for farmers' practice and AWD varied from 589 mm to 1326 mm and from 528 mm to 1147 mm, respectively.

Table 3.20 Water supply 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)		Reduction in water application by AWD (%)
		FP	AWD	FP	AWD	FP	AWD		FP	AWD	
1	BRRI dhan29	10	10	15	13	744	671	248	1,109	1,031	9.7
2	Hybrid Heera	11	14	16	13	881	702	445	1,326	1,147	20.3
3	Hybrid Heera	12	13	13	11	621	481	384	1,005	866	17.6
4	BRRI dhan28	12	13	11	9	768	660	323	1,091	985	22.5
5	Hybrid Heera	8.5	8.5	14	12	768	660	484	1,252	1,145	14.0
Avg.	**Rangpur**			**13.8**	**11.6**	**756**	**635**	**377**	**1,133**	**1,012**	**16.8**
1	Minikit	50	50	16	12	836	665	237	1,073	902	20.4
2	Minikit	17	41	16	12	825	626	283	1,108	909	24.2
3	Minikit	17	40	16	12	868	667	215	1,083	882	23.2
4	BRRI dhan29	33	17	16	12	717	582	283	1,000	865	18.8
Avg.	**Pabna**			**16.0**	**12.0**	**812**	**635**	**328**	**1,066**	**890**	**21.6**
1	BRRI dhan29	25	25	13	11	715	627	209	924	836	12.3
2	BRRI dhan28	15	15	10	8	528	446	188	716	634	15.5
3	BRRI dhan29	25	25	12	9	710	549	209	919	758	22.7
Avg.	**Thakurgaon**			**11.7**	**9.3**	**651**	**541**	**202**	**853**	**743**	**16.8**
1	Minikit	32.8	32.7	10	8	400	341	196	596	538	14.7
2	Minikit	25.3	31.0	10	8	404	332	196	600	528	17.8
3	Minikit	31.4	29.5	11	9	394	335	196	590	531	14.9
4	Minikit	37.9	35.9	10	8	393	343	196	589	539	12.6
Avg.	**Bogura**			**10.3**	**8.3**	**398**	**338**	**196**	**594**	**534**	**15.0**
Avg.	**Overall**			**13.0**	**10.3**	**654**	**537**	**277**	**929**	**811**	**17.6**

Table 3.21 shows the area, number of irrigations applied, depth of irrigation and depth of rainfall received in the demonstration plots for both AWD and FP for 2017-18. The plot sizes for farmer's practice 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 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. In all 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 reduction in irrigation water supply by AWD compared to FP varies from 10 to 21 percent. The reduction was highest in Rangpur followed by Bogura, Thakurgaon and Pabna. The

overall average reduction in irrigation water supply 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 supply reduction was about 23.4% relative to continuous flooding.

Table 3.21 Water supply 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	1,032	931	12.0
R-2	BRRI dhan28	10	20	16	12	807	638	366	1,173	1,004	21.0
R-3	Hybrid Surma	42	32	14	11	728	613	419	1,147	1,032	15.8
Avg.	**Rangpur**	**24**	**22.3**	**15.3**	**12.0**	**794**	**665**	**243**	**1,117**	**989**	**16.2**
P-1	Minikit	33	17	15	13	765	672	236	1,001	908	12.2
P-2	Minikit	50	50	18	15	861	757	236	1,097	993	12.1
P-3	BRRI dhan63	25	30	16	14	795	715	268	1,063	983	10.1
P-4	BRRI dhan28	50	50	16	13	832	721	236	1,068	957	13.4
Avg.	**Pabna**	**41.6**	**43.3**	**16.3**	**13.8**	**813**	**716**	**244**	**1,057**	**960**	**11.9**
T-1	BRRI dhan29	12.5	12.5	10	8	587	502	134	721	636	14.5
T-2	BRRI dhan29	25	25	10	8	564	486	134	698	620	13.7
T-3	BRRI dhan29	50	50	12	10	553	486	134	687	620	12.1
Avg.	**Thakurgaon**	**29.2**	**29.2**	**10.7**	**8.7**	**568**	**491**	**134**	**702**	**625**	**13.4**
B-1	Minikit	31.4	26	11	9	614	514	202	816	716	16.3
B-2	Kajollota	31.6	30.4	11	9	620	522	202	822	724	15.8
B-3	Kajollota	32.8	33.0	11	9	634	543	202	836	745	14.4
Avg.	**Bogura**	**31.9**	**29.8**	**11**	**9**	**623**	**526**	**202**	**825**	**728**	**15.5**
Avg.	**Overall**	**31.8**	**30.1**	**13.5**	**11.1**	**708**	**609**	**227**	**935**	**836**	**14.1**

3.8.3 Water productivity

Table 3.22 shows the grain yield, water productivity under AWD and Farmers' practice which indicates 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 indicates that safe AWD could able to maintain the rice yield at per continuous standing water over the locations. The slightly higher yield for AWD may be due to expansion of roots (Sandhu et al., 2017) and reduction of redundant vegetative growth, improved canopy structure and root growth. It also elevated hormonal levels, in particular increases in abscisic acid levels during soil drying and cytokinin levels during rewatering and enhanced carbon mobilization from vegetative tissues to grain (Yang et al., 2017). AWD also improve rice quality, including reductions in grain arsenic accumulation. With an appropriate nitrogen application rate, it may exert a synergistic effect on grain yield and result in higher WUE and nitrogen use efficiency (Yang et al., 2017). But Bouman and Toung (2001) reported no yield advantage by AWD irrigation though it reduced irrigation water supply and improved the water productivity. On the other hand, lower yield in some AWD plots may be due to inferior weed control compared to Farmers' practice plot.

Table 3.20 also shows that irrespective of trials, the total water productivity (in terms of irrigation water supply) of AWD plots are higher than that of FP plots. The total water productivity for FP ranges from 0.46 to 0.97 kg/m^3 and for AWD practice ranges from 0.51 to 1.25 kg/m^3, respectively (Table 3.22). 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.

There was no change in ET which was reflected from the grain yield data (Tables 3.22 and 3.23). But the reduced irrigation amount in AWD compared with CF comes from the reduced S&P (Maniruzzaman, 2012, Belder et al., 2007, Cabangon et al., 2004).

Maniruzzaman (2012) showed that evapotranspiration decreased by 10 to 15% in AWD compared to CSW. This was mainly due to less evaporation in AWD (22 to 33%) compared to CSW treatment. The differences of evaporation between CSW and AWD were insignificant. There was no change in transpiration, which was reflected from grain yield data (Figure 3.8). This suggests that ET is not significantly reduced by AWD and these findings are in consistent with those presented in existing literature (Belder et al., 2007; Cabangon et al., 2004). The S&P losses in AWD treatment was reduced by 19 to 26% as compared to CSW. Lower S&P in AWD largely contributed to the reduced amount of total water input for rice cultivation.

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 1,033 to 2,176 lit/kg and for AWD ranges from 803 to 1,950 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/m³)		Reverse water productivity (lit/kg)	
		FP	AWD	FP	AWD		FP	AWD	FP	AWD
1	BRRI dhan29	1,109	1,031	6.67	6.79	1.85	0.60	0.66	1,663	1,517
2	Hybrid Heera	1,326	1,147	6.96	7.06	1.38	0.53	0.62	1,904	1,625
3	Hybrid Heera	1,005	866	5.97	6.04	1.22	0.59	0.70	1,684	1,432
4	BRRI dhan28	1,091	985	5.43	5.51	1.40	0.50	0.56	2,008	1,787
5	Hybrid Heera	1,252	1,145	5.75	5.87	2.02	0.46	0.51	2,176	1,950
Avg.	**Rangpur**	**1,133**	**1,012**	**6.16**	**6.25**	**1.57**	**0.54**	**0.61**	**1,867**	**1,642**
1	Minikit	1,073	902	6.97	7.11	2.13	0.65	0.79	1,541	1,268
2	Minikit	1,108	909	6.97	6.57	-5.84	0.63	0.72	1,589	1,384
3	Minikit	1,083	882	6.68	6.79	1.63	0.62	0.77	1,620	1,298
4	BRRI dhan29	1,000	865	7.19	7.26	1.10	0.72	0.84	1,391	1,191
Avg.	**Pabna**	**1,066**	**890**	**6.95**	**6.93**	**-0.25**	**0.65**	**0.78**	**1,530**	**1,282**
1	BRRI dhan29	924	836	8.50	8.69	2.33	0.92	1.04	1,087	962
2	BRRI dhan28	716	634	5.60	6.18	10.29	0.78	0.97	1,279	1,027
3	BRRI dhan29	919	758	8.89	9.44	6.11	0.97	1.25	1,033	803
Avg.	**Thakurgaon**	**853**	**743**	**7.66**	**8.10**	**6.24**	**0.89**	**1.09**	**1,124**	**920**
1	Minikit	596	538	4.52	4.83	6.99	0.76	0.90	1,320	1,112
2	Minikit	600	528	4.88	5.10	4.46	0.81	0.97	1,230	1,036
3	Minikit	590	531	4.33	4.19	-3.24	0.73	0.79	1,364	1,269
4	Minikit	589	539	4.43	4.61	4.02	0.75	0.85	1,328	1,170
Avg.	**Bogura**	**594**	**534**	**4.54**	**4.68**	**3.06**	**0.76**	**0.88**	**1,309**	**1,140**
Avg.	**Overall**	**929**	**811**	**6.33**	**6.49**	**2.37**	**0.69**	**0.81**	**1,514**	**1,302**

Table 3.23 shows the comparative yield performance of the demonstrations under AWD and FP along with respective total water productivity and reverse water productivity for 2017-18. 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. 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. This indicated that yield reduction is not the main concern of AWD technology adoption in farmers field.

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 1.1 kg/m^3 and 1.28 kg/m^3, respectively. The lowest water productivity for FP and AWD were 0.55 kg/m^3 and 0.60 kg/m^3, respectively. The average water productivity for FP and AWD were 0.73 kg/m^3 and 0.83 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. Table 3.23 also indicates that maximum water needed to produce 1 kg of rice under FP and AWD practice were 1,836 lit and 1,689 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 rice under FP and AWD were 1,475 and 1,293 litres, respectively.

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	1,032	931	6.18	6.26	1.3	0.60	0.67	1,671	1,488
R-2	BRRI dhan28	1,173	1,004	6.42	6.92	7.8	0.56	0.69	1,827	1,452
R-3	Hybrid Surma	1,147	1,032	6.59	6.33	-3.9	0.57	0.61	1,741	1,631
Avg.	**Rangpur**	**1,117**	**989**	**6.40**	**6.50**	**1.6**	**0.57**	**0.66**	**1,746**	**1,523**
P-1	Minikit	1,001	908	5.99	5.96	-0.5	0.60	0.66	1,671	1,524
P-2	Minikit	1,097	993	5.98	5.95	-0.5	0.55	0.60	1,836	1,669
P-3	BRRI dhan63	1,063	983	6.32	6.09	-3.6	0.60	0.62	1,681	1,613
P-4	BRRI dhan28	1,068	957	5.83	5.98	2.6	0.55	0.62	1,833	1,601
Avg.	**Pabna**	**1,057**	**960**	**6.03**	**6.00**	**-0.5**	**0.57**	**0.63**	**1,755**	**1,602**
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**	**625**	**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	1,365	1,108
B-2	Kajollota	822	724	6.25	6.83	9.3	0.76	0.94	1,315	1,061
B-3	Kajollota	836	745	5.72	5.99	4.7	0.68	0.80	1,461	1,244
Avg.	**Bogura**	**825**	**728**	**5.98**	**6.43**	**7.5**	**0.73**	**0.88**	**1,380**	**1,138**
Avg.	**Overall**	**935**	**836**	**6.47**	**6.62**	**2.3**	**0.73**	**0.83**	**1,475**	**1,293**

Table 3.24 shows the statistical analysis of the experimental results. The mean yield for AWD was slightly higher than the FP for both years. There was no significant difference between the mean grain yield under AWD and FP for both years. But the mean amount of irrigation applied for AWD was significantly lower than that for FP. But there was no significant difference found in total water (irrigation supply + rainfall) 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

Economic analysis

The study findings revealed that average water supply was 824 mm in AWD and 932 mm in FP and average water supply reduction was 16% (calculation based on Table 3.20 and 3.21). It also indicated that reduction in water supply by AWD was about 108 mm. The lower amount of water withdrawal from groundwater reserve also reduce the pumping cost as well the irrigation cost of the farmers. Based on the average discharge of the pumps (15.5 lps), to irrigate 108 mm water per hectare of land it required 12 hours. On an average STW consumed 1 litre of diesel per hour and accordingly polythene pipe irrigation reduced 12 litre of diesel fuel, which cost is about BDT 780 (diesel cost @ BDT 65/lit.). Most of the cases farmers reported that AWD increase the weed pressure and about 2-3 extra labour needed for weeding per hectare of land and it may need extra cost of about 600-900 BDT. But, Maniruzzaman (2012) reported that proper herbicide application with one hand weeding could successfully control the weed pressure with less cost. In crop sharing water pricing system, farmers have no direct benefit from AWD technology, for that reason farmers are reluctant to adopt this. However, in volumetric water pricing system, farmers are benefited in this technology. Moreover, in crop sharing system, pump owner is benefited to adopt this technology by less pumping as well as less fuel used.

3.9 Environmental impact of water saving technologies

Considering this water reduction in water supply and pump discharge by AWD about 12 liters diesel fuel was saved per hectare of land irrigation. On the other hand, if we considered the polythene pipe water distribution system was introduced, which reduced about 32 liters diesel fuel for irrigation of per hectare land. To consider the combined effect of polythene pipe and AWD water management, per hectare fuel reduced was about 44 liters, which is equivalent to 440 kg CO_2 emission (Haque et al., 2017). 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 (Haque et al., 2016 and 2017; Wassman et al., 2010; Yagi et al., 1996; Lu et al., 2000). Through midseason 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).

3.10 Farmers perceptions about technologies and management

Farmers' group discussion (FGD) was conducted with key informant farmers (KIF) to delineate their perceptions about potential and existing technologies, management and purpose of adopting different rice cultivars. An FGD was conducted with 12-15 KIF in each trial village of Mithapukur and Badargonj Sub-Districts in Rangpur District and Sadar Sub-District in Thakurgaon District.

Farmers' observation about AWD

Farmers in group discussion said that AWD gives higher yield (0.4-0.5 t/ha) than that of traditional practice. Besides, infestation of sheath blight and sheath rot is few under AWD irrigation system. Additionally, it reduces cost of fuel per hectare BDT 1,600-1,900 and environment friendly (less extraction of underground water). Farmers in the group discussion said that some neighboring farmers are been interested to adapt the AWD irrigation system through observing its benefits. However, farmers in group discussion reported that key constrains of large-scale dissemination of AWD method is that higher infestation of weeds, botheration of frequent monitoring moisture level of rice fields but farmers are to pay same amount for irrigation in per unit area under electricity operated pumps for traditional and AWD methods. Additionally, farmers have lack of knowledge about the technology as they perceived that application of limited irrigations may reduce yield. Farmers perceived that providing training to farmers on AWD method and arrangement of a field day for showing better performance of rice crops under AWD could alleviate farmers perceived adverse consequences of the technology and motivate for adoption.

Some farmers in Thakurgaon said that AWD method is not so suitable for areas with clay soil where crack is formed immediately after drying the soil because physiologically, they unable to bear that their rice fields is been cracked. Addition cost for herbicides and manual weeding per hectare is about BDT 1,000 -1,200 but save cost of fuel per hectare about BDT 800-1,000. Additionally, AWD give per hectare 0.4 – 0.6 tons higher yield than that of traditional system. Although it does not take longer hour even for closely monitoring the fields to assess the threshold moisture level for irrigation application. However, farmers feel botheration of frequently visiting fields observing moisture level. On the other hand, farmers supposed that performance of rice crops will not be satisfactory until and unless water remain stagnant in the fields up until the grain filling stage.

Farmers' observation about plastic hose for irrigation

Farmers in group discussion said that there is no operation loss of irrigation water through leakage and percolation under plastic hope irrigation as traditional system under earthen drainage. However, cost of saving from loss of irrigation water does not compensate the cost of plastic hose (mostly last for a year) and needed operator for moving the hose from fields to fields. Therefore, pump owners are not much interested to use plastic hose for irrigation.

Farmers' observation about check valve

Farmers is group discussion said that check valve facilitate to available water in tubewell of pump so that alleviate an arduous of operation of manually pumping tubewell for up taking water from underground before starting pumps. Additionally, it is less costly and ensure availability of water in tubewell for continued pumping of water during operating period of the pump. However, before introducing check valve, sometimes pumps would operate without producing water if water from the tubewell would go down because of leakage of earthen plaster. Therefore, not only the fuel would wastage but also would damage the pump for operating longer hours without producing water. Thus, most pumps irrespective of fuel types (diesel or electricity) introduced check valve. However, most farmers have lack of knowledge about proper method of usages of check valve and some are not aware of benefit of the tools as well. Therefore, providing training on technique of using the tool and arranging a field day of showing its advantages could to motivate farmers for large scale dissemination.

4. Conclusions and Recommendations

a. Conclusions:

- Use of polythene pipe irrigation water distribution system was found effective in minimizing conveyance loss of irrigation water. It may reduce water supply by 20-25% and also saves irrigation time by 25%. Thickness of polythene pipe should be used 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’ choice of the variety depends upon the yield, grain quality, growth duration and price of local market.

- AWD technique for irrigation scheduling was found effective for reduction in irrigation water supply by about 14-18% in Boro rice cultivation. Mass adoption of this technology by the farmers will reduce significant amount of irrigation water pumping and fuel use. It will also reduce the greenhouse gas emission.

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 this technology.

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