Bangladesh Rice J. 25 (2) : 1-10, 2021, doi.org/10.3329/brj.v25i2.62702

Low-Cost Solar Pump Irrigation System for Irrigated Rice Production

P K Kundu[1*], P L C Paul[2], M B Hossain[2], D Roy[2], M N H Mahmud[2], M S Yesmin[2] and M T Islam[3]

ABSTRACT

Irrigation pumps operated by diesel and electricity are commonly used for irrigated rice cultivation, but fuel cost expansion and doubtful accessibility of power hampers the continuous irrigation. A solar pump would be an alternative option for irrigation to contribute in expanding rice production and food security to the growing population. Field experiments were conducted at Bangladesh Rice Research Institute, Gazipur, farm during Boro season from January – May in 2015, 2016 and 2017, respectively to determine the economic feasibility of a low cost 1.5 Horsepower (hp) capacity solar irrigation pump for rice cultivation. BRRI dhan63 was tested under four irrigation treatments as flood irrigation (continuous standing water at 7 cm depth above the soil surface), 3 cm irrigation at saturation level, 3 cm irrigation in AWD (alternate wetting and drying) practice, and 5 cm irrigation in AWD practice. The CROPWAT 8.0 model was used to ascertain crop water requirement (CWR) and irrigation requirement of each rice growth phase in each year using weather data. In 3 cm irrigation in AWD practice, about 1.0 ha of paddy field can be irrigated with the 1.5 hp solar pump without any or a few water deficits in reproductive and ripening phases. In both years, rice yield did not differ among the irrigation treatments. The benefit-cost ratio was 1.09, 1.18 and 1.02 for Aman, mustard and Boro season respectively. A 1.5 hp solar pump is the best feasible when it is used year-round for three or more crops. Although solar pump irrigation system involved higher initial cost, it was found economically sound and environment friendly. Thus, proper policy support is required to encourage solar power utilization for irrigation.

Key words: Solar irrigation pump; rice cultivation; benefit-cost ratio; renewable energy; water requirement

INTRODUCTION

Bangladesh's economy is profoundly reliant upon agriculture, especially rice production (Islam *et al.*, 2017; Kabir *et al.*, 2015). Rice is a primary staple food of about 160 million individuals in Bangladesh. It contributes about 48% of rural employment and 66% of the complete calorie supply of a normal individual in the country. Rice is grown in about 75% of the total cropped area and 80% of total irrigated area of Bangladesh. Boro rice (dry season rice) is one of the major contributors to the total rice production in Bangladesh, which is fully irrigated. Therefore, irrigation is most crucial for Boro rice cultivation. Fossil fuel is intensively used to supply the energy for operating the irrigation pumps. However, the supply of energy is interrupted because of increasing costs and unavailability of fuel.

Bangladesh's primary energy consumption expanded to almost 28.2 million tons' oil equivalents (metric ton) in 2014 (Halder, 2016), which has become higher in recent years. The energy interest of the nation is increasing surprisingly because of fast change in the economy and industrialization. For reducing the global warming and also fulfilling the energy need, many countries are now considering sustainable energy sources from solar and wind (Islam *et al.*, 2014). Solar energy is the energy that derived directly from the sun.

Geographically, solar energy is sufficiently available in Bangladesh with a range of average solar radiation in between 4 and 6.5kW/m^2/day, which can be utilized for agricultural production (Islam *et al.*, 2017; Hossain *et al.*, 2015). In Bangladesh, over 17.5

[1]Scientific Officer; [2]Senior Scientific Officer; [3]Chief Scientific Officer; Irrigation and Water Management Division, Bangladesh Rice Research Institute, Gazipur 1701.
[*]Corresponding author's E-mail: kundu22_bau@yahoo.com (P K Kundu)

lakhs irrigation pumps are being utilized from which 82% are diesel engine operated and 18% are electricity operated (Islam *et al*., 2019; Islam *et al*., 2017). Every year, the government of Bangladesh provides a subsidy to keep the diesel price lower. This creates extra pressure on the economy. Thus, to overcome the economic pressure and increasing rice production, solar irrigation system is a possible alternative option (Islam *et al*., 2017). It is necessary to ensure food security, especially Boro rice production (about 54% of total rice production of Bangladesh), should not be hampered (Kabir *et al*., 2020). A solar-powered pumping system primarily has greater expenses than diesel or electric controlled pump, yet it needs very low maintenance and labour cost. Considering the long term benefits (20 years' period), a solar pump can be effective and an alternative choice for limited scope of water application for crop cultivation. Due to limited fossil fuel on the earth, many countries have started to produce electricity from renewable energy. Bangladesh Government has additionally intended to deliver 5% of total electricity production by 2015 and 10% by 2020 from sustainable power sources like air, waste and solar (Karmaker *et al*., 2020). Some government and non-government institutions have already installed solar pump in different areas of Bangladesh for irrigation and other purposes.

In Bangladesh, the limit of solar pumps fluctuated from 300 to 1,190 watt-peak (Wp) and discharge rate differed from 2,000 to 800,000 l/day (Hossain *et al*., 2015). The solar pump can be used to withdraw both surface and groundwater, which is able to pump up to 2000 gallons/minute (Tietjen *et al*., 2008). In Bangladesh, only 60% areas are covered by irrigation but a huge scope is available to extend te area especially in coastal, hilly and charland areas by using solar power. For increasing agricultural production and fulfilling the sustainable development goal (SDG) 7.2, i.e., increase substantially the share of renewable energy, solar irrigation pumps can be used for improving crop production through increasing irrigated areas. Currently, the available solar pumps are large in size, installation and maintenance costs are too high that are hard to afford for farmers. Hence, a low-cost solar pump would be feasible for marginal farmers if they grow both rice and non-rice crops. In this context, a study was undertaken to evaluate the economic performance of a 1.5 hp low cost solar pump for Boro rice cultivation under different irrigation regimes.

METHODOLOGY

Experimental site

Field experiments were conducted at Bangladesh Rice Research Institute (BRRI), Gazipur research farm, which is located between $23^{0}59'$ N and $90^{0}24'$ E (Fig. 1) and the elevation is 34 m above sea level. The soil type of the site is clay loam (Paul *et al*., 2013). The seasonal (December- May) average maximum and minimum temperatures of this area are 30.6 ^{0}C and 18.3 ^{0}C, respectively, and the average seasonal (December- May) rainfall is 310 mm (Hossain *et al*., 2021).

Set up and component of solar pumping system

The solar pump system consists of the panels, supporting structure with a tracking mechanism, electronic parts for regulation, cables accessories, pipes, and the pump itself. Solar panels or modules were the main forces driving the solar pump, which used the sunlight to produce electricity. Eight solar panels, size of 1 × 1.5 m^2 each connected in arrays, produce 1600 watt (W) DC (direct current) energy. A 1.1 KW AC 3-phase submersible pump was connected with a pump controller using cables. A pump controller was connected to convert DC from the solar array into AC (alternative current) for

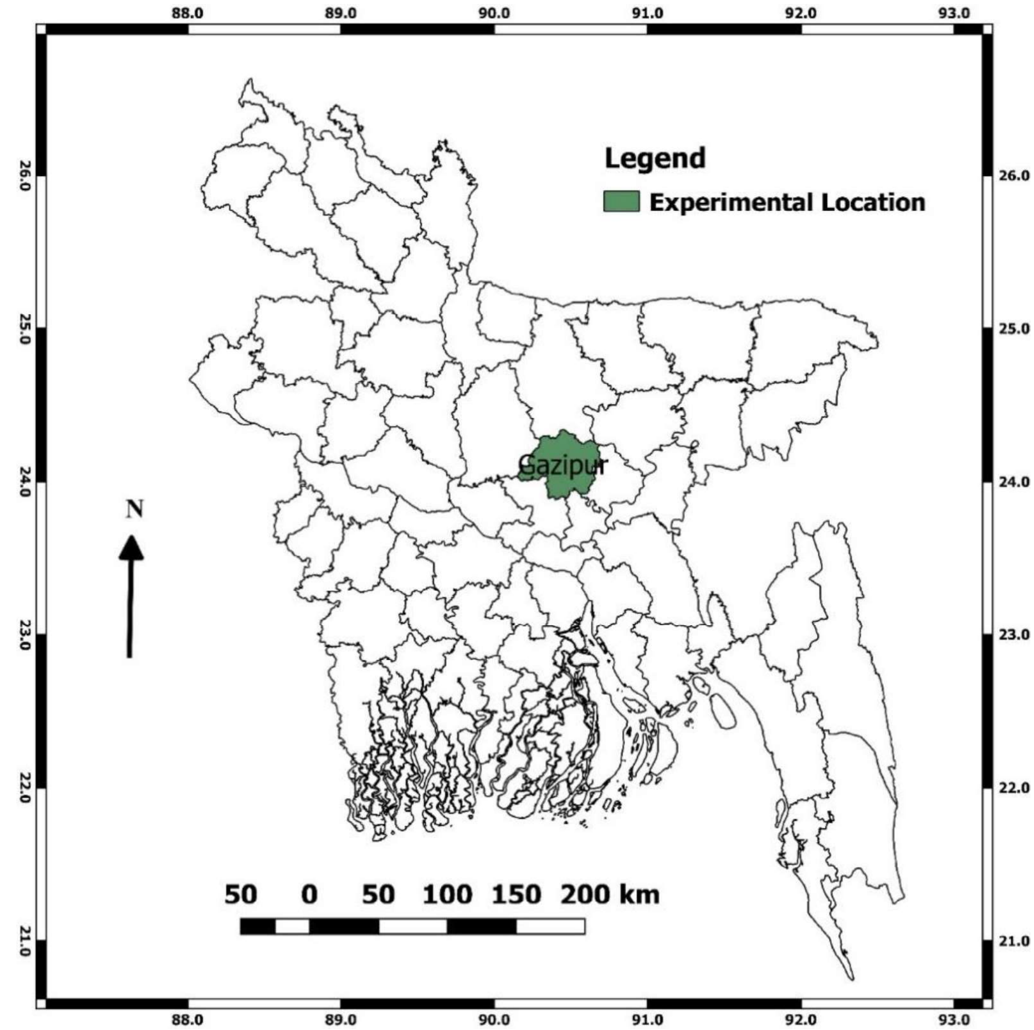

Fig. 1. Location of the experiment.

driving the pump, which regulates the output frequency according to irradiation in real-time to achieve the maximum power. For any low or high voltage and over the current situation, the pump controller controlled the pump and motor. A set of appropriate size cables were connected with junction boxes, switches, and motor to run the pump. The supporting structure (concrete base) and tracking mechanism were fixed with the solar system for the stability of solar panels and protecting them from theft or natural calamities. Both manual and the auto-tracking systems were used for the maximum output. The manual system produced less energy than auto-tracking. For obtaining the maximum output of energy, the panels were set along the direction to face the sun as it moved across the sky and increased the output of discharge. A submersible pump of 1.5 hp capacity was installed for testing discharge output and irrigated area coverage. The delivery pipe diameter was 50 mm and the discharge head was 4-5 m. Data were collected, including voltage and current of each panel, hourly and daily discharge of the pump, rice irrigation amount and yield components. A flow meter was connected between delivery pipes to measure the water volume.

Solar radiation and pump discharge

Solar radiation (W/m^2) and discharge (m^3/hr) was measured at a regular interval from dawn to dusk in each year. Hourly discharge (m^3/hr) was recorded in April 2015, 2016, and 2017 to see the variation of discharge with radiation. The maximum and average discharge during the dry period from January to June in 2015, 2016, 2017, was also measured. The measured solar pump discharge was adjusted with the irrigation requirement for rice cultivation in each growing season.

Treatments and crop management

The solar pump was operated for the Boro rice cultivation in four irrigation treatments during 2014-15, 2015-16 and 2016-17 growing seasons. The treatments were: T_1 = Flood irrigation (continuous standing water at 7 cm above the soil surface), T_2 = 3 cm irrigation at saturation level, T_3 = 3 cm irrigation in AWD (alternate wetting and drying), and T_4 = 5 cm irrigation in AWD. The rice cultivar was BRRI dhan63. Forty-day-old seedling was transplanted on 19 December 2014, 22 December 2015 and 23 December 2016. The experiment was carried out by randomized complete block design (RCBD) with three replications. The fertilizer rate was 258 kg urea-100 kg TSP-120 kg MOP-112 kg, zypsum-11 kg zinc per hectare (BRRI, 2020). All fertilizers except urea were applied during land preparation. Urea was used at three splits at 15, 30 and 45 DAT. Weeding and other cultural practices were followed BRRI guidelines. To practice AWD, perforated PVC pipe was installed ten days after transplanting in each plot. Paddy was harvested on 01 May 2015, 03 May 2016 and 05 May 2017, respectively. In each plot, sample crop from 6 m^2 area was harvested to calculate the final yield adjusted at 14% moisture content (w/w).

Estimation of irrigation requirement

Crop water requirement (CWR) is the amount of water that plant uptake through rooting system to meet water loss by evapotranspiration and maintain plant growth and development. CWR can be calculated by the following equation (Michael, 1974).

$$\mathrm{CWR} = \sum(\mathrm{ET_o} \times \mathrm{k_c}) \quad \text{(i)}$$

Where CWR = crop water requirements in mm, ET_0 = reference crop evapotranspiration (mm) and k_c = crop coefficient. The daily maximum and minimum air temperature, relative humidity, wind speed, sunshine hour, daily rainfall during the growing period were collected from Plant Physiology Division, BRRI, Gazipur. The Penman-Monteith method is used to calculate the reference crop evapotranspiration using the following equation

$$\mathrm{ET_0} = \frac{0.0408\,\Delta\,(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)} \quad \text{(ii)}$$

Where, ET_0 = reference crop evapotranspiration (mm d^{-1}); R_n = net radiation at the crop surface (MJ $m^{-2}d^{-1}$); G = soil heat flux (MJ $m^{-2}d^{-1}$); T = average air temperature (°C); U_2 = wind speed measured at 2 m height (m s^{-1}); (e_s−e_a) = vapor pressure deficit (kPa); Δ = slope of the vapor pressure curve (kPa °C^{-1}); γ = psychometric constant (kPa °C^{-1}) and 900 conversion factor. Irrigation requirement (IR) was calculated according to FAO (2009) as:

$$\mathrm{IR} = \sum(\mathrm{ET_c} - \mathrm{P_{effective}}) \quad \text{(iii)}$$

Where, IR = irrigation requirement (mm), ET_c = crop evapotranspiration in mm, and $P_{effective}$ = effective rainfall in mm.

Effective rainfall is the part of total annual or seasonal rainfall that is directly or indirectly useful for crop production (Dastane, 1972). The effective rainfall was calculated using the soil conservation service method (Geleta, 2019) is given below:

$$\mathrm{P_{effective}} = \mathrm{P} * \frac{(125 - 0.2\,\mathrm{P})}{125} \text{ For P<250 mm} \quad \text{(iv)}$$

$$\mathrm{P_{effective}} = 125 + 0.1\,\mathrm{P} \text{ For P>250 mm} \quad \text{(v)}$$

Where, $P_{effective}$ = effective rainfall (mm) and P = monthly rainfall (mm)

Economic analysis

The installed solar pump only tested for Boro rice cultivation. However, there is a possibility to use the solar pump for irrigation in the Aman and Rabi season. If we consider Aman (15 July-15 October) – Mustard (25 October-10 January) – Boro (15 January- 30 May) cropping pattern, then the whole year can be irrigated by solar pump. We calculated the benefit-cost ratio for Boro rice and year-round crops (considered the rice equivalent yield). Total cost of solar pump was the summation of fixed cost and the variable cost. The variable cost included the total annual depreciation due to use and time, interest on capital cost, repair and maintenance. Solar pump life was assumed to be 20 years. The annual interest rate was normally 14% of the capital price of the pump. The variable cost was the total of input and operating cost. Variable cost depended on some factors. If a farmer had his own land and machinery to cultivate the land, then the variable cost would be lower than the other farmers.

Statistical analysis

Analysis of variance (ANOVA) among the irrigation treatments was regulated by using the STAR software. The comparison of means was tested using the least significance difference (LSD) at the 95% confidence level.

RESULTS AND DISCUSSION

Relationship between solar pump discharge and radiation

Pump discharge was positively correlated with solar radiation (Fig. 2). Pump discharge increased with increasing solar radiation. Pump discharge increased from 2 m^3/hr at 100 W/m^2 radiation to 11 m^3/hr at 1000 W/m^2 radiation. Manar *et al.*, (2019) also found the same result in their research.

Variation of the pump discharge

In each year, the pump discharge was monitored from dawn to dusk in April. Pump discharge was low in the morning, below 7 m^3/hr until 9 am (Fig. 3). Pump discharge increased with the increase the sunshine hour. The highest discharge was recorded at noon at 12 pm. After that, discharge decreased gradually until of the evening at 6 pm. The reason for higher pump

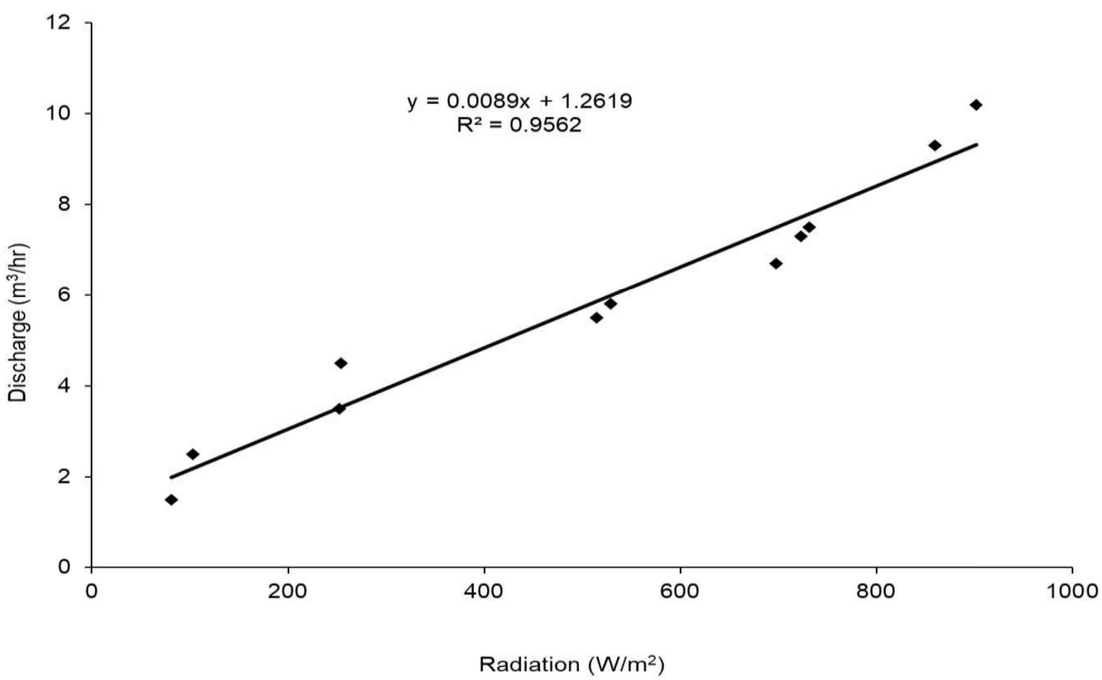

Fig. 2. Relationship between pump discharge and solar radiation.

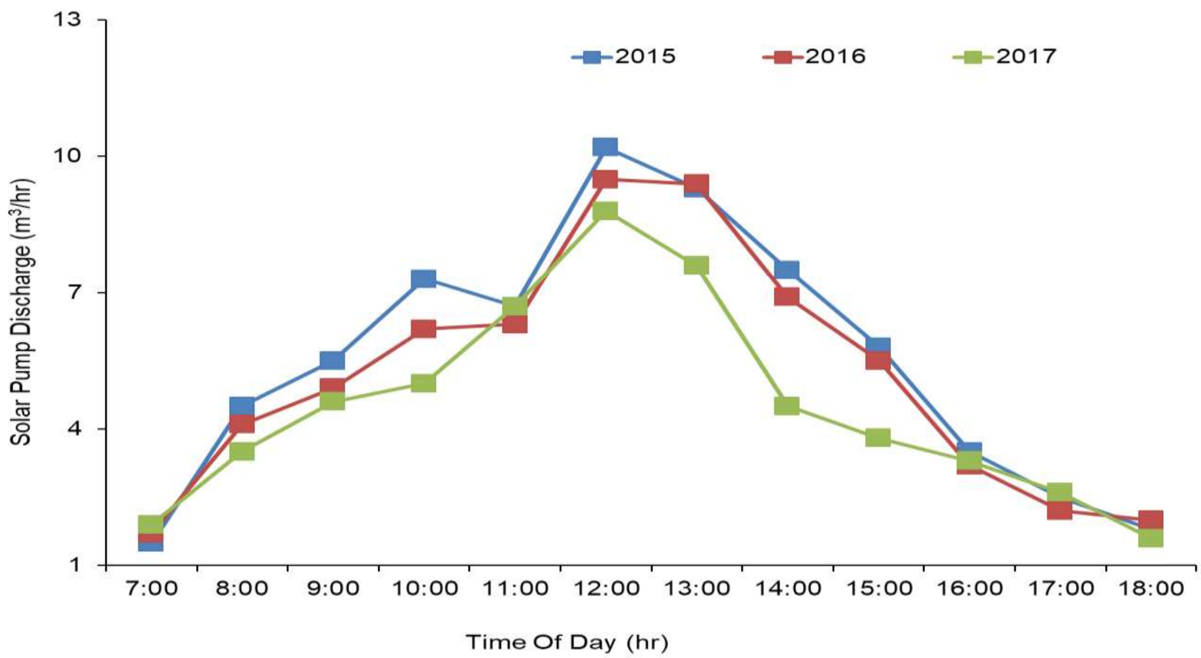

Fig. 3. Variation of pump discharge at different times of a day.

discharge at noon (12 pm) might be the sun location that was the closest to the earth during mid of the day and hence more radiation were obtained. Hossain *et a*l., (2014) conducted an experiment on a solar pump irrigation system for different crops in different regions of Bangladesh and found the same discharge trends over time. Benghanem *et al*., (2018) and Tiwari and Kalamkar (2018) also found that discharge rate was higher at noon at 12:00 pm and lower at afternoon. However, Benghanem *et al*., (2018) estimated the daily flow rate of solar powered photovoltaic water pumping systems, and they showed that discharge rate was lower at noon than afternoon because of the cloudiness.

Monthly pump discharge during the Boro season

During the Boro season, monthly (January-June) pump discharge was recorded (Figure 4) where the average discharge varied from 62 m^3/day to 40 m^3/day in 2015, 58 m^3/day to 40 m^3/day during 2016 and 2017. The maximum discharge was 68 m^3/day, 64 m^3/day and 63 m^3/day in March 2015, April 2015; March 2016; March 2017, and June 2017 respectively. The lowest discharge was 45 m^3/day, 53 m^3/day and 55.6 m^3/day in June, May and June in 2015, 2016 and 2017 respectively. The variation of discharge in the different months was related to the variation of day length, sunshine hour and radiation (Manar *et al*., 2019). In the current study, even though the day length was longer in May and June in 2015, the discharge rate was lower due to less sunshine hour.

Irrigation water requirement and pump discharge for different irrigation treatments during the Boro season

For every month (January-April) of Boro season irrigation water requirement was measured by CROPWAT (version 8.0) software. It was observed that during land preparation in January, irrigation requirement was higher than solar pump discharge in each irrigation treatment in every year (Figure 5). For the treatment T_1 (flood irrigation), pump discharge was deficit only in February about 53.3 mm, 66.6 mm, and 62.2 mm than the irrigation requirement in 2015, 2016 and 2017

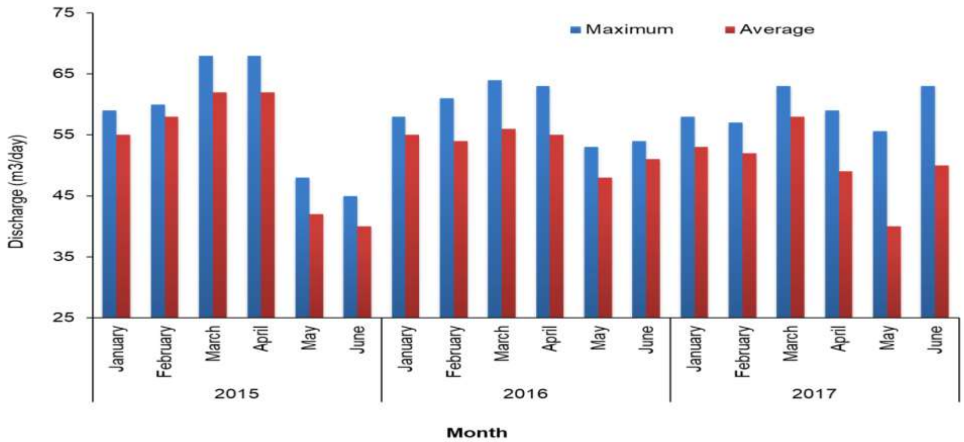

Fig. 4. Monthly average and maximum discharge of solar pump during 2015-2017.

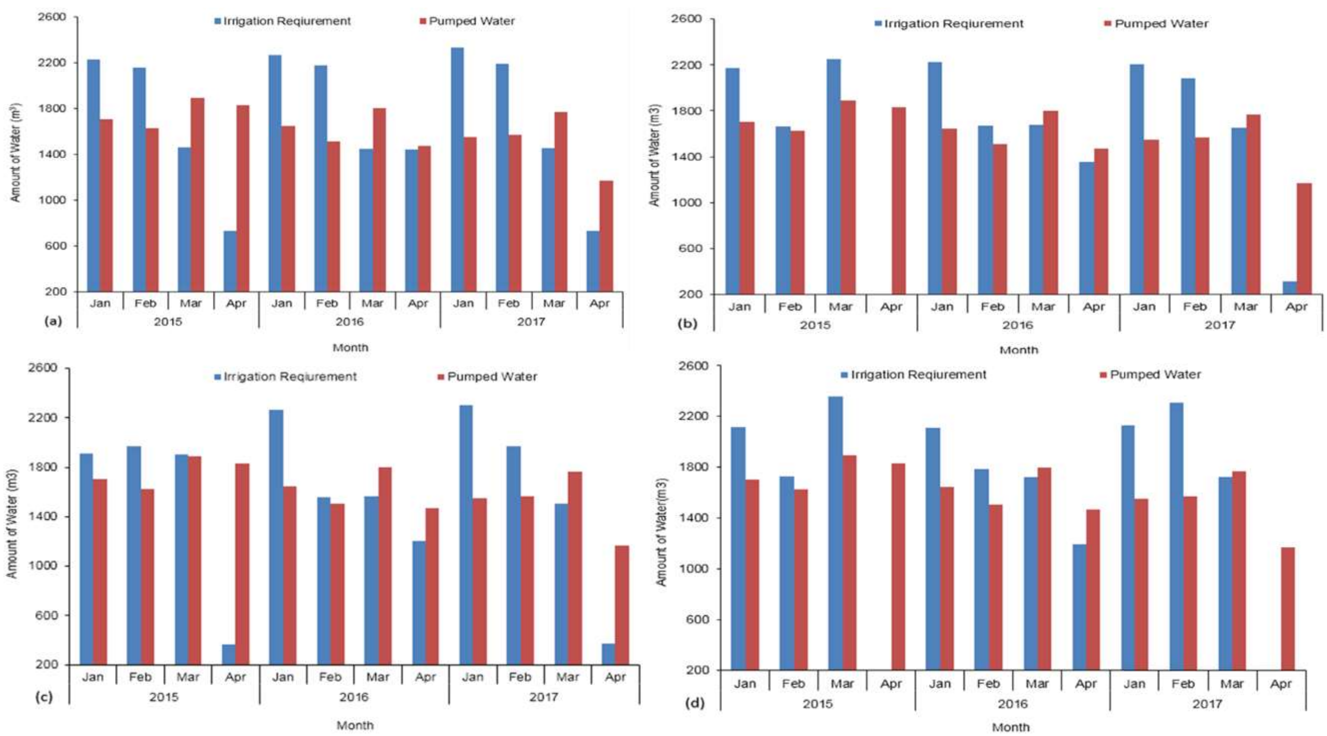

Fig. 5. Monthly irrigation requirement and solar pump discharge at different treatments (a) flood irrigation, (b) irrigation at saturation level (3 cm) (c) irrigation in AWD (3 cm) and (d) irrigation in AWD (5 cm) for Boro rice in 2015-2017.

respectively, considering one hectare of cultivable area. However, pump discharge was surplus for March and April. Similarly, for the treatment T_2 (3 cm irrigation at saturation) irrigation requirement (IR) did not meet up by about 36 mm in March, 16 mm in February, and 51.3 mm in Feb in 2015, 2016 and 2017 respectively. Water pumping in February and March was slightly lower than the required irrigation. Irrigation water deficit was same in February for the treatment T_3 (3 cm AWD) and T_4 (5 cm AWD). Therefore, by practicing flood irrigation and irrigation at 3 cm at saturation level, the total cultivable land was less than one hectare because of the insufficient irrigation water by 1.5 hp solar pump (1600 solar energy). But for the AWD practices, water requirement was almost the same or lowered than the pumped water. In that case, a designed 1.5 hp solar pump could cultivate one hectare of land without any alternative source of pumping. It was observed that, January and February in each year was the critical time for the solar pump irrigation due to lower discharge compared to crop demand. However, during the reproductive and ripening phases (March and April) there was no or minimal water shortage for the irrigation requirement (Fig. 5).

Yield of rice in different irrigation treatments

Table 1 presents The mean yield of BRRI dhan63 under four irrigation treatments. Yield did not get any significant difference among the irrigation treatments. The maximum yield was 5.4 t/ha, 5.8 t/ha, and 5.9 t/ha in 2015, 2016 and 2017, respectively. The lowest yield was 4.9 t/ha, 5.3 t/ha, and 5.5 t/ha in 2015, 2016 and 2017 respectively. In 2015, the yield was comparatively lower than in 2016 and 2017 (the optimum yield was 6.5 t/ha), because the land was reclaimed just before the experiment setup. The water depletion up to 15 cm below the soil surface (T_3) saved the irrigation water and there was no yield reduction. Therefore, for increasing the irrigation area and maintained the yield potential, AWD practice (applied 3 cm water when water goes to 15 cm below the soil surface) could be practiced. Previous studies also showed that AWD practice reduced irrigation water and had similar yield with continuous standing water.

Economic analysis of the solar system

Table 2 shows the benefits of solar pump for rice cultivation as well as non-rice crops. The initial cost of the solar pump including

Table 1. Yield of BRRI dhan63 under four irrigation treatments in 2015-2017.

Treatment	Year 2015 Mean yield (t/ha)	 2016 Mean yield (t/ha)	 2017 Mean yield (t/ha)
T_1 = Flood irrigation (7 cm)	5.4	5.8	5.9
T_2 = 3 cm irrigation at saturation level	5.2	5.6	5.6
T_3 = 3 cm irrigation in AWD	5	5.5	5.8
T_4 = 5 cm irrigation in AWD	4.9	5.3	5.5
LSD	NS*	NS	NS

*NS indicates non-significant

Table 2. Economic analysis of solar pump for round the year (rice and non-rice crops).

Cost and return (Tk/ha)	Aman	Mustard	Boro
1. Variable cost			
I. Input cost (Seed, fertilizer, herbicide, insecticide, labour cost etc)	15500	23800	19300
II. Labor cost	35000	25000	42000
III. Repair	2000	1000	2000
IV. Depreciation	5830	4380	7290
V. Interest	8200	6125	10210
Total	66530	60305	80800
2. Fixed cost			
I. Land rent	40000	20000	40000
Total cost (Fixed + Variable)	106530	80305	120800
REY	5300	4500	5800
Price (Tk./kg)	20	20	20
Return from paddy (Tk./ha)	106000	90000	116000
Return from Straw (Tk./ha)	10500	5000	7500
Gross return (Tk./ha)	116500	95000	123500
BCR	1.09	1.18	1.02
Gross margin(Tk.)	49970	34695	42700

installation was BDT 3,50,000 and the expected service life was considered 20 years. Command areas of 1.5 hp solar pump for Boro rice cultivation was one hectare. After Boro season, solar pump can be used for Aman rice and Rabi crops (i.e., Mustard). So, the benefit-cost was calculated considering one-hectare command areas for Boro, Aman and Mustard. In this experiment, variable cost was measured by summarizing the items such as seed, fertilizer, herbicide, insecticide, labour cost and land preparation cost, depreciation cost of solar pump, interest on solar pump investment, repair, and maintenance. Land rent was considered as fixed cost throughout the season. After calculating gross return and total cost, the benefit cost ratio was found 1.09 for aman season, 1.18 for mustard and 1.02 for Boro season.

CONCLUSION

A 1.1 KW solar power irrigation system is suitable for Aman-Mustard-Boro cropping pattern. During Boro season, applying AWD practice increases the command area of solar pump. The input cost was higher for solar pump but maintenance cost was comparatively low. So, solar pump irrigation system could be an option to minimize the energy consumption and fuel cost for irrigation purpose in the long run. We need to modify the existing system so that we can use it to irrigate crop land in a mass scale by groundwater and surface water. Solar pump is technically and economically feasible to supply power for irrigation in crop production throughout the years. Government subsidy is initially required for installing solar power pump to the farmers' level for popularizing and utilizing solar power in agricultural production.

ACKNOWLEDGEMENT

The authors are thankful to Bangladesh Rice Research Institute authority for funding this research through Irrigation and Water Management Division. Authors also gave much appreciation to ALAWRM (Agricultural Land and Water Resources Management) Research group for directing and guiding during experimentation, data analysis, and manuscript writing.

REFERENCES

Benghanem, M, K O Daffallah and A Almohammedi. 2018. Estimation of daily flow rate of photovoltaic water pumping systems using solar radiation data. *Results in Physics*, *8*, 949-954. DOI: 10.1016/j.rinp.2018.01.022

BRRI (Bangladesh Rice Research Institute). 2020. Adhunik Dhaner Chash (Modern Rice Cultivation), 23rd special edition. Bangladesh Rice Research Institute, Gazipur 1701, Bangladesh (in Bangla)

Dastane, N. 1972. A practical manual for water use research in agriculture. Navabharat Prakashans.

FAO, (Food and Agriculture Organization). 2009. CROPWAT Software, Food and Agriculture Organization, Land and Water Division; Available at: http://www.fao.org/nr/water/infores_databases_cropwat.html.

Geleta, C D. 2019. Effect of first watering month on water requirement of sugarcane using CROPWAT Model in Finchaa Valley, Ethiopia. *International Journal of Water Resources and Environmental Engineering*, *11*(1), 14-23. DOI: 10.5897/IJWREE2018.0821

Halder, P K. (2016). Potential and economic feasibility of solar home systems implementation in Bangladesh. *Renewable and Sustainable Energy Reviews*, *65*, 568-576. DOI: 10.1016/j.rser.2016.07.062

Hossain, M A, M S Hassan, S Ahmmed and M S Islam. 2014. Solar pump irrigation system for green agriculture. *Agricultural Engineering International: CIGR Journal*, *16*(4), 1-15.

Hossain, M, D Roy, M Maniruzzaman, J C Biswas, U A Naher, M Haque and N Kalra. 2021. Response of Crop Water Requirement and Yield of Irrigated Rice to Elevated Temperature in Bangladesh. *International Journal of Agronomy*, *2021*. DOI: 10.1155/2021/9963201

Hossain, M, M Hassan, M A Mottalib and M Hossain. 2015. Feasibility of solar pump for sustainable irrigation in Bangladesh. *International Journal of Energy and Environmental Engineering*, 6(2), 147-155. DOI: 10.1007/s40095-015-0162-4

Islam, M R, P C Sarker and S K Ghosh. 2017. Prospect and advancement of solar irrigation in Bangladesh: A review. *Renewable and Sustainable Energy Reviews*, *77*, 406-422. DOI: 10.1016/j.rser.2017.04.052

Islam, M R, Y Guo, J Zhu, H Lu and J X Jin. 2014. High-frequency magnetic-link medium-voltage converter for superconducting generator-based high-power density wind generation systems. *IEEE Transactions on Applied Superconductivity*, *24*(5), 1-5. DOI: 10.1109/TASC.2014.2339137

Islam, M, M Bakhtierkhalzi, S Ahmed and P Das. 2018. Agricultural Scenario and Solar Irrigation System of Bangladesh.

Kabir, J, S Kabir, A Salam, A Islam, I Omar, A Sarkar, C Rahman, A Chowdhury, S Rahaman, L Deb, A Aziz, A Siddique and A Mandal. 2020. Harvesting of Boro Paddy in Haor Areas of Bangladesh: Interplay of Local and Migrant Labour, Mechanized Harvesters and Covid-19 Vigilance in 2020. 40 pages, BRRI, Gazipur, Bangladesh, 2020. Available online: https://www.researchgate.net/publication/342530055_Harvesting_of_Boro_Paddy_in_Haor_Areas_of_Bangladesh_Interplay_of_Local_and_Migrant_Labour_Mechanized_Harvesters_and_Covid-19_Vigilance_in_2020.

Kabir, M S, M U Salam, A Chowdhury, N M F Rahman, K M Iftekharuddaula, M S Rahman, M S Rashid, S S Dipti, M A Latif and A S Islam. 2015. Rice vision for Bangladesh: 2050 and beyond. *Bangladesh Rice Journal*, 19(2), 1-18. DOI: 10.3329/brj.v19i2.28160

Karmaker, A K, M M Rahman, M A Hossain and M R Ahmed. 2020. Exploration and corrective measures of greenhouse gas emission from fossil fuel power stations for Bangladesh. *Journal of Cleaner Production*, 244,118645. DOI: 10.1016/j.jclepro.2019.118645

Manar, E, A M El Gindy, Y E Arafa and A A Hegazi. 2019. SOLAR POWERED IRRIGATION SYSTEM FOR TURF AREA. *Arab Universities Journal of Agricultural Sciences*, *27*(1).

Michael, A. (1974). Irrigation engineering: theory and practice. In: Vikas Publishing House, New Delhi.

Paul, P L C, M Rashid and M Paul. 2013. Refinement of alternate wetting and drying irrigation method for rice cultivation. *Bangladesh Rice Journal*, 17(1-2), 33-37. DOI: 10.3329/brj.v17i1-2.20899

Tietjen, W, J Grande, T Nitzsche and E Dager. 2008. Solar pump drip irrigation for vegetable production, ASP proceedings. Rutgers CES of Warren County, 165, 07823-01949.

Tiwari, A K, and V R Kalamkar. 2018. Effects of total head and solar radiation on the performance of solar water pumping system. *Renewable Energy*, 118, 919-927. DOI: 10.1016/j.renene.2017.11.004