Project ID: 814

Competitive Research Grant

Sub-Project Completion Report

on

Development and Adaptation of Water Saving Irrigation Techniques for Upland Crops

Project Duration

May 2016to September 2018

Irrigation and Water Management Division
Bangladesh Agricultural Research Institute (BARI)
Joydebpur, Gazipur-1701

Submitted to
Project Implementation Unit-BARC, NATP 2
Bangladesh Agricultural Research Council
Farmgate, Dhaka-1215

September 2018

Project ID: 814

Competitive Research Grant

Sub-Project Completion Report

on

Development and Adaptation of Water Saving Irrigation Techniques for Upland Crops

Project Duration

May 2016 to September 2018

Irrigation and Water Management Division
Bangladesh Agricultural Research Institute (BARI)
Joydebpur, Gazipur-1701

Submitted to
Project Implementation Unit-BARC, NATP 2
Bangladesh Agricultural Research Council
Farmgate, Dhaka-1215

September 2018

Citation:
Sarker, K. K. and Biswas, S. K. 2018. Development and Adaptation of Water Saving Irrigation Techniques for Upland Crops. Project Implementation Unit, National Agricultural Technology Program-Phase II Project (NATP-2), Bangladesh Agricultural Research Council (BARC), New Airport Road, Farmgate, Dhaka-1215, Bangladesh.

Edited and Published by:

Project Implementation Unit
National Agricultural Technology Program-Phase II Project (NATP-2)
Bangladesh Agricultural Research Council (BARC)
New Airport Road, Farmgate, Dhaka – 1215
Bangladesh

Acknowledgement

The execution of CRG sub-project has successfully been completed by Irrigation and Water Management Division under Bangladesh Agricultural Research Institute (BARI), Gazipur using the research grant of USAID Trust Fund and GoB through Ministry of Agriculture. We would like to thanks to the World Bank for arranging the grand fund and supervising the CRGs by BARC and IWM Division, BARI. We would like to acknowledge the contribution and cooperation of NRM Division, BARC, Dhaka. It is worthwhile to mention the cooperation and quick responses of PIU-BARC, NATP 2, in respect of field implementation of the sub-project in multiple sites. Preparing the project completion report required to contact a number of persons for collection of information and processing of research data. Without the help of those persons, the preparation of this document could not be made possible. All of them, who made it possible, deserve thanks. Our thanks are due to the Director PIU-BARC, NATP 2 and his team who given their whole hearted support to prepare this document. We hope this publication would be helpful to the agricultural scientists of the country for designing their future research projects in order to technology generation as well as increasing production and productivity for sustainable food and nutrition security in Bangladesh. It would also assist the policy makers of the agricultural sub-sectors for setting their future research directions.

Published in: September 2018

Printed by: Madina Printing &Packeging
5 no. Madina Market, Muncipara Road
Joydebpur, Gazipur-1700.
Email: mppgazipur@gmail.com
Mobile: 01819067299

Acronyms

ASAE	American Society of Agricultural Engineers
AFI	Alternate Furrow Irrigation
ARS	Agriculture Research Station
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
CRG	Competitive Research Grant
CWU	Crop Water Use
CU	Co-efficient Uniformity
DU	Distribution Uniformity
DI	Deficit Irrigation
EFI	Every Furrow Irrigation
EV	Evaporation
EU	Emission Uniformity
FFI	Fixed Furrow Irrigation
FIW	Field Irrigation Water
IR	Irrigation
IWM	Irrigation and Water Management
NATP	National Agricultural Technology Program
OFRD	On-Farm Research Division
SAAO	Sub-Assistant Agriculture Officer
WP	Water Productivity
WUE	Water Use Efficiency

Table of Contents

List of Tables

List of Figures

41 Experts/Specialists, farmers and monitoring team members were visited the field experiments at Gazipur. 40

Executive Summary

Irrigation water is an essential component for sustainable crop production in Bangladesh. Agriculture is the dominant economic activity in Bangladesh but irrigated agriculture will come under increased climate and global pressures in the 21st century. Most of the upland high value major crops are widely grown during rabi season (November-April) and crop production is affected by drought or salinity in Bangladesh where irrigation water is necessary for optimum yields. Proper irrigation practices can maintain crop growth and yield by avoiding water stress and suppressing the buildup of soil salinity. Water saving irrigation techniques are now essential for improving water productivity in the areas where water resources are limited. Therefore, the sub-project on "Development and adaptation of water saving irrigation techniques for upland major crops" have been taken to conduct the field experiments at the drought prone area of Dinajpur and salt affected area of Koyra, Khulna and one additional site of IWM Research field, BARI, Gazipurunder the CRG, NATP II, Project for sustainable food security. The objectives of this sub-project were to(i) develop raised bed alternate and fixed furrow irrigation techniques for upland major crops in salt prone areas, (ii) develop drip irrigation systems with higher water distribution uniformity and water use efficiency for high value upland crops, and (iii) validate and adapt the site specific water saving technologies at farmers' field condition for crop production.

New emitter with low pressure (gravity) drip irrigation system was developed to slowly apply water directly to individual plants at frequent intervals rather than broadcasting over the whole field area. Based on available raw materials in local market, the compensating type of emitter was developed by IWM Division, BARI, Gazipur through ARFA local manufacturer in Dhaka. New emitter with low pressure (gravity) drip irrigation system was installed, evaluated and compared with Chinese emitter to determine the hydraulic parameters at lab condition. New emitter discharge was measured under the variable operating heads and slopes at lab conditions of Gazipur. The hydraulic performance of the developed drip irrigation system was found better at 1.5 m to 2 m operating head with various slopes of 0% and 1%, and emitter discharge rate was found from 3 to 5 litre/hour. The idea on raised bed planting with fixed furrow irrigation (FFI) techniques have been established, evaluated and compared with alternate furrow irrigation (AFI) and traditional/every furrow irrigation (EFI) at the salt affected area of Koyra, Khulna. . Total 10 famers (5 farmers from each site) were selected for adaptive trails. Six major crops, like as, maize, sunflower, potato, tomato, brinjal and watermelon were selected for adaptive trails. Site specific water saving technologies, like as, drip-irrigation at 3-5 days interval (Saline and non-saline area), AFI (Saline & non-saline area) and FFI techniques (Salt-affected area) were conducted in experiments at farmers' field conditions. Water saving techniques of alternate or fixed furrow irrigation saved seasonal crops (potato, maize, sunflower, brinjal) water use from 24 to 32% and it also improved water productivity from 28 to 40% while drip irrigation at 3-5 days interval saved seasonal crops (brinjal, tomato, watermelon) water use from 38 to 47% and improved water productivity from 50 to 60% compared to traditional furrow irrigation.

The water salinity of pond, tubewell and river at 10 days interval was recorded from 2.7, 3.7, 10.5 dS/m in December 2017 to 4.6, 6.1 and 18.7 dS/m in April 2018, respectively during the crop growing season at Koyra. The average changes in soil salinity (ECe) varied from 1dS/m (November 2017) to 15 dS/m in March 2018 in 45cm soil profiles with 15 cm increments due to more water uptake and evaporation from soil surface and accumulated salts in the upper soil layers. The average osmotic potential ranged from -90 kPa to 627 kPa which effects the plant growth and yield at later growth stages of 2222222222222222222222222crops because of insufficient soil moisture as well as lack of irrigation water.

A total of 51 farmers including SAAO were trained in the project area of Koyra, Khulna and Dinajpur. One additional program on field day was organized at Dinajpur. Some other activities like as BTV recorded and newspaper clipping were published. Total fund was released BDT 19,16,796 (95.84% of the approved budget) and expenditure was BDT 19,16,796.

Based on one year study, drip irrigation, alternate/fixed furrow irrigation methods are highly recommended to site specific areas of Bangladesh for a sustainable use of this natural water resources because of the insufficiency of surface and ground water resources and raising salinity. However, water saving techniques have the potential to save water without any sacrifice in yields of crops. Moreover, because of the insufficiency of

surface and ground water resources and raising salinity,these efficient irrigation techniques are needed to continue and expansion of different rabi crops at drought and coastal salt affected areas of Bangladesh for sustainable food security.

CRG Sub-Project Completion Report (PCR)

A. Sub-project Description

1. **Title of the CRG sub-project**:**Development and Adaptation of Water Saving Irrigation Techniques for Upland Crops**

2. **Implementing organization**: Irrigation and Water Management Division, Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur 1701

3. **Name and full address with phone, cell and E-mail of PI/Co-PI (s):**

3.1 ***Principal Investigator:***

Dr. KhokanKumer Sarker
Scientific Officer, IWM Division, BARI, Gazipur
Email: ksarkerwrc@gmail.com
Phone: 01711244003

3.2 ***Co-Principal Investigation:***

Dr. Sujit Kumar Biswas
Senior Scientific Officer, IWM Division, BARI, Gazipur
Email: sujitbari@yahoo.com
Phone: 01994081999

4. **Sub-project budget** (Tk):

4.1 **Total:** Tk 20, 00,000.00 (Twenty lac)

4.2 Revised (if any): -

5. **Duration of the sub-project:**

5.1 Start date (based on LoA signed) : 14 May 2017
5.2 End date : 30 September 2018

6. **Justification of undertaking the sub-project:**

Water is an essential component of sustainable crop production in Bangladesh. Amount of water application and timing affect the crop growth, yield and water productivity. Most of the upland major (cereals and vegetables) crops are widely grown in Bangladesh during dry environments (November-April) where irrigation water is necessary for optimum yields. At present situation, Bangladesh is affected by drought or by salinity during *rabi*season (November-April) which is the more risk for crop production in the country under changing climate (changing temperature and rainfall). Generally, farmers cultivate their upland crops by traditional flood irrigation methods that are practiced extensively leading to excess uses of irrigation water, increase surface runoff, deep percolation, water-stagnant and decrease aeration, reduce yields and water use efficiency as well as lead to increase input costs, thereby net income is reduced. Water saving technology in agriculture is also a challenging task under climate change for improving water use efficiency. Improved irrigation method is essential for avoiding soil water and nutrient leaching as well as groundwater pollution and plays an important role in achieving desired crops yield (Pawar et al., 2013). Bangladesh government is stressing upon the importance of appropriate technologies in water management at farm level as a key issue for ensuring food security. Improved irrigation water application methods are very limited in Bangladesh even in the world. Suitable water saving irrigation methods like sprinkler, drip-fertigation and furrow are limited to Bangladesh. The most common method of irrigation in Bangladesh is still the surface flooding technique. The expansion of drip system is still limited due to non-uniformity of water distribution and small size of water tank requires frequent refilling which farmers feel inconvenience.These problems need to be solved to popularize the drip irrigation to a greater part of farmer's community both small and large farmers for higher water use efficiency (WUE). Water saving strategies like, deficit irrigation (DI) where irrigation water is applied as a percentage of evapotranspiration or less than field capacity to the entire root-zone which maintain high crop yields and substantially improve WUE, but it requires knowledge or experience on crop growth stages which may difficult to practice in field conditions.Controlled application methods on micro irrigation, sprinkler and partial root-zone drying (PRD) could be considered for DI. PRD is a new irrigation technique where water is applied to only one portion of the root-zone while the remaining portion keeps dry during each irrigation event. In recent years, some studies (Kang and Zhang, 2004; Zegbe et al., 2004; Topcu et al., 2007; Milena et al., 2012) have been reported that PRD system saved water and increased the water use efficiency without significant yield reduction.

Presently, the new thinking of alternate furrow irrigation (AFI) technology has been raised and increased considerable interest for alternate irrigation to plants for adoption to change the old paradigms of traditional furrow or flooding irrigation methods. The concept and practice of AFI technique is an ideal improvement of DI and PRD technique which is more essential under limited water resources and is relatively easy to apply in the field conditions for sustainable increasing WUE. AFI is a way of irrigation method for row crops cultivation technique where irrigation water is supplied in alternate furrows and keep in-between furrow dry. The soil sub-surface might be wetted after irrigation due to lateral movement (Majumdar, 2004). AFI method could save substantial amount of water by 25 to 35% with insignificant increase or reduction of crops yield to the extent of 2 to 6% (Reddi and Reddy, 2009; Sarker et al. 2016).

Soil salinity is another constraint for crop production in the southern region of Bangladesh. About 1.05 m ha in the southern region are affected by soil salinity of which most of the lands remain fallow in the dry season because of salinity hazardable and lack of available soil moisture and fresh water for irrigation (MoA and FAO, 2013). The sub-soil and sub-strata remain saline throughout the year and shallow groundwater also remains harmful to very harmful stage (SRDI, 2010). Due to severe soil and water salinity scope *rabi* crops (maize, sunflower, watermelon, sweet-gouard, etc) is very limited high yielding varieties (SRDI, 2003). Coastal soils vary widely in nature of salinity, depth of groundwater and salinity of surface water. In coastal saline areas, soil and water salinity and scarcity of irrigation water make it impossible to grow any crops during the dry season (December-April). Farmers can only grow T. Aman during the monsoon when the soil salinity remains less than 2.0 dS/m. As a consequence, about 90-95% of saline areas remain fallow during the dry season. Fallow lands can be brought under crop cultivation in the dry season by improved soil and water salinity management techniques. Some previous studies (Alam et al., 2001; Mridha et al., 2001; Abdullah et al., 2005; Akanda et al., 2015) such as drip-fertigation, raised beds with or without mulches, and some other related irrigation techniques in the coastal areas of Bangladesh showed that raised beds with mulch and drip irrigation systems on different crops reduced soil salinity to a considerable extent from 10-12 dS/m to 4.5-5.5 dS/m) and saved irrigation water. Permanent skip furrow irrigation (PSFI) technology has the potential to save water and reduce salt concentrations on the top and the side of the raised beds by 2-3 times compared to every furrow irrigation practice and salt concentration towards to the dry side of the furrows (Devkota et al., 2015).

However, AFI or PSKFI is an inexpensive method of irrigation and can be used as an alternative choice in drought and salt response areas, respectively compared to more expensive methods of irrigation such as, sprinkler or drip irrigation techniques. Similar type of research works have not yet performed in the country. Therefore, some extensive studies are needed to increase crop production and water productivity through research and adaptation of water saving technologies on various upland major crops like maize, sunflower, tomato, potato and watermelon in the areas where irrigation water resources are limited. However, keeping all these factors, this project has been undertaken to improve and adopt the innovative water saving irrigation techniques for sustainable agriculture crop production in drought and saline prone areas of Bangladesh. Water saving techniques will help the farmers/extentionists/researchers in contributing to produce additional crop yields for improving their livelihoods in the saline and drought prone areas of Bangladesh.

7. Sub-project goal:

The goal of the sub-project is to increase water use efficiency through development and adaptation of improved water saving technologies in drought and saline prone areas of Bangladesh.

8. Sub-project objective (s):

The objectives of this sub-project were

(i) to develop raised bed alternate and fixed furrow irrigation techniques for upland major crops in salt prone areas,

(ii) to develop new emitter with drip irrigation system for higher water distribution uniformity of high value upland crops, and

(iii) tovalidate and adapt the site specific water saving technologies at farmers' field condition for crop production.

9. Implementing location (s): DinajpurSadar, Dinajpur and Koyra, Khulna

10. Methodology in brief:

Water saving (drip and fixed furrow irrigation) techniques are improving through the integration of engineering, physiological, soil nutrient and management aspects in drought and salt prone areas. The major approach is to be followed in the sub-project to establish the innovative water saving methods in identifying the suitable and best water saving technologies for upland major crops production. The investigators of the sub-project were directly involved in developing and conducting the adaptive research trials simultaneously under different BARI promising crops. PI/Co-PI and part time accountant staff were conducted all activities through OFRD, BARI Khulna and ARS, BARI, Dinajpur. PI/Co-PI is being visited and monitored at each site to implement and achieve the sub project activities. The methodology of development and adaptive trials of water saving technologies are briefly described according to sub-project objectives and activities. The lab and field experiments were conducted at Gazipur and the farmers' fields of Koyra, Khulna and DinajpurSadar, Dinajpur under the sub-project of CRG, NATP II Project.

10.1. Development of raised bed alternate and fixed furrow irrigation techniques for upland major crops at salt affected area

The developed idea and adaptive trails of furrow irrigation techniques with schematic figures (**Fig. 1, 2 & 3**) are given. The adaptive research ideas are alternate furrow irrigation (AFI) with single row raised bed planting and fixed furrow irrigation (FFI) with single row raised bed planting based on partial root-zone drying (PRD) technique is developed and compared with farmers' practice for small and relatively large crop fields. AFI indicates that one of the neighboring furrows are alternately irrigated during consecutive watering. It means that irrigation water is applied only one side of the root system for wetting the root with each irrigation event while the other side of the root kept for drying (**Fig. 1**). FFI means that it is fixed to one furrow of the neighboring two furrows from first irrigation to last irrigation (**Fig. 2**). Traditional (every) furrow irrigation (TFI) indicates that traditional every furrow irrigation is the traditional way where all furrows is irrigated for each irrigation (**Fig. 3**). It means that irrigation water is applied on both sides of the root system for each irrigation event. Traditional flooding irrigation indicates that irrigation is the traditional way where flooding irrigation is applied on the flat land.

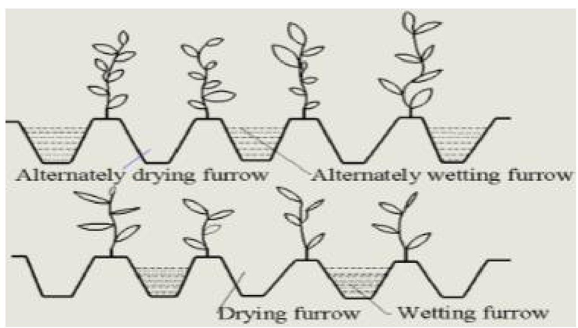


Fig. 1. Schematic view of new establishment of alternate furrow irrigation and planting method with top corner/side slope of the raised bed at drought area

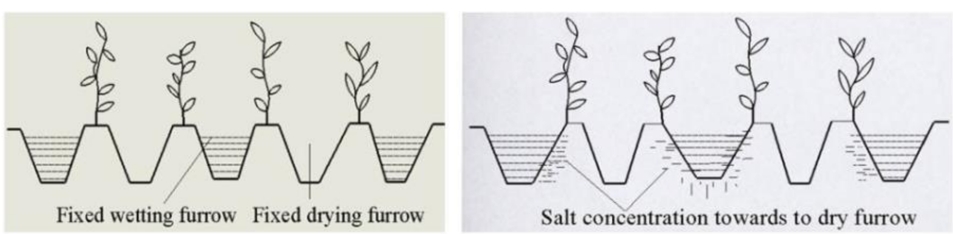


Fig. 2. Schematic view of new establishment of fixed furrow irrigation and planting method with top corner/side slope of the raised bed at salt affected area

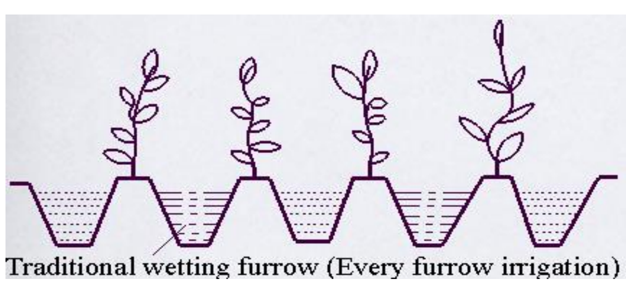


Fig. 3. Schematic view of new establishment every furrow irrigation and planting with top corner/side slope of the raised bed at drought and saline areas of Bangladesh

10.2: Development of new emitter with drip irrigation system for higher water distribution uniformity for high value crops

The heart of the drip irrigation system is the water application device which name is emitter. The emitter delivers water in small amounts to individual plants rather than broadcasting water over the whole field area. Application of only a small quantity of water to each plant means that uniform distribution of water is extremely critical for drip-irrigation success. Therefore, new emitter with drip irrigation systems for small farmer have been developed, installed at lab conditions and evaluated at lab and field conditions.

Development, installation and evaluation of new emitter with low pressure (gravity) drip irrigation system for small farmers

Design principles

New emitter with drip irrigation system was designed to slowly apply water directly to individual plants or small group plants through small emitter operating from plastic tubing at low flow rates and low pressures at frequent intervals .Drip tubing and emitters are laid out, or parallel to row crops on the soil surface (uses small pipes and tubing).This system may be pressurized with flow emitters or may operate under gravity pressure. The spacing of the emitters, the layout and cost of the system depends on the crop spacing, roots and soil characteristics. In this study, pressure compensating emitters attempted to provide a constant flow rate to overcome the hydraulic constraints imposed by orifice, long-flow path emitters. These emitters usually allow only small changes in emitter flow rate as pressure is changed within a given design range. Compensating emitters may be the only way to achieve uniform water application when slopes are steep or when the topography is hilly and uneven. The heart of the drip irrigation system is the water application emitter, delivering water in small amounts to individual plant rather than broadcasting over the whole field area. Application of only a small quantity of water to each plant means that uniform distribution of water is extremely critical for drip irrigation systems. That is the drip irrigation system must be designed and operated so that plants all receive within reasonable limits the same amount of during any irrigation events which indicates the acceptable uniformity of water application. The uniformity of water application from drip irrigation system depends on the operation pressure (operating head) and response of the emitter to that pressure, operating head, distributing sub main and lateral pipe diameter and length and type of emitter. Generally, individual emitter flow non-uniformity is caused primarily by manufacturing variations of emitters. Therefore, system water application uniformity is the combination of flow variations of all emitters in the system.The type and portion of control influences the system layout, when laterals are long a slope or are very long, the pressure compensating emitters are required to maintain uniformity.

System measurement

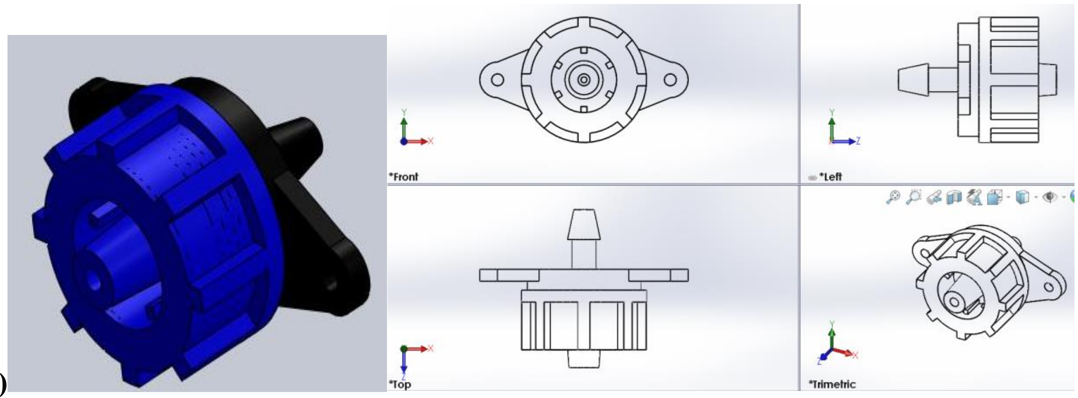
Based on design principles and availability of raw materials in local market, one compensating low discharge type of online emitter was developed by IWM Division, BARI, Gazipur through ARFA local manufacturer in Dhaka, Bangladesh, as shown in **Fig. 4, 5**and**6**. Newly developed of emitter by IWM Division, BARI was used and compared with one type of commercial online emitter in the laboratory test to evaluate the installation and hydraulic performances. Emitters were tested in the laboratory at IWM division, BARI during August/October, 2017 (**Fig. 5**). Two types of emitter (compensating) obtained one from newly developed and other from Chinese manufacturers which is exported and recently available in the market were used in the laboratory tests to determine the hydraulic parameters. Chinese emitters available in the market but its hydraulic performances characteristics are not available. Therefore, the test parameters of drip irrigation system such as co-efficient of variation (CV_m), emission uniformity (EU), co-efficient of uniformity (CU), distribution uniformity (DU), statistical uniformity of water application (Us), and head-slope-discharge relationship were evaluated at lab conditions. A set of lab experiment was done for getting improved gravity fed drip irrigation system. The laboratory drip irrigation system was consisted of tank (500 litre), disk type filter, one sub main pipe (¾″ dia), 8 sub lateral pipe (½″ dia), and 200 emitters (25 emitter/each sub line). A water tank (500 litres) was set at 1.5 m, 2.0 m and 2.5 m height above the emitters by manually and maintained water pressure by gauges. The emitter spacing was 0.75 m *1 m with emitter to emitter to 0.75 m and row to row 1 m a shown in **Fig. 5**. The sub-main and lateral length used in all test runs was kept 8 m and 20 m, respectively. A ¾ inch dia (19 mm) main pipe line with zero slope was maintained at each time and eight ½ inch dia (13 mm) sub-main pipeline with 3 different slopes of 0%, 1 % and 1.5% was used every time under suggested operating 3 different heads (pressure) of 1.5 m (1.5 kPa), 2.0 m (20 kPa), 2.5 m (24 kPa). Unused materials from original 2017 purchase was evaluated in the laboratory using the same pressure regulating valves as those used in the lab instalment. Five emitters are each lateral line at equal distance and total 40 emitters out of 200 emitters were tested simultaneously for a period of 2 min under different heads (pressures) with 3 different slopes of 0%, 1 % and 1.5%. A disk type filter, controlled valve and pressure gauge was used to control the head as well as pressure for each operation. The water source for tests was deep ground water with p^H, water salinity and temperature of 7.02, 0.0035 dS/m and 28^0C. Volumetric water pots (measuring 500 ml water beakers) were used for discharge collection and the collected water was also weighed by precision digital balance. The water volumes and their weight were collected and recorded by manually. The discharge of emitters was measured volumetrically and weighed of collected water with three times replicated. A stop watch was used to measure flow times. The operating head (pressure) and pressure remained constant during each set of measurements. The operating pressure was measured using pressure gauges at starting point of the water supply to the system. The ASAE test standards procedure (1996) was followed to determine the hydraulic parameters of CV, EU, CU, DU, Us and Q_{var}.

a) (b) (c)

Fig. 4. Developed new emitter (a) and its components (b, c)

(a) (b) (c)(d)

Fig. 5. Installation of new emitter (a, b) and data collection (c, d) under low pressure (gravity) drip irrigation system at lab condition

(a)


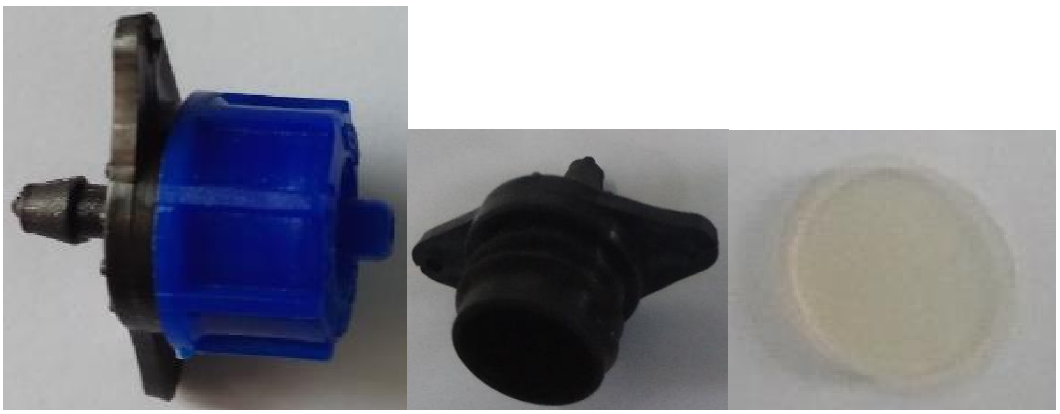
(b)


Fig. 6. Modified newly developed emitter (a: 3 D and 2 D using Solidworks) and produced emitterand its components(b).

(a) **(b)** **(c)** **(d)**

Fig. 7. Photographic view of Scientists (a)/Professor/Students (b)/Manufacturer (c)/Supplier (d) visited and evaluated the new emitter under low pressure (gravity) drip irrigation system at lab condition

The properties of new emitter is shown in **Table 1.** The discharge of new emitter (IWM01) was varied from 3 to 5litre per hour**.**

Table 1. Properties of the newly developed emitter (IWM01*).

Emitter parameters		Dimension
LabyrinthDimensions	Width of flow (mm)	0.75
	Depth of flow (mm)	0.75
	Detention width (mm)	1.00
	Detention height (mm)	0.90
	Length of flow (mm)	25
SectionofEntry	Dia of entry (mm)	1.75
	Length of entry (mm)	8.75
	Fin spacing (mm)	2.27
	Number of fins	6
	Length of a fin (mm)	1.25
Coefficient of manufacturer variation (CV_m)		0.04-0.08
Shape of the diaphragm		Circular
Diameter of the diaphragm (mm)		5
Discharge (L/h)		3 - 5

*IWM01 indicates the code number of newly developed emitter by Irrigation and Water management Division and ARFA manufacturer.

10.3. Validation and adaptation of the site specific water saving technologies at farmers' field condition

Site selection for experiments

Site specific water saving technologies can play a major role for judicious use of water for increasing crop production and WUE. The communications, discussions and other formalities are being done with respective resource personnel for implementing the project activities as well as achieve the goal of the project. Therefore, the site specific methods were selected to achieve the goal of the project. Water saving technologies for high value crops in the project areas was selected. The selected site for the project was DinajpurSadar, Dinajpur for drought and Koyra, Khulna for salt-affected areas of Bangladesh. Adaptive trials on water saving technologies were carried out and validated at farmers' field conditions with the help of ARS, BARI, Rajbari, Dinajpur and OFRD, BARI, Doulatpur, Khulna through current recommended crop management practices. One common field experiment was also conducted at IWM Research Field, BARI, Gazipur, Dinajpur and Khulna.

Farmers and crops selection

Five farmers were selected from each site. The selection was based on availability of land and labor, and source of irrigation water (**Fig. 8** and **9**). Six major upland crops (maize, sunflower, potato, tomato, bt-brinjal (eggplant) and watermelon were selected for adaptive trails.

(a) (b)

Fig. 8. Group discussion with farmers (a, b) for development and adaptation of water saving technologies at drought prone area of Dinajpur in Bangladesh

(a) (b)

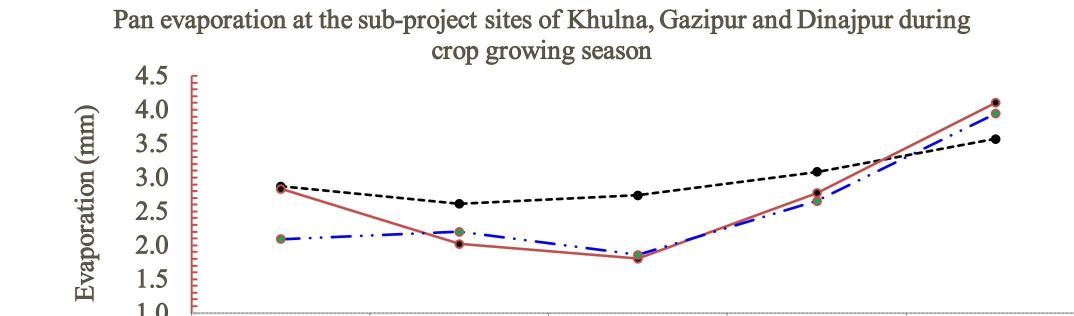
Fig. 9. Group discussion with farmers and farmers' field visit (a, b) for development and adaptation of water saving technologies at salt affected area of Koyra, Khulna in Bangladesh

Basic information of the sub- project site

The soil physical properties of the selected sites of the sub-projects are shown in **Table 2.** The soil type was similar silt loam in the location of Khulna, Gazipur and Dinajpur **(Table 2).** The pan evaporation (EV) was varied from location to location of the project sites. The similar trend was observed in Dinajpur and Gazipur but higher in Khulna (**Fig.10**.). The precipitation/ainfall (mm) at the sub-project sites of Khulna, Gazipur and Dinajpur from November 2017 to March 2018 is shown in **Fig. 11**. The highest total rainfall was observed at Gaipur among the project sites. Water salinity of river, pond and tubewell at 10 days interval at the project site of salt-affected area of Koyra, Khulna from December 2017 to April 2018 is shown in **Fig. 12**. The water salinity increased in pond, river and canal from December 2017 to April 2018 (**Fig. 12**).

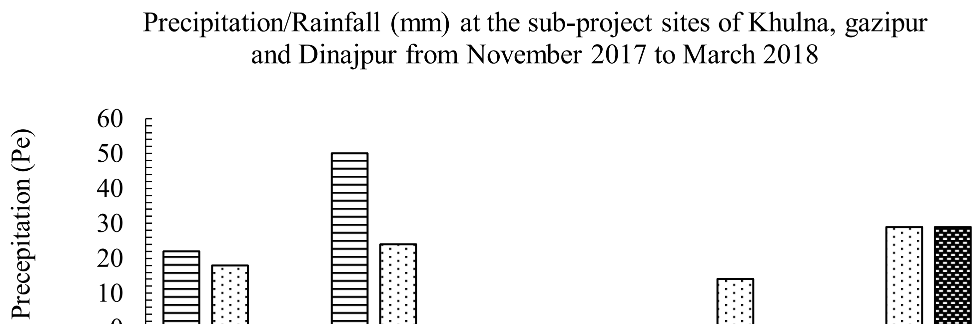
Table 2. Soil physical properties at different experimental location under CRG, NATP II Project

Depth(cm)	%Sand			%Silt			%Clay			Soil type
	Dinajpur	Gazipur	Khulna	Dinajpur	Gazipur	Khulna	Dinajpur	Gazipur	Khulna	
0-15	28.4	19.2	29.2	62	72	54	9.6	8.8	16.8	Silt Loam
15-30	26.4	17.2	19.2	64	66	64	9.6	16.8	16.8	Silt Loam
30-45	22.4	13.2	29.2	68	66	48	9.6	20.8	22.8	Silt Loam



	Nov	Dec	Jan.	Feb	Mar
Khulna	2.87	2.61	2.74	3.08	3.57
Gazipur	2.83	2.02	1.80	2.77	4.10
Dinajpur	2.09	2.20	1.86	2.65	3.94

Fig. 10. Pan evaporation at the sub-project sites of Khulna, Gazipur and Dinajpur during crop growth period of November 2017 to March 2018



	Nov	Dec	Jan.	Feb	Mar
Khulna	22	50	0	0	0
Gazipur	18	24	0	14	29
Dinajpur	0	0	0	0	29

Fig. 11. Precipitation/Rainfall (mm) at the sub-project sites of Khulna, Gazipur and Dinajpur from November 2017 to March 2018

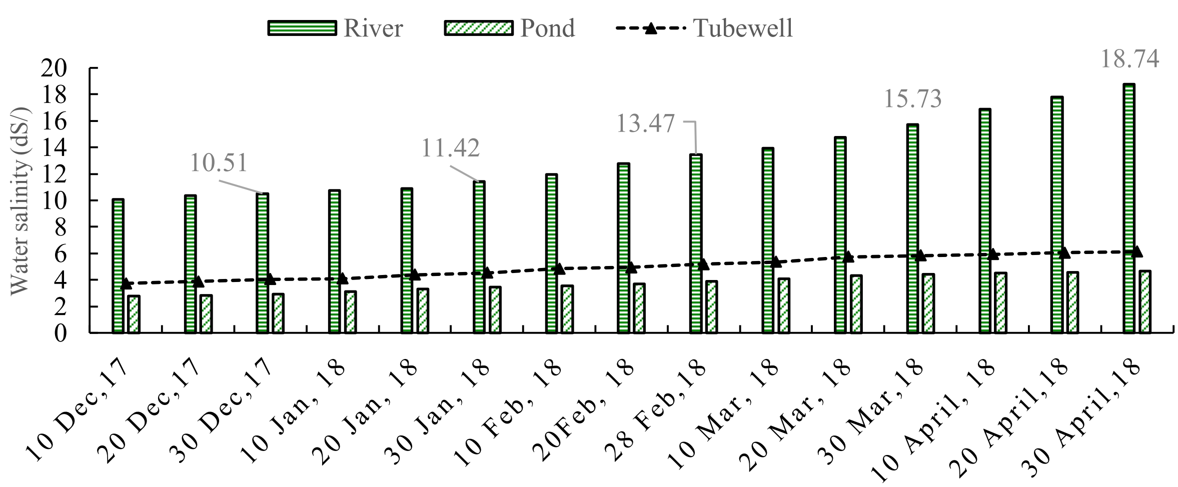


Fig .12. Water salinity of river, pond and tubewell at 10 days interval at the project site of salt affected area of Koyra, Khulna from December 2017 to April 2018

Experimental design

The field experiments were laid out in a randomized complete block design with different irrigation treatments for maize and potato, tomato, watermelon, sunflower and maize, and bt-brinjal (eggplant) and replicated thrice. The list of field experiments at drought and salt-affected area under the sub project is shown in **Table 3**.The irrigation treatments and crop management based on experiments were given.

Table 3. Adaptation of fieldexperiments at drought and salt-affected area under CRG, NATP-II sub project

Field Expt no.	Title	Crop	Location
01	Adaptation of raised bed alternate furrow irrigation technique on yield and water use efficiency of maize and potato in drought area of Bangladesh	Maize, Potato	Dinajpur
02	Adaptation of drip-fertigation on yield, water and fertilizer use efficiency of tomato in drought and saline prone area of Bangladesh	Tomato	Dinajpur, Koyra
03	Adaptation of drip-fertigation on yield, water and fertilizer use efficiency of watermelon in drought and saline prone area of Bangladesh	Watermelon	Dinajpur, Koyra
04	Development and adaptation of raised bed furrow irrigation technique on salinity, yield and water use efficiency of sunflower and maize in saline area of Bangladesh	Sunflower, Maize	Koyra, Khulna
05	Comparative study on irrigation methods for Bt-brinjal (Eggplant) cultivation in Bangladesh	Bt-brinjal	Koyra, Khulna

Field Expt. 1: Adaptation of alternate furrow irrigation technique for maize and potato cultivation at Dinajpur

Treatment*:*

- (i) Raised bed with alternate furrow irrigation
- (ii) Farmers practice (Raised bed with every furrow irrigation)

Crop management

The standard crop management practices for maize and potato were followed (Table 4, 5 and Fig. 13, 14).

Table 4. Crop management practices for **maize** and **potato** under adaptation of alternate furrow irrigation techniques at Dinajpur during the year of 2017-2018

Crop and variesy	Planting system	Fertilizer dose	Method of fertilizer application	Irrigation scheduling
Maize, Hybrid Maize NK 40	Row to row and plant to plant spacing was considered as 60 and 20 cm, respectively. Each plot size was 135 m^2.	N_{255} P_{75} K_{120} S_{52} Mg_{15} Zn_4, $B_{1.4}$ kg/ha.	One-third of N and K and all of P, K, S, Mg, Zn and B were applied as basal during final land preparation. Remaining two-third of N and K was applied in two equal splits as side dressing in maize rows at 30-35 DAS and 50-60 DAS (tasseling stage).	Irrigation at initial vegetative stage (25-35 DAS), tasseling (50-60 DAS), silking (80-90 DAS) and grain filling (105-115 DAS) stages of maize.
Potato, BARI Alu 25	Ridge-top centre to ridge-top centre distance and plant to plant spacing was considered 60 and 20 cm, respectively. Each plot size was 135 m^2.	$N_{120,}$ $P_{30,}$ $K_{100,}S_{15,}$ $Zn_{4,}$and$B_{1.4}$ kg/ha	Half of the nitrogen and potassium and all phosphorous, sulphur, zinc, boron and cowdung was applied as basal doses. Remaining nitrogen and potassium were applied as side dressing at 20-25 days after planting (DAP) during earthing up operation followed by irrigation.	Irrigation at stolonization stage (20-25 DAP), tuberiszation stage (40-45 DAP) and at tuber enlargement stage (60-65 DAP) stages of potato.

Table 5. Crop phonological dates of **maize** and **potato** under adaptation of alternate furrow irrigation techniques at Dinajpur during the year of 2017-2018

Crop	Sowing date	1st IR	2nd IR	3rd IR	4th IR	Harvesting
Maize	15-11-2017	16-12-2017	10-01-2018	08-02-2018	10-03-2018	12-04-2018
Potato	14-11-2017	08-12-2017	28-12-2018	15-01-2018	29-01-2018	29-02-2018

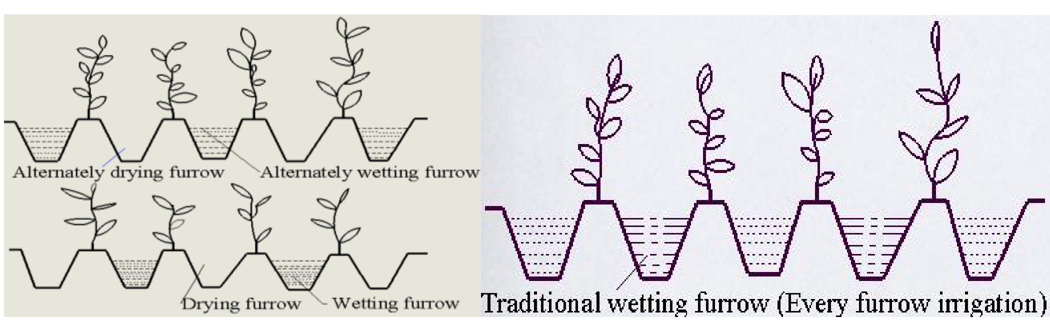


Fig. 13. Schematic view of establishment of raised bed alternate furrow irrigation every (traditional) furrow irrigation (60 cm furrow to furrow center) at Dinajpur

Fig. 14. Field experiments set up on raised bed alternate furrow irrigation technique for maize and potato cultivation at Dinajpur farmers' field

Expt. 2: Adaptation of drip-fertigation for tomato cultivation in drought and saline prone area of Dinajpur and Koyra, Khulna

Treatment:

(i) Drip fertigation at 3-5 days interval

(ii) Conventional/Farmer's irrigation practice (Three/four furrow irrigations at different growth stages from initial to fruit setting)

Crop management

Variety		BARI Tomato-14 at Koyra and Romavf (Local variety)
Each plot Size	:	5 decimal
Planting System and spacing	:	Furrow to furrow center distance was 60cm. and plant to plant spacing was 40 cm.
Fertilizer dose and Method of application	:	$N_{253} P_{90} K_{125} S_{22} Zn_{1.0} B_2$ kg/ha. Half cowdung and full phosphorus, sulphur. Zinc and boron was broadcast and incorporate during final land preparation. Nitrogen and potassium was applied in three and two equal installments at 10, 25, 40 and 25 and 40, respectively days after transplanting as drip-fetigation method followed by irrigation depending on soil moisture.

Fig. 15. Field experiments set up on drip-fertigation at salt-affected area of Koira, Khulna and Dinajpur farmers' field

Table 6. Crop phonological dates of tomato cultivation at the Koyra and Dinajpur

Location	Sowing date	Irrigation	Harvesting
Khulna	30-11-2017	3-5 days interval	20-03-2018
Dinajpur	05-12-2017	3-5 days interval	25-03-2018

Expt. 3: Adaptation of drip-fertigation for watermelon cultivation in drought and saline prone area of Dinajpur and Koira, Khulna

Treatment:

DF: Drip-fertigation (N K) in raised bed at 3-5 days interval from sowing DAE) to fruit setting straw mulch (2-3 t/ha)

CP: Conventional/Farmer's practice (Three/four irrigations at different growth stages from initial to fruit setting with mulch)

Crop management

Variety	**:**	Bigtop (F_1 Local hybrid) at Dinapur and Sinnor (F_1 Local hybrid) at Koira, Khulna.
Each plot size	:	5 decimal
Planting System and spacing	:	Pit to pit (plant to plant) spacing was considered as 1.5 × 1.5 m.
Fertilizer dose and Method of application	:	FRG, BARC (N_{55} P_{33} K_{50} S_{30} $B_{1.2}$ kg/ha for drip-fertigation, and N_{99} P_{33} K_{81} S_{30} $Zn_{1.2}$ $B_{1.2}$ kg/ha for common practices. The N and K were applied into four equal splits at 15, 30, 45 and 60 DAE using drip-fertigation.

Table 7. Crop phonological dates of watermelon at the salt affected area of Koyra, Khulna

Location	Sowing date	Irrigation	Harvesting
Khulna	19-01-2018	3-5 days interval	18-04-2018
Dinajpur	25-12-2017	3-5 days interval	*

* Seedlings of watermelon damaged at the village of Dinajpursadar. Data on Dinajpur site is not included in this report.

Expt. 5: Development and adaptation of furrow irrigation technique on salinity, yield and water productivity of sunflower and maize in saline area of Koyra, Khulna

Treatment:

Factor A**:** Planting method (PM)

- Top center of the raised bed (conventional practice) (PM_1)
- Top corner of the raised bed of the raised bed (PM_2)

Factor B**:** Irrigation method (M)

- Raised bed with alternate furrow irrigation (M_1:AFI)
- Raised bed with fixed skip furrow irrigation (M_2: FFI)
- Raised bed with (traditional) every furrow irrigation (M_3: EFI)

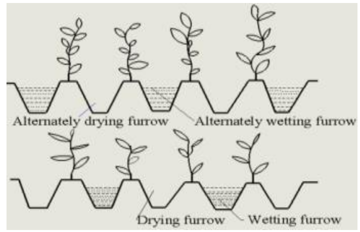


Fig. 16. Schematic view of new establishment of alternate furrow irrigation and planting method with top corner/side slope of the raised bed (60 cm furrow to furrow center) at salt affected area ofKoyra, Khulna

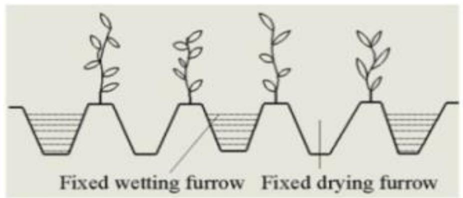


Fig. 17. Schematic view of new establishment of fixed furrow irrigation and planting method with top corner/side slope of the raised bed (60 cm furrow to furrow center) at salt affected area of Koyra, Khulna

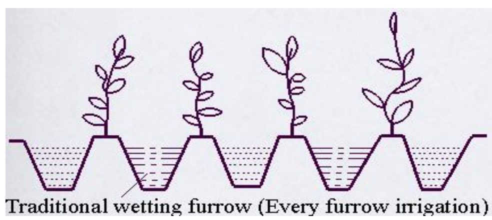


Fig. 18. Schematic view of new establishment every furrow irrigation and planting with top corner/side slope of the raised bed (60 cm furrow to furrow center) at saline areas of Bangladesh

Crop management

The standard crop management practices for sunflower and maize were as followed (Table 8, 9 and Fig.19, 20).

Table 8. Crop management practices for **sunflower** and **maize** under raised bed planting and furrow irrigation techniques at Koyra, Khulna during the year of 2017-2018

Crop and variety	Planting system	Fertilizer dose	Method of fertilizer application	Irrigation scheduling
Sunflower (Hisun-33)	Row to row and plant to plant: 60 × 40 cm, each plot size25.2 m^2	N_{129} P_{32} K_{60} S_{21} Mg_6 $Zn_2B_{1.6}$ kg/ha	Half of nitrogen (N) and potassium (K) and all of phosphorus, sulphur, magnesium, zinc, boron and organic matter (if used) was applied as basal during final land preparation. Remaining N and K was applied as top dress in two equal splits at 20-25 DAS and 40-45 DAS (before flower initiation stage).	Irrigation at initial vegetative growth (25-30 DAS), flowering (55-60 DAS) and grain development (80-85 DAS) stages of sunflower.
Maize(BARI Hybrid Maize-12)	Row to row and plant to plant: 60 × 20 cm, each plot size25.2 m^2	N_{255} P_{75} K_{120} S_{52} Mg_{15} Zn_4, $B_{1.4}$ kg/ha	One-third of N and K and all of P, K, S, Mg, Zn, and B were applied as basal during final land preparation. Remaining two-third of N and K was applied in two equal splits as side dressing in maize rows at 30-35 DAS and 50-60 DAS (tasseling stage).	Irrigation at initial vegetative growth (25-35 DAS), tasseling (50-60 DAS), silking (80-90 DAS) and grain filling (105-115 DAS) stages of maize.

`

Table 9. Crop phonological dates of **sunflower** and **maize** under raised bed planting and furrow irrigation techniques during the year of 2017-2018

Crop	Sowing date	1st IR	2nd IR	3rd IR	4th IR	Harvesting
Sunflower	30-11-2017	06-01-2018	10-02-2018	04-03-2018	-	21-03-2018
Maize	30-11-2017	0601-2018	10-02-2018	04-03-2018	24-03-2018	18-04-2018

Fig. 19. Development and adaptation of raised bed furrow irrigation and planting (top/centre of raised bed) technique for sunflower in salt-affected area of Koyra, Khulna

.

Fig. 20: Development and adaptation of raised bed furrow irrigation and planting (top/centre of raised bed) techniques for maize in salt-affected area of Koyra, Khulna

Expt. 6: Comparative study on irrigation methods for Bt-brinjal (Eggplant) cultivation of Dinajpur, Khulna and Gazipur

Treatment:

- **(i)** Drip irrigation at 3-5 days interval (M1)
- **(ii)** Alternate furrow irrigation at 10-12 days interval (M2)
- **(iii)** Fixed furrow irrigation at 10-12 days interval (M3)
- **(iv)** Deficit irrigation (80% of FC, i.e. 20% less of full irrigation water at each irrigation event) (M4)
- **(v)** Farmers ‘practice/Traditional every furrow irrigation (M5)

Crop management

Variety	:	BARI Bt-Begun-2
Planting System and spacing	:	Row to row and plant to plant spacing was considered as 75 and 1m, respectively. Total plot size was 22decimal (Gazipur), 16 decimal at Dinajpur and Koyra, Khulna

Fertilizer dose and Method of application	:	FRG, BARC 2012 (N_{175} P_{60} K_{132} S_{23} Zn_3, $B_{1.7}$kg/ha). All of P, S, Zn, B and organic manure was applied as basal during final land preparation. N and K were applied in four equal splits as side dressing in brinjal rows at 20, 40, 60 and 80 DAP of different growth stages.

Fig. 21. Field experiments set up on different water saving irrigation techniques at Dinajpur, Koyra and Gazipur for Brinjal cultivation during 2017-2018

Table 10. Crop phonological dates of Brinjal at the location of project sites of Khulna, Gazipur and Dinajpur during 2017-2018

Crop and variety	Location	Sowing	1st IR	2nd IR	3rd IR	4th IR	5th IR	Harvesting
Brinjal, BARI Bt-Begun-2	Khulna	06-12-17	14-01-18	08.-02-18	26-02-18	10-03-18	12-04-18	30.-04-18
	Gazipur	23-11-17	03-01-18	18.-01-18	18-02-18	10-03-18	-	09-.04-18
	Dinajpur	15-11-17	20-12-17	15-01.-18	13-02-18	-	-	23.-03-18

Observed test parameters

Field data were collected. Data are collecting on according to experiment requirements.Before crop sowing, soil samples were randomly collected from the depth (0-45 cm) of the experimental plots with 15 cm incremental soil layer to determine the soil physical at the farmers' field of Koyra, Khulna (**Fig. 22**) and Dinajpur under the sub-project sites. Data on crop and irrigation water management practices were recorded determined.

Fig. 22. Collection of soil samples for analysis

Soil was also collected for monitoring soil moisture content, soil salinityand osmotic potential at different growth stages and soil profiles. Soils were sampled from 0-15, 15-30 and 30-45 cm soil depths at the time of sowing to harvest. The Electrical conductivity of $EC_{1:5}$ was determined (**Fig.23**) and converted to actual salinity EC_e of soil water content (dS/m) while using the formula derived from Richards (1954). Field soil gravimetric moisture content was determined. The soil samples were taken from each plot in 15 cm increments, well-mixed together, subsampled, weighed, dried at 105°C, and reweighed to determine gravimetric moisture content. $EC_{1:5}$ was also converted to osmotic potential (kPa) of field soil solution using the formula derived from Rengasamy (2010).$EC_{1:5}$ were determined using portable instrument of water and soil conductivity meter with sensor probes that can inserted directly into the soil solution. The water salinity of river, pond and river at the salt affected site of Koyra, Khulna was monitored at 10 days interval during the crop growing season.

Fig. 23. Photographic view of collected soil sample preparation and determining the soil salinity ($EC_{1:5}$, dS/m)

Irrigation scheduled was followed according to BARI IWM recommendations. Irrigation frequency was considered at every certain interval depending on the different growth stages (initial stage, vegetative stage, flowering and grain development stages (Reddi and Reddy 2009; Sarker et al, 2016) from plant establish to before final harvest. Irrigation water was applied based on the pan evaporation method at different crop growth stages. Data on pan evaporation and precipitation(rainfall) were collected from Khulna, Gazipur and Dinajpur weather station based on location based experiment to estimate irrigation water requirement (I, mm) for full irrigation using the following equation.

$$I = E_p \times K_p \times A \qquad (1)$$

$$FIW = \frac{I}{E_a} \times 100 \qquad (2)$$

Where, I is the amount of irrigation water amount (litre), A is the area of the plot (m^2), E_p is the cumulative pan evaporation (mm) and K_p is the pan coefficient and was considered 0.7 (Michael, 1978). FIW is the amount of field irrigation water amount, Ea is the field irrigation application efficiency (in %).Thetypical irrigation efficiencies for surface irrigation system of surface flood, furrow and drip are 45-55%, 65-75% and 90-95%, respectively. The calculated amount of irrigation water was measured by volumetric method and supplied to the experimental plots using a polyethylene hose pipe. Each experiment plots were separated by a distance of 1.5 m to prevent the lateral movement of water from one to another. Total seasonal crop water use (SCWU) was calculated as the sum of total irrigation water applied (FIW), effective rainfall (P_e) and soil water contribution (SWC) between plantation and final harvest and expressed by the following equation. Effective rainfall was estimated by using the USDA Soil Conservation Method (Smith, 1992).

$$SCWU = FIW + Pe \pm SWC \qquad (3)$$

The quantity of water saving was computed by the following way:

$$\text{Water saving (\%)} = \frac{\text{SCWU in EFI or TFI} - \text{SCWU in DI or AFI or FFI}}{\text{SCWU in EFI or TFI}} \qquad (4)$$

Where, EFI/TFI indicates the traditional every furrow irrigation, DI: Drip irrigation, AFI: Alternate furrow irrigation and FFI: Fixed furrow irrigation.

The yield contributing characters and grain/tuber/seed/fruit yield of maize, sunflower, potato, tomato and watermelon were recorded from the plants during the experimental period. Three plants were randomly chosen to measure the yield components from each treatment. Economical yield (t/ha) were measured from the plants harvested from the selected rows of each plot. Yield was manually harvested. Water productivity (WP) was calculated as the ratio of yield and total seasonal water use which was expressed by the following equation.

$$\mathrm{WP}\ (\mathrm{kg}/m^3) = \frac{\mathrm{CY} \times 100}{\mathrm{SWCU}} \qquad (5)$$

Where, WP is the water productivity (kg/m^3), CY is the crop yield (t/ha) and SCWU is the amount of seasonal crop water use (mm).

11. Results and discussion

Data on hydraulic performances of new emitter, yield attributes, crop yield and water productivity were statistically analyzed to test the effects of irrigation levels and methods using R software version 3.5.0. All the treatment means were analyzed and compared for any significant differences using Microsoft Excel and R-statistical models at 5% (P≤0.05) probability level of significant. The figures were drawn using Microsoft Excel 2010. The analysis of the collected information/data based on lab and field experiments were as followed:

11.1 Development and evaluation of new emitter with low pressure (gravity) drip irrigation system

Hydraulic performances of new emitter and drip irrigation system

The mean discharge of new emitter rate at different operating pressures with various slopes was shown in **Fig. 25**. The hydraulic performances of new emitter with drip irrigation system for small farmers were measured and compared with Chinese emitter (**Table 11**). The results indicate that the slope of the drip irrigation increased, the discharge of the emitter also slightly increased. But the uniformity of the emitter discharge was not satisfactory. It was found that emitter discharge rates were observed nearly similarly trend at 1.5 m and 2.0 m operating pressure with 0% and 1% slopes. The discharge varied from 3.77 to 3.84 litre per hour at 1.5 m operating pressure, 4 to 4.9 litre per hour at 2 m operating pressure and 4.75 to 5.3 litre per hour at 2.5 m operating pressure with various slopes of 0, 1 and 1.5%, respectively. The hydraulic performance of drip irrigation system found the flow rate of emitter was increased when the increased of the pressure but there was a slight effect of slopes on emitter discharge. It is proved that the emitter discharge variation is mainly due to pressure differences and the manufacturing material quality. The performance of the new emitter and drip irrigation system was found better 1.5 m to 2.0 m operating pressure head at various slopes of 0%, 1% and 1.5 % slope respectively.

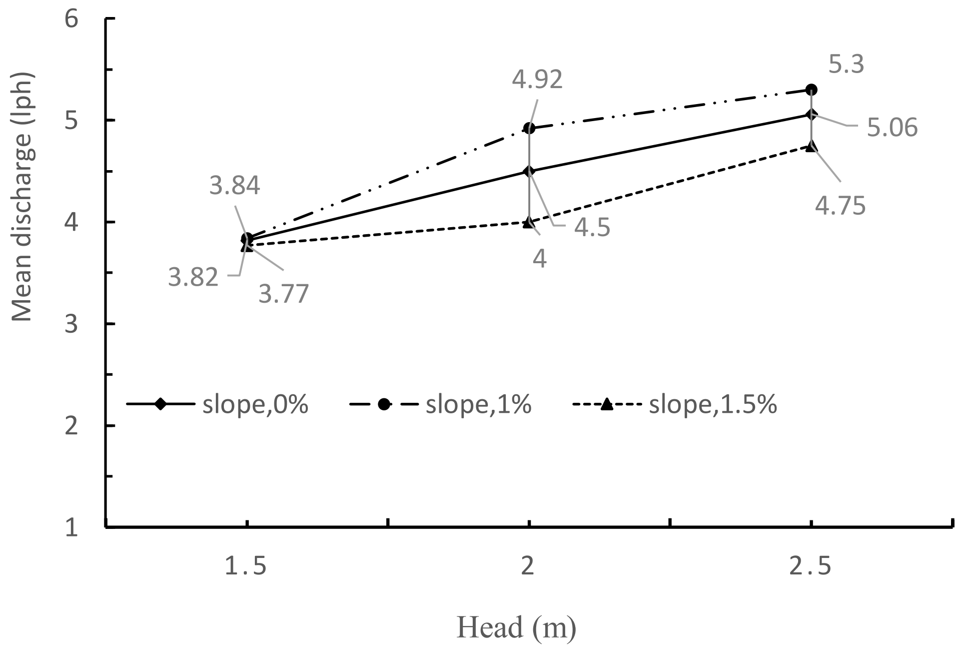


Fig. 24. Emitter mean discharge rate at different operating pressures with various slopes

Table 11. Test parameters of hydraulic performances

Head	Slope (%)	CV_m CN	CV_m IWM01 (BARI)	EU (%) CN	EU (%) IWM01 (BARI)	CU_c CN	CU_c IWM01 (BARI)	DU (%) CN	DU (%) IWM01 (BARI)	U_s CN	U_s IWM01 (BARI)	Q_{var} CN	Q_{var} IWM01 (BARI)
1.5m (15 kPa)	0	0.06	0.06	88.74	84.79	95.79	95.28	92.11	91.00	93.56	94.02	0.206	0.211
	1	0.07	0.06	89.70	88.31	93.77	95.22	91.61	92.92	92.87	94.25	0.210	0.203
	1.5	0.07	0.06	88.46	83.84	93.70	93.37	91.80	88.98	92.80	92.35	0.226	0.219
2.0 m (20 kPa)	0	0.04	0.05	90.41	88.10	96.77	96.52	92.10	93.94	95.98	95.53	0.136	0.181
	1	0.05	0.06	90.05	87.78	95.05	95.41	91.71	93.14	93.74	94.46	0.160	0.195
	1.5	0.06	0.08	88.10	85.68	95.8	93.33	92.47	89.73	94.32	92.70	0.170	0.219
2.5 m (24 kPa)	0	0.07	0.06	90.40	88.35	92.38	95.66	91.73	92.40	92.84	94.34	0.171	0.205
	1	0.06	0.04	88.05	88.98	94.85	96.60	92.42	94.12	94.11	95.15	0.186	0.195
	1.5	0.05	0.06	88.19	88.22	95.37	95.21	94.21	92.71	95.29	94.31	0.192	0.200

CN: Chinese manufacturer (Huawei), IWM01:New emitter developed by Irrigation and Water Management (IWM) Division under BARI and local manufactured by ARFA; CV_m indicates the co-efficient of variation, EU: Design emission uniformity, CU: Co-efficient of uniformity, DU: Distribution of uniformity, Us: Statistical uniformity and Qvar: Variable discharge.

However, new emitter with low pressure (gravity) drip irrigation system was installed, evaluated and compared with Chinese emitter at lab condition. The hydraulic parameters were determined and compared with Chinese emitter at lab conditions. Emitter discharge was measured under the variable operating heads of 1.5 m (15 kPa), 2.0 m (20 kPa), and 2.5 m (24 (kPa) and slopes of 0, 1 and 1.5 % at lab conditions. The performance of the new emitter with low pressure (gravity) drip irrigation system was found better 1.5 m to 2 m operating head at various slopes of 0% and 1%, respectively.

11.2 Adaptation of alternate furrow irrigation technique for maize and potato cultivation atDinajpur

Grain yield of maize

The effect of irrigation method yield and yield components of maize grain yield are presented in **Table 12**. It shows that grain yield of maize was nearly similar between the method of alternate furrow irrigation (T1) and the every furrow irrigation (T2). The grain yield of maize was slightly lower 2.6% in T1 as compared to T2 although alternate furrow irrigation (T1) saved 31% than traditional every furrow irrigation (T2) (**Table 14**). The mean yield was related to the amount of water supply and irrigation method. On an average, the total grain yield of maize produced almost similar in T_1 by 10.5 t/ha and T_2 by 10.8 t/ha (**Table 12**) when irrigated by AFI and EFI. The results indicated that when less amount of irrigation water was applied, the technique T_1 could maintain approximately similar grain yield compared to T_2 with almost 31% reduction in irrigation water. This technique involves alternately half of the root system being exposed to drying soil while the remaining half is normally irrigated with each irrigation event.

Table 12. Yield components and yield of **maize** under adaptation of alternate furrow irrigation technique at Dinajpur during 2017-2018

Location	Treatment	Cob length(cm)	Grain/cob (no.)	Grain weight /cob (g)	100 Seed weight (g)	Grain yield (t/ha)
Dinajpur	AFI	16.2 (11.04)	323.2 (15.78)	181.8 (9.77)	37.40 (7.05)	10.53 (6.38)
	EFI	16.4 (11.1)	325 (14.67)	178.8 (6.68)	37.35 (6.83)	10.82 (7.33)

In parentheses indicates the CV (Co-efficient of variation, %). IR: Irrigation, P_e: Precipitation/Rainfall (mm), T1: Alternate furrow irrigation (AFI), T2: Every furrow irrigation (EFI)

Tuber yield of potato

Yield and yield components of potato tuber under different AFI and EFI methods are shown in **Table 13**. The effect of irrigation methods showed that total potato tuber yield in $T1_3$ was similar trend as compared to traditional method of EFI. On an average, the total tuber yield produced almost similar in AFI by 29.9 t/ha and EFI by 30.9 t/ha (**Table 13).** On an average, the treatment T1 produced 3.2% lower tuber yield than the EFI although AFI saved 24% irrigation water than every furrow irrigation method (**Table 15**). This result indicates that the influence of irrigation methods had on tuber production. The average yield was related to the amount of water supply and distribution method. A successful AFI irrigation management depends on crops and cultivars, growing stage, evaporative demands, soil texture and soil water balance. AFI is generally a successful irrigation strategy in climates where drought-sensitive crops such as potatoes might not be under severe evaporative demands. Tuber yield reduction could be avoided due to controlling soil water.

Table 13. Yield components and yield of **potato** under adaptation of alternate furrow irrigation system

Location	Treatment	Tuber number/Plant (no.)	Tuber number/m^2 (no.)	Tuber yield/plant (kg)	Tuber yield (kg/m^2)	Tuber yield (t/ha)
Dinajpur	AFI	7.88 (11.76)	65.74	0.359	0.299	29.9 (22.44)
	EFI	8.0 (23.39)	66.67	0.371	0.309	30.91 (21.85)

In parentheses indicates the CV (Co-efficient of variation, %). IR: Irrigation, P_e: Effective precipitation rainfall (mm), T1: Alternate furrow irrigation (AFI), T2: Every furrow irrigation (EFI).

Fig.25. Adaptation of alternate furrow irrigation technique for maize and potato cultivation at the project site of Dinajpur during 2017-2018

Seasonal water use, water saving and water productivity of maize

The component of SCWU and WP of maize is shown in **Table 14**. SCWU and WP varied between the irrigation methods due to the variation of irrigation water use. AFI method greatly affected the WP for maize production (**Table 14**). Results show that T_1technique had greater WP compared to T_2 due to lower irrigation application and higher grain yield. AFI system gave higher WP compared to other method of EFI for maize cultivation. The water application method of AFIsaved 30% SCWU compared to EFI. The result indicated that T_1system maintained desired yield when rewatering irrigation was applied alternatively. As a result, WP was substantially improved by AFI. Therefore, water productivity was improved around 40% by AFI than EFI.

Table 14. Number of irrigation event, amount of applied irrigation water, seasonal crop water use (SCWU) and water productivity (WP) of **maize** cultivation under adaptation of alternate furrow irrigation at Dinajpursadarduring 2017-2018

Crop	Treatment	1st IR* (mm)	2nd IR (mm)	3rd IR (mm)	4th IR (mm)	P_e(mm)	SWC (mm)	SCWU (mm)	WP (kg/ha)	Water saving (%)
Maize	AFI	42	40	44	64	26	-12	204	5.16	31
	EFI	65	60	67	98	27	-22	295	3.67	-

*IR: Irrigation, P_e: Precipitation rainfall (mm), Alternate furrow irrigation (AFI), Every furrow irrigation(EFI)

Seasonal water use, water saving and water productivity of potato

The component of seasonal crop water use (SCWU) and water productivity of potato cultivation are shown in **Table 15**. SCWU and WP varied between the methods of AFI and EFI due to the variation of irrigation water apply to the fields. WP of AFI significantly increased as compared to EFI (**Table 15**). The mean values of WP were recorded 26 kg/m^3 for AFI followed by 20 kg/m^3 for EFI. The water application method of AFI saved 24% seasonal irrigation water than EFI. On the other hand, WP was increased in AFI by 28% compared to EFI. However, AFI has the potential to save water and is a useful irrigation water application method where water and water supply methods are limited to irrigation for crop cultivation.

Table 15. Number of irrigation event, amount of applied irrigation water, seasonal crop water use (SCWU) and water productivity (WP) of **potato** cultivation under adaptation of alternate furrow irrigation at Dinajpursadarduring 2017-2018

Crop	Treatment	1st IR (mm)	2nd IR (mm)	3rd IR (mm)	4th IR (mm)	P_e(mm)	SWC (mm)	SCWU (mm)	WP (kg/ha)	Water saving (%)
Potato	AFI	31	28	23	24	0	9	115	26.0	24
	EFI	46	42	40	0	0	24	152	20.34	-

IR: Irrigation, P_e: Precipitation rainfall (mm), T1: Alternate furrow irrigation (AFI), T2: Every furrow irrigation (EFI)

Based one study, it may be concluded that alternate furrow irrigation (AFI) has the potential to improve the water productivity. On average, AFI and EFI produced around 10.5 and 10.8 t/ha of maize grain yield and 29.9 and 30.9 t/ha of potato tuber yield. AFI technique saved seasonal crop water use around 31% for maize and 24% for potato and water productivity improved by 40% for maize and 28% for potato cultivation. AFI is a useful irrigation water application method where water and water supply methods are limited to irrigation for crop cultivation.

11.3 Adaptation of drip-fertigation for tomato cultivation in drought and saline prone area of Dinajpur and Koira, Khulna

Fruit yield of tomato

Yield components of tomato influenced by the methods of irrigation water application are shown in **Table 16**. The water application method had effect on marketable yield of tomato between the treatments of drip fertigation and traditional farmers' irrigation practices. In treatment T1 (Drip fertigation) produced 62 t/ha in Khulna and 51.5 t/ha in Dinajpur and T2 (Traditional irrigation practices) produced 48.4 t/ha in Khulna and 46.9 t/ha in Dinajpur. On an average, tomato fruit yield was found in higher around 22% in Khulna and 8.9% in Dinajpur in treatment T1 as compared to T2. The results (**Table 16, Fig. 25**) indicates that drip fetigation with the less amount of irrigation water may take the advantage of the physiological response which can maintained more yield as compared to traditional.

Table 16. Yield components and yield of **tomato**under adaptation of drip irrigation system in Khulna and Dinajpur

Location	Treatment	Fruit /Plant (no.)	Fruit weight/ plant (kg)	Fruit yield (t/ha)
Khulna	* Drip irrigation	53 (5.66)	2.55 (4.89)	62.14 (4.90)
	Farmers' practice	44 (6.01)	1.98 (5.60)	48.39 (5.70)
Dinajpur	Drip irrigation	50 (11.23)	2.13 (9.1)	51.45 (9.13)
	Farmers' practice	46 (6.87)	1.86 (3.96)	46.89 (3.96)

*T1: Drip irrigation at 3-5 days interval, T2: Farmers' practice (Traditional surface flooding irrigation). In parentheses indicates the CV

Fig.26. Adaptation of drip-fertigation on tomato in salt-affected area of Koira, Khulna and Dinajpur

Seasonal water use and water productivity of tomato

Seasonal crop water use (SCWU) and water productivity (WP) of tomato over two locations are shown in **Table 17.** SCWU and WP varied between the treatments of T1 (Drip irrigation) and T2 (Traditional irrigation practices) due to the variation of water saving technique. **Table 17** shows that the water application method of T1 saved averagely 45% SCWU compared to T2 in both locations of Khulna and Dinajpur. The highest WP obtained in T1 (Table 17) but did not produce the noticeably higher yield. WP was greater by 57% in Khulna and 50% in Dinajpur in T1 than T2. Traditional irrigation system states that yield is sensitive to water application method, irrigation interval and water stress. From this study, T1 system maintained tomato yield when irrigation was applied frequently with low irrigation water supply. As a result, WP was substantially improved by T1. The results indicated that T1 had the potential to save water and may useful irrigation water application method where water and water supply methods are limited to irrigation for crop production.

Table 17. Amount of applied irrigation water, seasonal crop water use (SCWU) and water productivity (WP) of **tomato** cultivation under different irrigation technique at Koyra and Dinajpur

Crop	Location	Treatment	PE (mm)	Total applied water (mm)	Effective P_e (mm)	SWC (mm)	SCWU (mm)	WP (kg/ha)	Water saving (%)
Tomato	Khulna	* Drip irrigation	3	143	46	2	194	32.03	46
		Farmers' practice	3	314	46	-5	358	13.51	-
	Dinajpur	Drip irrigation	5	110	27	11	153	33.62	45
		Farmers' practice	5	241	27	6	279	16.80	-

*T1: Drip irrigation at 3-5 days interval, T2: Traditional surface flooding irrigation, PE: Plant establishment irrigation water, SWC: Soil water contribution, SWU: Seasonal crop water use

Soil moisture dynamics

The soil moisture content (SMC) variations with in 0-45 cm soil depth with 15 cm increaments obtained regular interval from sowing to harvest in the experimental plot during the growing season of tomato under the drip fertigation (P1 near to emitter, P2 in between two emitter) and traditional farmers practice (P1 near to plant and P2 in between two plant) are shown in **Fig. 27**. Soil moisture content was increased or decreased followed by irrigation or rainfall and then decreased gradually. The figures indicate that soil moisture increased in drip fertigation (T1) at the emitter position P1 and decreased in between two emitter (T1-P2) during the tomato growing season. The plants extractable available soil water which was not drasticaly reduced due to maintain the irrigation at 3-5 days intervals and supply the desired amount of irrigation water for tomato production. Soil water content was observed greater in treatments T1 in the soil layer of 0-45 cm with increments 15 cm depth. The soil water content was decreased the irrigation method of famers practice of T2 in postion P2.

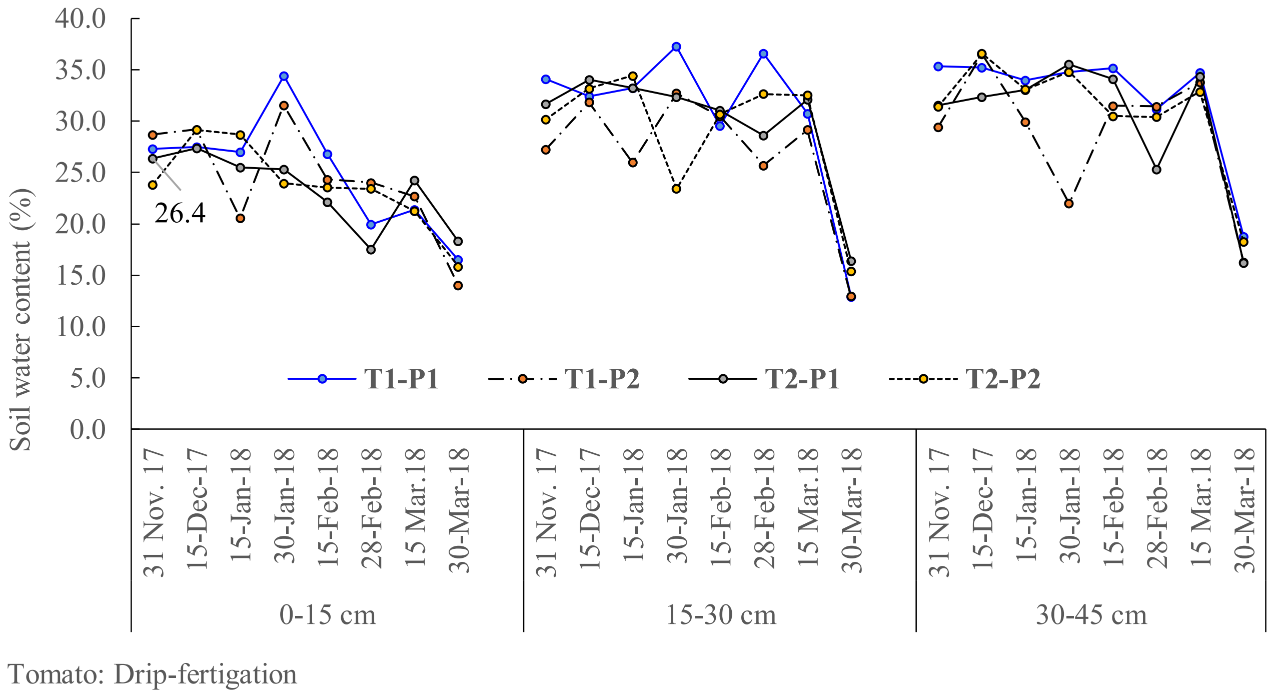


Fig. 27. Variations of gravimetric soil water content (SWC) at different soil layers with 15 cm increment during crop growth season of 2017-2018 at Koyra, Khulna. Soil sampling P1 near to emitter, P2 in between two emitter and soil sampling P1 near to plant and P2 in between two plant in farmers'practice.

Soil salinity dynamics

During the tomato growing season from November 2017 to March 2018, the variations of soil salinity in 0-45 cm soil depth with 15 cm increaments for the irrigation method of drip irrgation in position P1 near to emitter, P2 in between two emitter and traditional practices in position P1 near to plant and P2 in between two plant are in **Fig. 28**. The changes in soil salinity varied from 2.8 dS/m (November, 2017) to 15 dS/m (February/March, 2018) in 45 cm soil profiles with 15 cm increments. The greater changes in soil salinity occurred at the end of the growing season of February/March 2018 in treatment T2 (Traditional irrigation practices) and varied from 7 to 15 dS/m to the beginning (November 2017) of the growing season on average 2.8 to 3.7 dS/m on the top layer of the soil profiles. Similar trends were observed on the other soil profiles. In this study, the salinity dynamics showed that salt accumulation occurred around 12 to 20% lower (on average) in drip irrigation (T1) than traditional farmers' practices (T2) in 0-45 cm depth of soil profiles. In this study, the figures indicate that the soil salinity was not substantially greater salt accumulation in T1 than the treatment of T2 due to continuous soil wet the root zone portion of plant. Besides, salt accumulation was generally higher in the soil surface in treatment T2 due to water uptake and more soil evaporation. However, drip irrigation could be practiced with pond or brackish water (low salinity) for tomato cultivation in the salt affected coastal areas of Bangladesh.

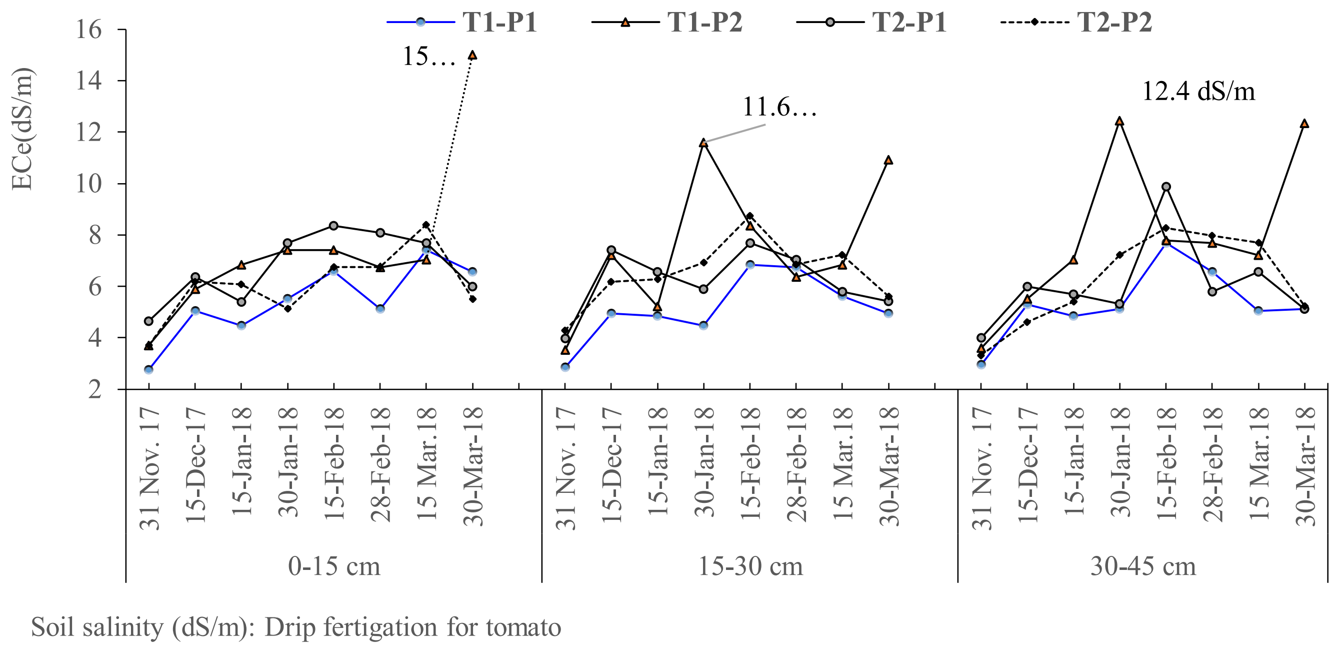


Fig. 28. Variations of soil salinity dynamics expressed as EC_e of soil solution ($EC_{1:5}$) over the soil profile during crop growth season of 2016-2017 at Koyra, Khulna. Soil sampling P1 near to emitter, P2 in between two emitter and soil sampling P1 near to plant and P2 in between two plant).

Osmotic potential

The osmotic potential in the soil profiles during the tomato growing season from November 2017 to March 2018 for drip irrigation in two position (P1 near to emitter, P2 in between two emitter) and traditional irrigation practices treatments (P1 near to plant and P2 in between two plant) are shown in **Fig. 29**. The Osmotic effects on plants that is associated with soil salinity. Generally, plants struggle to take up water when the total potential of the soil solution exceeds -1000 kPa and will permanently wilt at -1500 kPa. Osmotic potential of the soil solution increase with increasing soils dry as decreasing soil moisture and vise-versa. The figures indicate that the osmotic pressure was found lower in drip irrigation system (T1) in position near to emitter P1 than traditional farmers' irrigation practices in the soil profiles of 0-45 cm depth with 15 cm increments. The higher osmotic pressure was found in later growth stages of crop and highest in March 2018 due to more soil water uptake and soil moisture evaporation from the soil surface. This study indicated that the osmotic potential ranged in both treatments was -378 kPa to -627 kPa from sowing to harvest which is also lower than severe value of -700 kPa. This study also demonstrated that the osmotic effect is reasonable in drip irrigation technique which has no influence in limiting crop production.

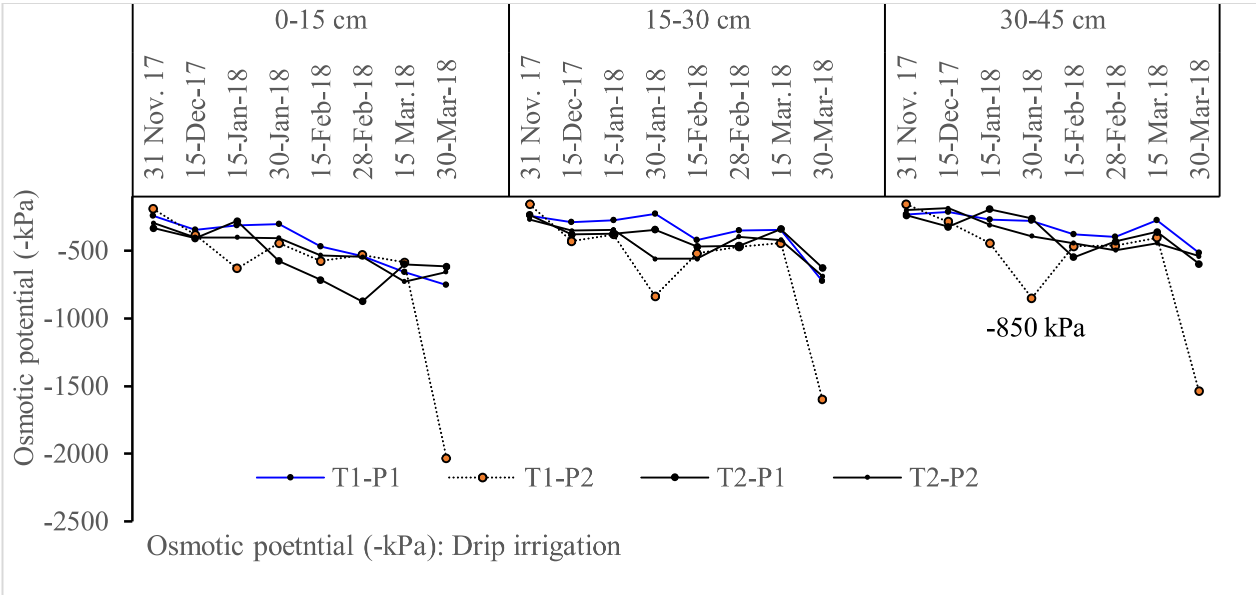


Fig. 29. Variations of soil osmotic potential (-kPa) dynamics at different depths of soil profiles with 15 cm increment during the crop growing season of 2017-2018. Soil sampling P1 near to emitter, P2 in between two emitter and soil sampling P1 near to plant and P2 in between two plant).

However, soil moisture content increased in drip irrigation technique (T1) decreased in traditional irrigation practices (T2) during the tomato growing season. The changes in soil salinity varied from 2.8 to 3.7 dS/m (November 2017) to 15 dS/m (February/March 2018) in 45 cm soil profiles with 15 cm increments. The salinity dynamics showed that salt accumulation occurred around 12 to 20% (on average) lower in T1 than T2. The osmotic pressure was found lower in T1 than T2. The higher osmotic pressure was found in later growth stages of crop and highest in February/March. The osmotic potential ranged in both treatments was -378 kPa to -627 kPa from sowing to harvest. T1 produced fruit yield of tomato 62.14 t/ha in Koyra, Khulna and 51.45 t/ha in Dinajpur and T2produced 48.39 t/ha in Khulna and 46.89 t/ha in Dinajpur. On an average, tomato fruit yield was found in higher around 22% in Khulna and 8.9% in Dinajpur in T1 as compared to T2. T1 saved averagely 45% SWU as compared to T2 in both locations of Khulna and Dinajpur. WP was greater by 57.8% in Khulna and 50% in Dinajpur in T1 than T2. This study also demonstrated that the soil moisture content, soil salinity and osmotic effects are reasonable in drip irrigation technique which has no influence in limiting crop production. Drip fetigation with the less amount of irrigation water may take the advantage of the physiological response which can maintained more yield as compared to traditional. So, drip irrigation had the potential to save irrigation water and may useful irrigation water application method where water and water supply methods are limited to irrigation for crop production.

11.4 Adaptation of drip-fertigation for watermelon cultivation in drought and saline prone area of Dinajpur and Koyra, Khulna

Yield of watermelon

Yield components and yield of watermelon under the adaptation of drip fertigation at the salt affected area of Koyra, Khulna is shown in **Table 18**. Number of fruit and unit fruit weight increased with drip fertigation with higher values for drip-fertigation at 3-5 days interval (T1) than conventional/farmers' practices (T2). In treatment T1 produced watermelon by 31 t/ha and T2 produced 25.4 t/ha. On an average, watermelon fruit yield was found in higher around 19% intreatment T1 as compared to T2. The results (**Table 18, Fig. 30**) indicates that drip fertigation with the less amount of irrigation water may take the advantage of the physiological response which can maintained greater size as well as yield of watermelon as compared to traditional farmers' practice.

Table 18. Yield components and yield of **watermelon** under adaptation of drip irrigation system

Location	[a]Treatment	Fruit/Plant (no.)	Unit fruit weight (kg)	Fruit weight per plant (kg)	Yield (t/ha)
Koyra, Khulna	*Drip irrigation	2.8 (39.12)	7.05	17.3 (20.12)	31.34 (42.22)
	Farmers'practice	2.2 (49.79)	5.72	10.49 (20.11)	25.41 (42.17)

*T1: Drip irrigation at 3-5 days interval, T2: Traditional surface flooding irrigation, PE: Plant establishment irrigation water, SWC: Soil water contribution, SWU: Seasonal crop water use

Fig. 30. Adaptation of drip-fertigation for watermelon cultivation at the salt affected area of Koyra, Khulna

Water use and water productivity of watermelon

Seasonal crop water use (SCWU) and water productivity (WP) of watermelon at the salt affected area of Koyra, Khulna is presented in **Table 19.** SWU and WP varied between the treatments of T1 (Drip fertigation) and T2 (Traditional irrigation practices) due to the variation of water supply technique. Total seasonal water use varied greatly across the two treatments, from 132 mm with drip fertigation at 3-5 days interval to 249 mm with farmers' practice. **Table 19** indicates that the water application method of T1 saved averagely around 47% SWU compared to T2. Water productivity was highest at drip fertigation with 3-5 days irrigation intervals, at around 23.7 kg/m^3 and 10.2 kg/m^3 in farmers' practice. The highest WP obtained in T1 (**Table 19**) but did not produce the noticeably higher yield. WP was substantially improved by T1, at around 132% as compared to T2. The results indicated that T1 had the potential to save irrigation water and may useful irrigation technique at the salt-affected areas of coastal region where water saving technique is limited to irrigation for watermelon cultivation.

Table 19. Amount of applied irrigation water, seasonal crop water use (SCWU) and water productivity (WP) of **watermelon** cultivation under adaptation of drip irrigation at Koyra, Khulna during 2017-2018

Crop	Location	Treatment	Total applied water (mm)	Effective P_e (mm)	SWC (mm)	SWU (mm)	WP Kg/m^3	Water saving (%)
Watermelon	Khulna	*Drip irrigation	55	75	2	132	23.74	47
		Farmers'practice	179	75	-5	249	10.20	-

T1: Drip fertigation at 3-5 days interval, T2: Traditional surface flooding irrigation, SWC: Soil water contribution, SWCU: Seasonal water crop use

The higher fruit yield (31.34 t/ha) of watermelon was obtained from the water saving technique of drip irrigation at 3-5 days interval (T1) upto full development of fruits, while the lower fruit yield (25.4 t/ha) was obtained from farmers practice treatment T2. Seasonal crop water use saved around 46% by drip irrigation at 3-5 days interval and water productivity was improved at around 132% by drip irrigation than traditional farmers' irrigation practices. Water productivity of watermelon was found to be the higher (23.7 kg/m^3) when irrigation was applied drip irrigation at 3-5 days interval while the lower (10.2 kg/m^3) was obtained from the farmers' practice in treatment T2. Drip irrigation technique at 3-5 days interval can be a good option for watermelon production at the salt affected areas of coastal regions of Bangladesh.

11.5 Development and adaptation of furrow irrigation technique on salinity, yield and water productivity of sunflower and maize in saline area of Koyra, Khulna

The innovative idea on fixed furrow irrigation (FFI) with planting techniques (top corner of the raised bed: 60 cm furrow to furrowcentre) have been established, evaluated and compared with alternate and traditional/every furrow irrigation at the salt affected area of Koyra, Khulna for maize and sunflower cultivation.

Soil water dynamics

The gravemetric soil water content (SWC) variations within 0-45 cm soil depth with 15 cm increaments obtained different interval from sowing (November 2017) to harvest (March, 2018) in the experimental plot during the growing season of sunflower for raised bed planting and furrow irrigation techiques are presented in **Fig. 31**. An increase or decrease soil water content was observed followed by irrigation or rainfall or water uptake by plant or evaporation from soil surface and then decreased gradually. During sowing of sunflower, initial soil water content among the treatments was similar trends at the upper layer of the soil (0-15 cm soil depth) and slightly more at lower depth of soil (**Fig. 31**). The trend of soil water contents among the treatments in 0-45 cm soil profiles decreased from sowing to harvest. Soil water content was observed greater in treatments T5 (EFI) than other treatments of T1, T2, T3 and T4 and T6 in the 60 cm soil profiles. The results (**Fig. 31**) indicate that SWC decreased during the growing season, but the soil water was not drasticaly reduced due to maintain the standard irrigation schedule and using the water saving techniques for sunflower cultivation.

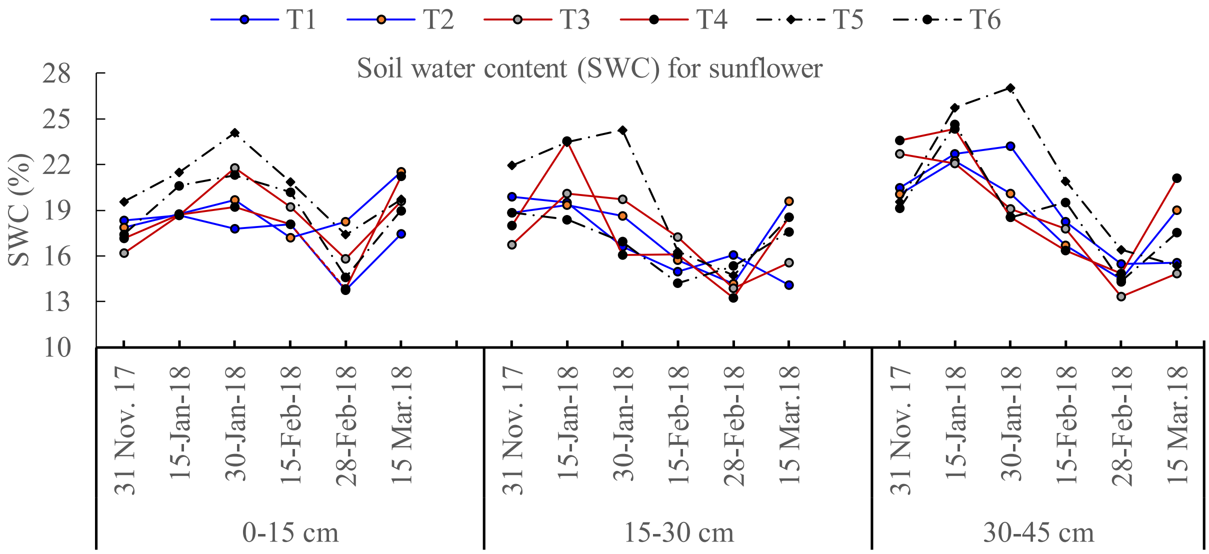


Fig. 31. Variations of gravimetric soil water content at different soil layers with 15 cm increment during crop growth season of November 2017 to March 2o18 at Koyra, Khulna.

Soil salinity dynamics

Soil salinity in 0- 45 cm soil profiles during the growing season of sunflower for various treatments are presented in **Fig. 32**. On average, the changes in soil salinity varied from 1.0 dS/m (November 2017) to 7.0 dS/m (February /March 2018) in 45 cm soil depth. The highest changes in soil salinity occurred at the growing season February/March 2018 compared to the beginning of the growing season November 2017. At sowing time, the soil salinity was observed in similar among the treatments in 0-45 cm soil layers with 15 cm increments soil depth. The salinity dynamics showed that the salt accumulation occurred greater in the treatment T5 (EFI) compared to the other treatments of T1, T2, T3, T4, and T6. The results of EC_e (**Fig. 32**) indicates that soil salinity almost similar to the treatment of T1, T2 (AFI) and T5, T6 (EFI) at the lower depth of soil layers but the soil salinity was slightly lower in treatment T4 and T3 (FFI) compared to the other treatments of AFI and EFI due to continue irrigation supply to the fixed furrow. As a result, the fixed furrow technique (FFI) keeps the soil wet and moves the salinity to the dry parts of the furrow. In this study, the figures indicate that the soil salinity was not substantially higher salt accumulation in soil profiles among the treatments due to irrigate the crop using pond water (low to medium salinity) and salinity may tolerable for sunflower crop production in the coastal areas of Bangladesh. However, sunflower production would be practiced using raised bed planting with water saving fixed furrow irrigation technique where salinity and available irrigation water problem in the coastal areas of Bangladesh.

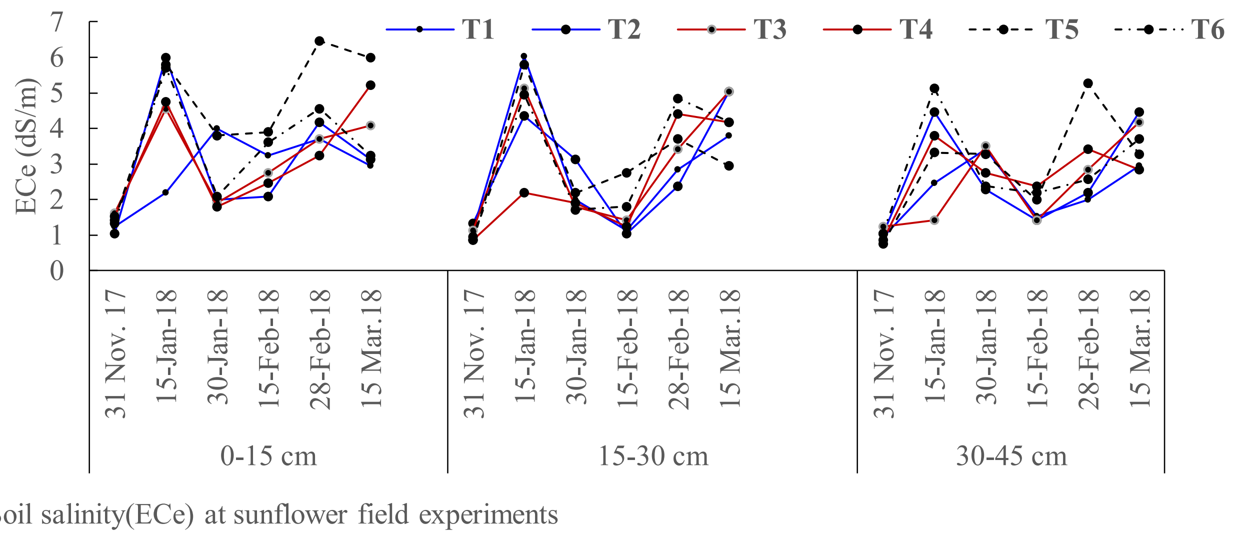


Fig. 32. Variations of soil salinity dynamics expressed as EC_e of soil solution ($EC_{1:5}$) over the soil profile of 0-45 cm during crop growth season of 2017-2018

Osmotic potential

The osmotic solute of the soil profiles 0 - 45 cm with 15 cm increments during the sunflower growing season from November 2017 to March 2018 for AFI, FFI and EFI techniques are shown in **Fig. 33**. The Osmotic effects on plants that is associated with soil salinity and soil water content. Generally, plants struggle to take up water when the total potential of the soil solution exceeds -1.0 MPa and will permanently wilt at -1.5 MPa. Osmotic potential of the soil solution increase with decreasing soil moisture and decrease with increase soil moisture. The results (**Fig. 33**) indicate that the osmotic pressure was found lower in FFI (T3 and T4) than EFI and AFI in soil profiles of 0-45 cm depth with 15 cm increments. The higher osmotic pressure (-kPa) was found in later growth stages of crop and highest in February 2018 due to more soil water uptake and soil moisture evaporation from the soil surface. This study indicated that the osmotic potential ranged in treatment of FFI was -90 kPa to -580 kPa from sowing to harvest which is also lower than severe value of -700 kPa. This study also demonstrated that the osmotic effect is reasonable in FFI and AFI technique which has no influence in limiting crop production.

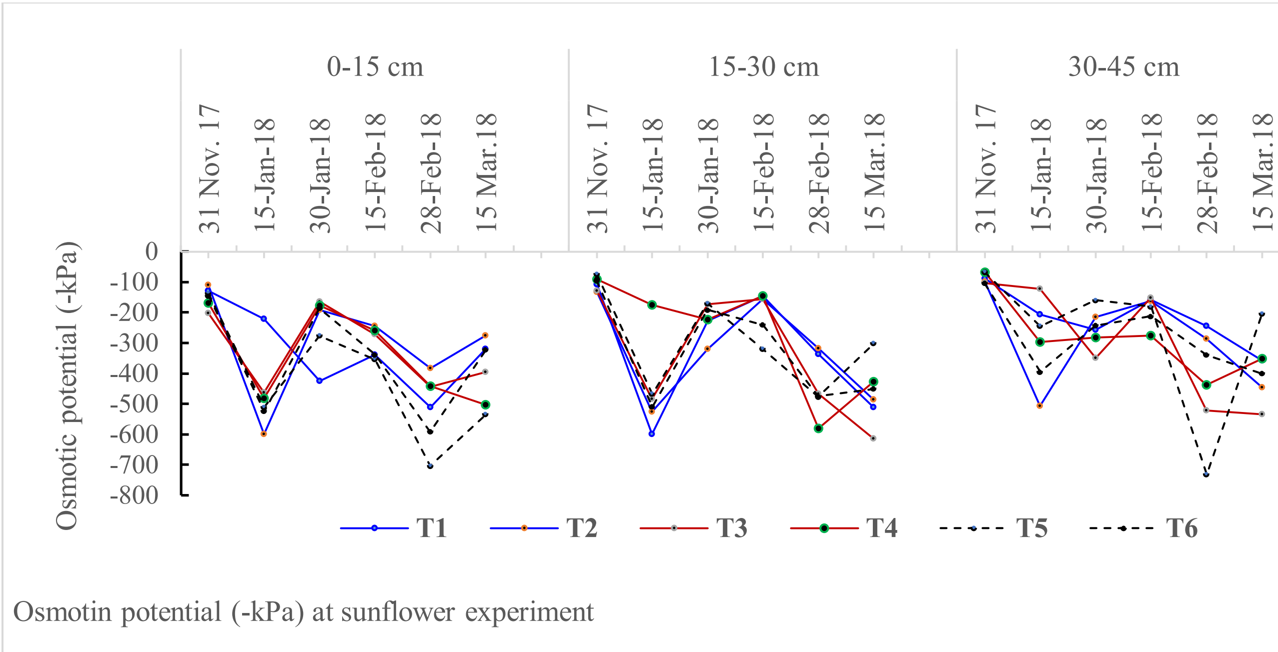


Fig. 33. Variations of soil osmotic solute of soil solution ($EC_{1:5}$) over the soil profile of 0-45 cm during sunflower crop growth season of 2017-2018

Yield and yield components of sunflower

Yield and yield components of seed yield under raised bed planting (topcentre and corner of raised bed) and furrow irrigation techniques for sunflower is shown in **Table 20 (Fig. 34).** The mean seed yield of sunflower ranged from 2.46 (T2) to 2.69 (T1) t/ha. The raised bed planting (topcentre and corner of raised bed) and the techniques of alternate and fixed furrow irrigation had no significant effect influenced on seed yield and yield components of sunflower. The seed yield contributing characters, like as head dia, seed weight per head, 100 seed weight and seed yield of sunflower were found insignificant difference among the treatments. The raised bed planting with saving furrow irrigation techniques (AFI and FFI) using pond or brackish water with EC of ≤4.5 dS/m) could be option for developing better irrigation practices for sunflower cultivation in coastal areas of Bangladesh.

Fig. 34. Photographic view of sunflowercultivation under raised bed planting and AFI/FFI irrigation technique at Koyra, Khulnaduring 2017-2018

Table 20. Yield and yield components of **sunflower** under raised bed planting and furrow irrigation techniques at Koyra, Khulnaduring 2017-2018

Crop	Treatment			Head dia (cm)	Seed/Head (no.)	Seed weight/ head (g)	100 Seed weight (g)	Seed yield (t/ha)
Sunflower	AFI	PM1	T1	19.3 ab	1358 b	114.1a	8.45 a	2.69 a
		PM2	T2	21.3 a	1804 a	115.4a	7.74 a	2.46 a
	FFI	PM1	T3	19.7 ab	1584 ab	115.0a	8.04 a	2.56 a
		PM2	T4	17.6 b	1483 ab	111.2a	8.10 a	2.58 a
	EFI	PM1	T5	18.7 b	1522 ab	113.7a	8.23 a	2.62 a
		PM2	T6	19.1 ab	1655 ab	114.3a	8.04 a	2.56 a
	CV			7.38	13.65	6.01	6.00	6.36

Yield and yield components of maize

Yield and yield components of maize under raised bed planting (top centre and corner of raised bed) and furrow irrigation techniques for maize is shown in **Table 21** (**Fig. 35)**. The yield contributing parameters like as, cob length, cob diameter, number of grain, grain weight per cob and grain yield were found non-significant difference among the treatments. The mean grain yield of maize ranged from 10. 31 t/ha (T4) to 10.55 (T3) t/ha. Yield almost similar among the treatments. There was no significant differences among the treatment. Results indicated that raised bed planting (top/centre of raised bed) and furrow irrigation techniques with EC of ≤4.5 dS/m (pond or brackish water) had no significant effect on grain yield of maize.The technique of fixed or alternate furrow irrigation with pond or brackish water irrigation (2 < EC ≤4.5 dS/m) could maintain approximately similar trend of grain yield at the salt affected areas of coastal zone where fresh water (low salinity) is not available for rabi crop cultivation.

Fig. 35. Photographic view of maizecultivation under raised bed planting and irrigation technique at Koyra, Khulnaduring 2017-2018

Table 21. Yield and yield components of **maize** under raised bed planting and furrow irrigation techniques at Koyra, Khulnaduring 2017-2018

Crop	Treatment			Cob length (cm)	Cob diameter (cm)	Grain /Cob (no.)	Grain weight /Cob (g)	Grain yield (t/ha)
Maize	AFI	PM1	T1	21.6 a	4.70 a	517 ab	182.8a	10.36 a
		PM2	T2	21.5 a	4.90 a	493 b	185.7a	10.52 a
	FFI	PM1	T3	21.2 a	4.63 a	522 a	186.3a	10.55 a
		PM2	T4	21.0 a	4.40 a	502 ab	182.0a	10.31 a
	EFI	PM1	T5	20.9 a	4.83 a	519 ab	184.4a	10.45 a
		PM2	T6	19.6 a	4.57 a	503 ab	182.9a	10.37 a
	CV			8.39	5.99	3.04	5.2	5.3

Water use and water productivity of sunflower

Seasonal crop water use (SCWU) and water productivity (WP) of sunflower under different raised bed planting and furrow irrigation techniques are given in **Table 22**. Seasonal water use ranged from 198 mm (T4) to 289 mm (T5) (**Table 22**) due to the variation of water saving technique. Water productivity of sunflower under different treatments ranged from 0.89 (T6) to 1.26 kg/m^3 (T1) (**Table 22**). The WP was found significant difference among the treatments but there was no significant difference between the irrigation technique of AFI (T1, T2) and FFI (T3, T4). The results indicate that WP values significantly affected by irrigation method, decreasing greatly with increasing amount of water supply. WP is also strongly related to climatic variability. WP varies not only from region to region but also from field to field depending on many factors including method, water, soil and crop management practices (**Table 22**). The results of this study indicate that increasing seasonal irrigation with decreasing WP. Less irrigation allowed greater use of soil water and rainfall, thereby increasing the crop yield and water WP. SWU varied greatly across from the treatment of AFI (T1, T2) to 198 mm and FFI (T4, T5) to 198 mm with water saving technique to EEFI (T5, T6) to 289 mm with farmers' practice. **Table 22** indicates that the water saving method of AFI and FFI saved around 31% SWU compared to EFI. The water productivity was significantly found greater at AFI and FFI at around 1.31 to 1.36 kg/m^3 compared to 0.89 to 0.91 kg/m^3 in farmers' practice. The highest WP was substantially improved by AFI and FFI, at around 44% as compared to EFI. The results indicated that AFI or FFI had the potential to save irrigation water and may useful irrigation technique at the salt-affected areas of coastal region where water saving technique is limited to irrigation for *rabi* crops cultivation.

Table 22. Number of irrigation event, amount of applied irrigation water, seasonal crop water use (SCWU) and water productivity (WP) of **sunflower** cultivation under raised bed planting and irrigation technique at Koyra, Khulnaduring 2017-2018

Crop	Treatment			1st IR (mm)	2nd IR (mm)	3rd IR (mm)	P_e(mm)	SWC (mm)	SCWU (mm)	WP (kg/ha)		Water saving (%)
Sunflower	AFI	PM1	T1	53	52	41	46	5.88	198	1.36	a	31
		PM2	T2	53	52	41	46	6.25	198	1.25	a	
	FFI	PM1	T3	53	52	41	46	5.92	198	1.29	a	32
		PM2	T4	53	52	41	46	4.73	197	1.31	a	
	EFI	PM1	T5	88	85	67	46	2.55	289	0.91	b	-
		PM2	T6	88	85	67	46	2.42	288	0.89	b	

Water use and water productivity of maize

The component of seasonal crop water use (SCWU) and water productivity (WP) of maize under different raised bed planting and furrow irrigation techniques are presented in **Table 23**. Seasonal water use averagely varied from 260 mm (AFI or FFI) to 364 mm (EFI) with traditional irrigation practices (**Table 23**) due to the variation of water supply techniques. Water productivity of maize under different treatments varied from 2.9 (EFI) to 4 kg/m^3 (AFI/FFI) (**Table 23**). The WP was significantly different between the methods of AFI/FFI and EFI but there was no significant difference between the irrigation technique of AFI (T1, T2) and FFI (T3, T4). WP was substantially improved by AFI and FFI, at around 39% as compared to EFI. The results indicate that WP values significantly affected by irrigation method. WP decreases greatly with increasing amount of water supply and vise-versa. WP is also strongly related to climatic variability. WP varies not only from region to region but also from field to field depending on many factors including method, water, soil and crop management practices (**Table 23**). The results of this study indicate that increasing seasonal irrigation with decreasing WP. Less irrigation allowed greater use of soil water and rainfall, thereby increasing the crop yield and water WP. The results indicated that raised-bed planting with alternate or fixed furrow irrigation system had the potential to save irrigation water at the salt-affected areas of coastal regions where water saving technique is limited to irrigation water supply for maize or *rabi* crops cultivation.

Table 23. Number of irrigation event, amount of applied irrigation water, seasonal crop water use (SWU) and water productivity (WP) of **maize** cultivation under raised bed planting and irrigation techniques at Koyra, Khulnaduring 2017-2018

Crop	Treatment			1st IR (mm)	2nd IR (mm)	3rd IR (mm)	4th IR (mm)	P_e(mm)	SWC (mm)	SCWU (mm)	WP (kg/m^3)	Water saving (%)
Maize	AFI	PM1	T1	53	52	41	38	79	-4	259	4.00a	28.7
		PM2	T2	53	52	41	38	79	-4	259	4.06a	
	FFI	PM1	T3	53	52	41	38	79	-3	261	4.05a	28
		PM2	T4	53	52	41	38	79	-5	259	3.98a	
	EFI	PM1	T5	88	85	67	63	79	-18	364	2.87b	-
		PM2	T6	88	85	67	63	79	-19	363	2.86b	

Based on one year study, the raised-bed planting with fixed furrow system would be a water-wise irrigation based agriculture practice for row and high value-crops in the scarcity of fresh water at salt affected areas of coastal region in Bangladesh. AFI and FFI saved SCWU around 28 to 31% and WP was substantially improved at around 39 to 44% than traditional every furrow irrigation. The water saving technique of alternate or fixed furrow irrigation with pond water ($1.0 \geq$ EC dS/m ≤ 4.5) to irrigation at different growth stages of maize and sunflower crop in coastal areas of Bangladesh could be an alternative irrigation scheduled and method for increasing yield and water productivity during rabi (fallow) season in the salt affected areas of Bangladesh. However, further studies are needed to continue and expansion of maize crop in coastal salt affected areas of Bangladesh where fresh water (non-saline) is not available for irrigating the *rabi* crops.

11.6 Comparative study on irrigation methods for Bt-brinjal (Eggplant) cultivation of Dinajpur, Khulna and Gazipur

Yield and yield components of Brinjal over three locations

Yield and yield components of brinjal under different irrigation methods are shown in **Table 24**. There was a significant interaction between the location and water saving method of drip irrigation, alternate furrow irrigation (AFI), fixed furrow irrigation (FFI), deficit irrigation, and every furrow irrigation (EFI). The interactive effect of locations and methods showed that total marketable brinjal yield in drip irrigation (M1) was higher compared to other methods at three locations during the brinjal growing season of 2017-2018. The yield contributing parameters like as fruit per plant and fruit weight per plant were found significant difference among the methods of drip irrigation (M1), AFI(M2), FFI (M3), deficit irrigation (M4) and EFI (M5) under different locations. The M1 technique produced higher marketable fruit yield by 7.6, 28, 15 and 5.8% in Khulna, 2.1, 22, 19.6, 3.7 % and 6.3, 17.5, 21.52, 3.7% than M2, M3, M4 and M5 (**Table 24**). AFI (M2) and EFI (M5) produced almost similar yield but significantly varied from location to location.

Table 24. Yield and yield components of brinjal (BARI Bt-Begun-2) cultivation under different water saving techniques at Koyra, Khulna, Gazipur and Dinajpursadarduring 2017-2018

Location	Treatment	Fruit / plant (no.)		Fruit weight/ plant (kg)		Fruit yield (t/ha)	
Khulna	*M1	56.00	a	3.12	a	41.62	a
	M2	52.00	b	2.88	b	38.46	b
	M3	42.00	e	2.24	d	29.83	d
	M4	44.66	d	2.65	c	35.35	c
	M5	47.33	c	2.94	b	39.21	b
Gazipur	M1	24.33	f	2.24	d	29.91	d
	M2	23.33	f	2.19	d	29.28	d
	M3	20.66	g	1.74	fg	23.27	fg
	M4	19.66	g	1.80	ef	24.04	ef
	M5	25.66	f	2.16	d	28.88	d
Dinajpur	M1	20.00	g	1.95	e	25.98	e
	M2	20.66	g	1.82	ef	24.35	ef
	M3	18.33	g	1.61	gh	21.43	gh
	M4	20.00	g	1.53	h	20.39	h
	M5	20.33	g	1.88	ef	25.03	ef

*M1: Drip irrigation at 3-5 days interval, M2: Alternate furrow irrigation at 10-12 days interval, M3: Fixed skip furrow irrigation at 10-12 days interval, M4: Deficit irrigation (80% of FC, i.e. 20% less of full irrigation water at each irrigation event), M5: Farmers ‘practice/Traditional every furrow irrigation (M5).

Results showed that yields were not significantly differ among the methods. The water application method varied significantly on yield contributing parameters and total yield of Brinjal among the treatments over the locations. There was a consistent trend for similar yield among the irrigation methods over three locations. Total yield in treatment of FFI (M3) was found lightly lower over three locations due to limited nutrient uptake for prolonged soil drying in one side root of the plant for long duration of the wide space of raised furrow during the crop growing season. The results indicated that when less amount of irrigation water was applied, water saving technique of drip irrigation or AFI could maintain approximately increase or similar yield compared to EFI (M5) with almost 38% reduction in irrigation water by drip irrigation and 29% reduction in irrigation water by alternate furrow irrigation. These two techniques involve alternately half of the root system being exposed to drying soil while the remaining half is normally irrigated with each irrigation event.

Fig. 35. Photographic view of brinjal cultivation under different water saving technologies at Khulna, Gazipur and Dinajpursadarduring 2017-2018

Seasonal water use and water productivity of brinjal

Seasonal water use (SWU) and water productivity (WP) of brinjal over three locations are shown in **Table 25.** SWU varied among the treatments of irrigation method due to the variation of irrigation water supply technique. WP was significantly varied among the irrigation methods. **Table 25** shows that the water application method of drip irrigation technique (M1), alternate furrow irrigation (M2), fixed furrow irrigation (M3) and deficit irrigation (M4) saved averagely around 38%, 29% and 17 % SWU compared to traditional every furrow irrigation (M5), over three locations of Khulna, Gazipur and Dinajpur, respectively. The WP was obtained significantly highest in M1, at around 19.59 kg/m^3 and the WP of AFI, FFI, deficit irrigation and EFI were obtained averagely 16.22, 13.30, 11.43 and 11.54 kg/m^3. WP was substantially improved at M1, M2 and M3 by 69, 40 and 15% compared to M5. The results indicated that water saving technique of drip irrigation, AFI and FFI had the potential to save water and may useful as irrigation water application method where water and water supply methods are limited to irrigation for crop production.

Table 25. Comparative number of irrigation event, amount of applied irrigation water, seasonal crop water use (SCWU) and water productivity (WP) of Brinjal (BARI Bt-Begun-2) cultivation under different water saving technologies at Khulna, Gazipur and Dinajpursadarduring 2017-2018

Crop	Location	TT	PE (mm)	1st IR (mm)	2nd (mm)	3rd IR (mm)	4th IR (mm)	Effective rainfall (mm)	SWC (mm)	SCWU (mm)	WP (Kg/m^3)		Water saving (%)
Brinjal	Khulna	*M1	1	126				79	-19	187	22.25	a	38
		M2	1	50	41	32	27	79	-18	212	18.14	c	30
		M3	1	50	41	32	27	79	-20	210	14.20	g	31
		M4	1	65	55	42	35	79	-22	256	13.83	h	10
		M5	1	81	69	53	44	79	-21	306	12.81	i	-
	Gazipur	M1	3	130				63	-9	187	15.99	e	38
		M2	3	51	32	30	45	63	-10	214	13.68	h	29
		M3	3	51	32	30	45	63	-8	216	10.77	l	28
		M4	3	66	39	40	58	63	-5	264	9.10	n	13
		M5	3	82	48	50	72	63	-16	302	9.57	m	-
	Dinajpur	M1	3	87				27	13	127	20.54	b	38
		M2	3	46	29	32	0	27	8	145	16.85	d	29
		M3	3	45	27	30	0	27	12	144	14.93	f	29
		M4	3	60	36	40	0	27	14	180	11.35	k	12
		M5	3	75	45	50	0	27	5	205	12.24	j	-

*M1: Drip irrigation at 3-5 days interval, M2: Alternate furrow irrigation at 10-12 days interval, M3: Fixed furrow irrigation at 10-12 days interval, M4: Deficit irrigation (80% of FC, i.e. 20% less of full irrigation water at each irrigation event), M5: Farmers 'practice/Traditional every furrow irrigation (M5).

However, the results obtained showed that drip and alternate/fixed furrow irrigation methods might be optioned for irrigation water supply based on water utilization and yield compared to traditional furrow irrigation method at the stress prone areas of Bangladesh. Water saving techniques of drip irrigation technique, alternate furrow irrigation, fixed furrow irrigation and deficit irrigation saved averagely around 38%, 29% and 17 % SCWU and WP improved by 69%, 40%, and 15% compared to traditional every furrow irrigation over three locations of Khulna, Gazipur and Dinajpur, respectively. Water saving techniques of drip irrigation and alternate/fixed furrow irrigation with the less amount of irrigation water may take the advantage of the physiological response which can maintained more yield as compared to traditional. So, water saving techniques had the potential to save irrigation water and may useful irrigation water application method where water and water supply methods are limited to irrigation for crop production.

Other activities

One day training program was organized at drought and saline prone areas of Dinajpur and Koyra, Khulna during the project year of 2017-2018 with the improved water saving technologies of the adaptive trials. Local farmers/NGOs/SAEO selected for the training and total 51 participants were trained by two batches of the project sites during 2018. Twenty six farmers including SAAO were trained in the project area of Koyra, Khulna and twenty five farmers were trained in the project area of Dinajpur. All trainees were received skill training on the practical use of site specific water saving technologies of drip-fertigation, alternate and fixed furrow irrigation and every furrow irrigation. One additional activity on field day for water saving technologies for upland crops at Dinajpur was organized under this sub project (**Fig. 38**). Farmers, SAEO, scientists, specialists were attended this field day. Some other activities like as BTV recorded (**Fig. 39**) and newspaper clipping (**Fig. 40**) were published.

Fig. 37. Photographic view of farmers training at Dinajpur and Koyra, Khulna

Fig. 38. Photographic view of field day on water saving technologies for upland crops at Dinajpur

Fig. **39**. BTV recorded and published on water saving technologies at salt-affected area of Koyra, Khulna.

Fig. 40. Newspaper clipping for adaptation of water saving technologies in the sub-project sites of Dinajpur and Khulna.

Fig. **41**. Monitoring team members of Director, PIU, NATP-2, and CSO, NRM Division, BARC and Experts/Specialists/farmers were visited the field experiments at Gazipur.

However**,** based on one year study, improved irrigation water saving techniques were more effective for plant growth and desired yield in both locations. Proper irrigation practices can maintain crop growth and yield by avoiding water stress and suppressing the buildup of soil salinity in the salt affected area. Site specific water saving technologies, like as, drip-fertigation (Saline and non-saline area), alternate furrow irrigation (Saline & non-saline area) and fixed furrow irrigation techniques (Salt-affected area only) were selected and adapted at farmers' field conditions. The water saving techniques of drip irrigation at 3-5 days interval, AFI and fixed furrow irrigation method saved seasonal crop water use at around 24 to 44% and water productivity was substantially improved by 28 to 60% compared to traditional irrigation practices. Moreover, because of the insufficiency of surface and ground water resources and raising salinity, drip irrigation, alternate/fixed furrow irrigation methods are highly recommended to site specific areas of Bangladesh for a sustainable use of this natural water resources and changing climate. Further trials are needed to continue and expansion of *rabi* crops in dry environment of drought and saline prone areas of Bangladesh where fresh water (non-saline) is not available for *rabi* crops cultivation.

12. Research highlight/findings (Bullet point – max 10 nos.):

The major findings of the sub-project are as follows:

- The raised bed alternate and fixed furrow irrigation techniques for potato, maize, sunflowerand brinjal were developed.

- Water saving techniques of alternate or fixed furrow irrigation have been saved seasonal crops (potato, maize, sunflower, brinjal) water use from 24 to 32%while drip irrigation at 3-5 days interval saved seasonal crops (brinjal, tomato, watermelon) water use from 38 to 47%compared to traditional furrow irrigation.

- Water productivity has substantiallyimproved from 28 to 40% while drip-irrigation at 3-5 days interval improved water productivity from 50 to 60% compared to traditional furrow irrigationwhile drip irrigation at 3-5 days interval saved seasonal crops (brinjal, tomato, watermelon) water use from 38 to 47%compared to traditional irrigation.

- New emitter with low pressure (gravity) drip irrigation system was developed for efficient application of water to individual plant.

- The hydraulic performance of the developed drip irrigation system was found better at 1.5 m to 2 m operating head with various slopes of 0% and 1%, and emitter discharge rate was found from 3 to 5 litre/hour.

- A total of 51 farmers including SAAO were trained in the project areas of Koyra, Khulna and Dinajpur. Some other activities like field day at Dinajpur, BTV recorded at Koyraand newspapers clipping were published.

- Water saving techniques of alternate furrow irrigation, fixed furrow irrigation and drip-irrigation have the potential to save water without any sacrifice in yields of crops. Moreover, because of the insufficiency of surface and ground water resources and raising salinity, these efficient irrigation techniques are needed to continue and expansion of different *rabi* crops at drought and coastal salt affected areas of Bangladesh for sustainable food security.

B. Implementation Position

1. Procurement:

Description of equipment and capital items	PP Target		Achievement		Remarks
	Phy (#)	Fin (Tk)	Phy (#)	Fin (Tk)	
(a) Office equipment	GD-1 &GD-2	275,000.00	GD-1 &GD-2	207,500	Procurement was achieved 100% based on PP target and plan.
(b) Lab &field equipment	GD-3	184,000.00	GD-3	183,244	
(c) Other capital items	-	-	-	-	
Total	-	459,000.00	-	390,744	

2. Training/study tour/ seminar/workshop/conference organized:

Description	Number of participant			Duration (Days/weeks/ months)	Remarks
	Male	**Female**	**Total**		
(a) Training	46	5	51	One day	Two farmers' training conducted at the both sites of Koyra, Khulna and Dinajpur
(b) Workshop	-	-	-	-	-

C. Financial and physical progress

Fig in Tk

Items of expenditure/activities	Total approved budget as per PP	Revised budget	Fund received	Actual expenditure	Balance/ unspent	Physical progress (%)	Reasons for deviation
A. Contractual staff salary	221000	223484	223485	223485	0	100	• Extreme remote locations and various field experiments on various crops. • Slow process and limited fund released.
B. Field research/lab expenses and supplies	510000	602207	603811	603811	0	100	
C. Operating expenses	350000	319191	257904	257904	0	100	
D. Vehicle hire and fuel, oil & maintenance	175000	140075	132776	132776	0	100	
E. Training/workshop/seminar	150000	139300	139300	139300	0	100	
F. Publications and printing*	100000	150000	84042	*133776 (48776 + *85000)	-49734	100	
G. Miscellaneous	35000	35000	28000	35000	-7000	100	
H. Capital expenses	459000	390744	447478	390744	56734	100	
Total	**2000000**	**2000000**	**1916796**	**1916796**	**0**	**100**	

*PCR will be printed by PIU, NATP-2, BARC. BDT 85000 (Eighty five thousand) taka was transferred to PIU, NATP-1, BARC for PCR printing.

D. Achievement of Sub-project by objectives: (Tangible form)

Specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output(i.e. product obtained, visible, measurable)	Outcome(short term effect of the research)
i. To develop raised bed alternate and fixed furrow irrigation techniques for upland major crops in salt prone areas	• Raised bed furrow irrigation and planting method with top corner/side slope of the bed was established at the salt affected area.	• Alternate and fixed furrow irrigation and planting method with top corner/side slope of the bed were developed.	• Water saving techniques of alternate and fixed furrow irrigation have the potential to save water without any sacrifice in yields of crops.
ii. To develop new emitter with drip irrigation systems forhigher water uniformity of high value upland crops	• Development, installation and evaluation of new emitter with low pressure (gravity) drip irrigation system at lab conditions. • ASAE test standards procedure (1996) was followed to determine the hydraulic parameters of co-efficient of variation (CV_m), emission uniformity (EU), co-efficient of uniformity (CU), distribution uniformity (DU), and statistical uniformity of water application (Us) under different head and slopesat lab conditions.	• New emitter with low pressure (gravity) drip irrigation system was developed for efficient application of water to individual plant. • The hydraulic performance of the developed drip irrigation system was found better at 1.5 m to 2 m operating head with various slopes of 0% and 1%, and emitter discharge rate was found from 3 to 5 litre/hour. • About five thousand emitters are sold to the farmers/users during project periods.	Local manufacturer (ARFA) is producing new emitter which is developed during this sub-project.Some importer is imported from China and India with high cost. Now, price is drastically reduced for producing low cost new emitter through this sub-project.
iii. To validate and adapt the site specific water saving technologies at farmers' field condition for crop production.	• Selection of sites • Selection of farmers and crops • Basic information of the sites • Field experiments/adaptation of alternate furrow irrigation techniques on potato and maize, raised bed furrow irrigation and planting method with top corner/side slope of the bed,drip-fertigation on tomato and watermelon, and comparative study on irrigation methods for brinjalat the salt-affected and drought prone areas of Bangladesh were evaluated. • Training and skill development • Data collection and analysis • Field visit/Monitoring • Report preparation and submission	• Six major upland crops (maize, sunflower, potato, tomato, bt-brinjal (eggplant) and watermelon) were selected for adaptive trails. • Site specific water saving technologies on drip-fertigation, raised bed alternate and fixed furrow irrigation and planting techniques were selected. • Total 10 farmers were selected at both sites of the sub-project. • Five adaptive trials on each site based on site specific water saving technologies and crops were demonstrated widely for evaluation. • Water saving techniques of alternate or fixed furrow irrigation saved seasonal crops (potato, maize, sunflower, brinjal) water use from 24 to 32% while water productivity improved from 28 to 40%. • Drip irrigation at 3-5 days interval saved seasonal crops (brinjal, tomato, watermelon) water use from 38 to 47% and improved water productivity from 50 to 60% compared to traditional furrow irrigation. • One leaflet was published and distributed. • A total of 51 farmers including SAAO were trained in the sub-project areas of Koyra, Khulna and Dinajpur. • Some other activities like field day at Dinajpur, BTV recorded at Koyraand newspapers clipping were published.	• Improved water productivity • Increased efficient use of irrigation water • Improved the livelihood of the farmers • Increased awareness of the farmers and farmers are more confident that growing upland major rabi crops is possible in the salt affected remote area of Koyra, Khulna and drought area of Dinajpur. • Improved linkage among researchers, DAE and farmers.

E. Materials Development/Publication made under the Sub-project:

Publication	Number of publication		Remarks (e.g. paper title, name of journal, conference name, etc.)
	Under preparation	Completed and published	
Technology bulletin/ booklet/**leaflet**/flyer etc.		01 (Leaflet)	Low cost drip-fertigation irrigation technique for crop production
Journal publication	01 (Manuscript)	Accepted Date: 24 July 2019	**Title**: Development and Evaluation of an Emitter with a Low-pressure Drip-Irrigation System for Sustainable Eggplant Production **Journal name**: AgriEngineering **Publisher**: MDPI
Information development		-	-
Other publications, if any	-		National (Daily Ittefaq) and local newspapers and BTV have been recorded and published the sub-project activities to disseminate and awareness the water saving technologies.

F. Technology/Knowledge generation/Policy Support (as applied):

i. Generation of technology (Commodity & Non-commodity)

- Development of New Emitter with Gravity (low pressure) Drip Irrigation System for Small Farmers
- Development of raised bed alternate and fixed furrow irrigation with top corner/side slope planting technique at salt areas of Bangladesh

ii. Generation of new knowledge that help in developing more technology in future

Development of new online emitter with high pressure drip irrigation system, new establishment of raised bed alternate furrow irrigation, fixed furrow irrigation and planting method with top corner/side slope of the raised bed at drought and salt affected areas can offer an alternative and suggestive future technology in Bangladesh.

iii. Technology transferred that help increased agricultural productivity and farmers' income

Water saving methods on drip-fertigation for watermelon and tomato, alternate furrow irrigation and fixed furrow irrigation techniques for maize, potato, sunflowerhave potential to save water, labor, time and money as well as raise the farmers' income by increasing the crop and water productivity during *Rabi* season at the areas where irrigation water is not available for *Rabi* crops cultivation.

iv. Policy Support

Water saving irrigation techniques on drip-fertigation for watermelon and tomato, alternate furrow irrigation and fixed furrow irrigation techniques for maize, potato, sunflower etc. are needed to continue and expansion of different *Rabi* crops at drought and coastal salt affected areas of Bangladesh for increasing cropping intensity as well as sustainable food security. These technologies could be demonstrated among the farmers further in other drought and saline prone areas of Bangladesh to cope with the adaptation of climate change effects and to achieve the agricultural research vision 2030, sustainable development goal 13 and Vision-2021 (Target 7-sub-target 6) for sustainable food security.

G. Information regarding Desk and Field Monitoring

i) Desk Monitoring [description & output of consultation meeting, monitoring workshops/seminars etc.):

Group discussion with researchers/resource personnel was done for development and adaptation of water saving technologies at drought prone area of Dinajpur and salt affected areas of Koyra, Khulna. Region wise farmers was selected for this project through the assistance of OFRD, BARI and local office of DAE, Bangladesh. The standard procedure was followed to achieve the goal of the sub-project on water saving techniques for different crops. The site specific irrigation methods and crops selection was monitored based on availability of land and labor, soil properties, and source of irrigation water, the local climate, soil properties and existing practices of the farmers' field of the selected sites. Five major upland and high value crops (maize/potato/sunflower/tomato/watermelon) was selected after discussion with expert scientists. PIU, NATP-2, BARC was also monitored and regularly suggested to successfully implement the project activities.

ii) Field Monitoring (time& No. of visit, Team visit and output):

The physical progress, effect and short-term impact of the sub-project was major output of the field monitoring. Site specific water saving technologies and crops selection were done through group discussion with farmers, researchers, DAE and local personnel on 08-08-2017 in Dinajpur and 08-10-2017 at Koyra, Khulna. Director, PIU, NATP-2, BARC and Director (Research), BARI with experts/specialists/scientists was visited the field experiments at Gazipur on 14-03-2018. CSO, NRM Division, BARC was also visited and monitored the field experiments, training program at Gazipur and Koyra, Khulna on 18-03-2018. CSO (IWM), CSO (ASICT) & member secretary of CRG monitoring team of sub-projects under BARI, SSO (IWM, WRC), UAO (Koyra, Khulna), SO (IWM), BARI, SO (ARS), Dinajpur and SO (OFRD), Khulna were visited and regularly monitored the field research activities. Training and skill development program on water saving technologies was organized for farmers including SAAO on 18-03-2018 at Koyra, Khulna and 19-04-2018 at Dinajpursadar. The RFL Company, local manufacturer and Professors of BSMRAU was visited and suggested during the test of new emitter with drip irrigation systemon 19/21-09-2017. The RFL Company, local manufacturer are motivated and highly convinced for producing new emitter. The investigators of the sub-project, CSO and head of the IWM Division, BARI was directly involved in conducting the field trials. Related resource personnel was also invited for the field visit/training. To achieve the objectives, it was planned to implement the sub-project with collaboration of DAE and ARS/OFRD of BARI at grass root level with technical all supports assistance from IWM division, BARI, Gazipur.

H. Lesson Learned

We have learnt how to developed and disseminate the water saving technologies. Many farmers in the sub-project area were not used modern irrigation techniques for cultivation of rabi crops. Through our activities, they are learning how to use drip and furrow irrigation techniques for growing tomato, Brinjal, watermelon and potato, maize, sunflower. Farmers never seen before use drip irrigation, alternate and fixed furrow irrigation techniques. During our field experiments, we have found that some farmers are interested to use the modern irrigation techniques. I think, we have successfully organized and managed the farmers in every site, helping each other and sharing experiences and knowledge. Regular monitoring is also very important with local persons to the field sites. Water saving methodson drip-fertigation, alternate and fixed furrow irrigation techniques have potential to save water, labor, time and money as well as raise the farmers' income by increasing the crop and water productivity during rabi season in the areas where irrigation water is not available for crops cultivation.

I. Challenges

The effective period of this sub-project was very short for implementing the project activities to three sites including one remote site in the salt affected coastal zone of Koyra, Khulna with limited background and experiences. We have purchased some field and lab research equipment within limited time by following the guidelines.Many field experiments were conducted at the salt affected area of Koyra and drought prone area of Dinajpur although fund was limited. Slow process of limited fund released and received is challenged to implement the sub-project activities. Account pay check system and monthly reports/any time reports are sometimes difficult to submit in time. So, it was a challenge to develop and disseminate the water saving technologies and motivate the farmers for adaptation and adoption of the water saving technologies within very short period.

Signature of the Principal Investigator
Date ………………………….
Seal

Counter signature of the Head of the organization/authorized representative
Date ………………………….
Seal