EFFECT OF ALTERNATE WETTING AND DRYING FURROW IRRIGATION ON THE YIELD AND WATER USE EFFICIENCY OF MAIZE

A THESIS

BY

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Student No.: 1505286

Session: Thesis Semester: July-Dec/2016

MASTER OF SCIENCE (M.S.)
IN
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DEPARTMENT OF AGRICULTURAL AND INDUSTRIAL ENGINEERING

HAJEE MOHAMMED DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200

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JUNE, 2017

DEDICATED TO MY

BELOVED PARENTS

AND

HONORABLE TEACHERS

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The Author *June 2017*

ABSTRACT

Efficient irrigation method is now essential in the areas where water resources are scare for irrigation. Therefore, a new method of irrigation was used to investigate the effect of alternate furrow irrigation on crop performances, seasonal water use (SWU) and water use efficiency (WUE) of maize at ARS, BARI, Dinajpur. Field experiments were laid out in a randomized complete block design in a spilt plot design with nine treatments replicated thrice. The treatments were accommodated by three irrigation levels viz. I_1, I_2 and I_3: Irrigation water applied to 100%, 80% and 60% field capacity, respectively and three methods (M_1, M_2 and M_3:Alternate wetting and drying furrow irrigation (AWDFI), Fixed wetting and drying furrow irrigation (FWDFI) and Traditional furrow irrigation (TFI), of irrigation respectively). Results showed that AWDFI could maintain approximately similar grain yield compared to TFI with almost 50% reduction in irrigation water when irrigated to 100% FC. The interactive effect of irrigation levels and methods had significant effect on crop growth rate (CGR) in the crop biomass and grain yield among the treatments while the same level of irrigation produced insignificant difference between the alternate furrow irrigation (M_1) and traditional furrow irrigation (M_3) methods. But significantly better CGR and grain yield compared to the fixed furrow irrigation (M_2) method were obtained. AWDFI and TFI produced around 9.5 and 9.9 t/ha when irrigation water was applied to 100% field capacity. AWDFI saved 27, 24 and 19 % SWU compared to TFI when irrigation water was applied to 100, 80 and 60% FC. WUE was substantially improved by AWDFI. WUE was higher around 23, 22 and 19% in AWDFI system than TFI when irrigating with 100, 80 and 60 % FC. However, alternate wetting and drying furrow irrigation is an effective and water-saving irrigation technique which improves water use efficiency without insignificant yield reduction and may have the potential to be used in drought fields where maize production is heavily dependent on irrigation.

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ABBREVIATIONS

AEZ	:	Agro-ecological Zone
AFI	:	Alternate Furrow Irrigation
APRI	:	Alternate Partial Root-Zone Irrigation
AWD	:	Alternate Wetting and Drying
AWDFI	:	Alternate Wetting and Drying Furrow Irrigation
BARC	:	Bangladesh Agricultural Research Council
BARI	:	Bangladesh Agricultural Research Institute
BE	:	Bed Planting
BMD	:	Bangladesh Meteorological Department
CFI	:	Controlled Furrow Irrigation
CFI	:	Critical Furrow Irrigation
CFI	:	Conventional Furrow Irrigation
CGR	:	Crop Growth Rate
CI	:	Conventional Irrigation
cm	:	centimeter
DFI	:	Double Furrow Irrigation
DI	:	Deficit Irrigation
DU	:	Distribution Uniformity
Ea	:	Application Efficiency
EAFI	:	Exchangeable Alternate Furrow Irrigation
EC	:	Electrolyte Conductivity
EFI	:	Every Furrow Irrigation
ER	:	Effective Rainfall
et al	:	et alia (1) and other
ET	:	Evapotranspiration
etc	:	etcetera (L) and other
ETc	:	Crop Evapotranspiration
FAFI	:	Fixed Alternate Furrow Irrigation
FC	:	Field Capacity
FFI	:	Fixed Furrow Irrigation
FL	:	Flat Planting
FPRI	:	Fixed Partial Root-Zone Irrigation

FTF	:	Farmers Traditional Flooding
FU	:	Furrow Planting
FWC	:	Fruit Water Content
FWDFI	:	Fixed Wetting and Drying Furrow Irrigation
GY	:	Grain Yield
HSTU	:	Hajee Mohammad Danesh Science and Technology University
IWM	:	Irrigation and Water Management
IWP	:	Irrigation Water Productivity
IWUE	:	Irrigation Water Use Efficiency
Kg/m^3	:	Kilogram per Cube meter
Kg	:	Kilogram
LSD	:	Least Square Design
MOP	:	Murate of Potash
MSL	:	Mean Sea Level
NDVI	:	Normal Difference Vegetation Index
PRD	:	Partial Root Zone
RLD	:	Root Length Density
RS	:	Root System
SAFI	:	Surge Alternate Furrow Irrigation
SPAC	:	Soil Plant Atmosphere Continuum
SRDI	:	Soil Resource Development Institute
SWU	:	Seasonal Water Use
TDM	:	Total Dry Matter
TFI	:	Traditional Furrow Irrigation
TGW	:	Thousand Grain Weight
TSP	:	Triple Super Phosphate
USDA	:	United State Department of Agriculture
WCU	:	Water Consumptive Use
WP	:	Water Productivity
WR	:	Water Requirement
WUE	:	Water Use Efficiency

CHAPTER I

INTRODUCTION

CHAPTER I

INTRODUCTION

Maize is the third most important grain crop in the world. It is one of the most important high yielding cereal crops with wide adaptability to diverse agro-climatic conditions (Jat et al., 2006; Amiruzzaman and Hossain, 2015) after rice and wheat in Bangladesh. Recently, maize cultivation area and production is increasing rapidly due to high demand in dairy and poultry farm. Every year approximately 1.2 million ton maize is utilized of which only 42% is produced by the country and remaining is imported from other countries (BBS, 2005). Maize is also an excellent human food as well as animal feed and fodder (Alam et al., 2003). More than 90% of maize is used as poultry feed and the remaining in fish sector and as human food products. The country's poultry industry continues to grow and so there is also a growing demand for maize. The country has a great potentiality to improve and expand the maize production.

Maize is traditionally grown in dry season (Rabi season) under irrigated conditions. Water scarcity is the main constraint for crop production during Rabi season. Now, irrigation has become a vital issue to implement the concept of using less water to produce optimum yield. A sustainable use of water resources is increasingly becoming an acute world-wide problem. Generally, maize is grown either on raised bed in rows or by random broadcasting followed by traditional furrow or flooding irrigation systems. Traditional irrigation practices influence on water productivity and contribute greatly to the labor cost for excess irrigation and lower yield resulting in lower economic returns. Maize cannot tolerate more than 24 hours waterlogging conditions (Amiruzzaman and Hossain, 2015). Yield can be reduced due to excess soil moisture, nutrient and oxygen availability and disfavor temperature in the root zone whereas available soil water is necessary to maintain the effective leaf water potential under evaporative demand in the atmosphere (Quanqi et al., 2008).

So, sustainable irrigation water supply technique and effective water management methods are an urgent need today with changing climate. Water saving technology in agriculture is also a challenging task under climate change for improving water use efficiently (WUE). Suitable irrigation water supply methods such as sprinkler, drip-fustigation, sub-surface and sustainable available ground and surface water resources are limited in Bangladesh. Water saving technologies and productivity per unit of water are becoming of strategic importance for Bangladesh likewise many other countries, namely USA, China, India and Malaysia, etc.

Efficient on-farm water management practices have an important role to play in enhancing the improvement of water as well as nutrient use efficiency. Most of the surface irrigation methods result in poor water application efficiency. However, application efficiency may be achieved through efficient irrigation methods. PRD or alternate furrow irrigation (AFI) is an ideal improvement of DI, which is relatively easy to apply in the field conditions and it is essential in the areas where water resources are limited (Sepaskah and Ahmadi 2010). The idea of PRD irrigation was first introduced by Grimes et al. (1968) and later on, some extensive studies were conducted by Sepaskhah et al. (1976), Liu et al. (2003), Zegbe et al. (2004), Halim (2013), on various crops such as cotton, grape, potato, maize and tomato.

The idea of the AWDFI has been taken from the concept of partial root zone drying concept. This is essential to adopt under field conditions for sustainably increasing WUE. AWDFI is an irrigation technique by which water is applied in alternate furrows keeping the in-between furrow dry. In subsequent irrigation, water is applied to the alternate furrows that had been kept dry on the previous occasion. The soil sub-surface might be wetted after irrigation due to lateral movement. Partial drying of the root system saved water and increased the water use efficiency without much yield reduction (Kang and Zhang 2004; Li et al., 2007). It is reported that AFI technique can save irrigation water by 25 to 35% compared to TFI with the increase or decrease in crop yield to the extent of 2 to 16% (Reddi and Reddy 2009). The alternate furrow irrigation method is essential where the supply of irrigation water is limited. Therefore, water saving techniques, such as alternate wetting and drying furrow irrigation (AWDFI) for maize cultivation should be used. It may be introduced for improving water use efficiency (WUE) and other constraints associated with environment and socio-economic conditions.

Many studies (Khan et al., 1992; Roy et al, 1992; Biswas et al., 2002) have been conducted to improve the water use efficiency for maize cultivation. Islam et al. (2008) reported that irrigation up to 100% of depleted soil moisture with standard doses of fertilizer produced the highest maize yield. Regulated deficit irrigation can save water and maintain the maize production without drastic reduction of yield (Sarkar et al., 2012). But, there are still lack of reports on improving maize cultivation through the response of alternate wetting and drying furrow irrigation method. Hypothetically, it would increase the water productivity and reduce the input cost for maize cultivation. Therefore, the specific objectives of this study were:

- To assess the crop performances
- To evaluate the seasonal crop water use and water productivity.

CHAPTER II

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

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. Under climate change situation, Bangladesh agriculture will more affected by water scarcity during rabi season (November-April) which ultimately create a challenge to sustainability in crop production. Appropriate water saving technologies can address the upcoming challenge in agriculture due to climate change. Improved irrigation method is also essential for avoiding soil water and nutrient leaching as well as groundwater pollution and plays an important role in achieving desired crops yield. The most common method in Bangladesh practiced for cultivating maize crop is furrow and flood irrigation. 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 deficit irrigation and partial root-zone drying (PRD) technique which is essential under limited water resources and is relatively easy to apply in the field conditions for increasing WUE. AFI is a new water saving irrigation technology for row crops cultivation where irrigation water is supplied in alternate furrows and in-between furrow kept dry. The soil sub-surface will be wetted after irrigation due to lateral movement. In recent years, some studies have been reported that AFI system saved water and increased the water use efficiency without significant yield reduction. In this chapter, an attempt has been made to review on alternate furrow irrigation and its effect on growth, yield and yield components of maize.

Kang et al., (1998) designed and tested a new method of irrigation for its water use efficiency (WUE). Maize plants were grown in pots with their roots divided and established into two or three separated containers of which irrigation and soil drying was controlled alternately. Results showed that when the two halves of the root system were alternatively exposed to a drying soil and a soil with its water content maintained above 55% or 65% of its field capacity, water consumption was reduced by 34.4±36.8% and the total biomass production was reduced by only 6±11%, when compared to the well-irrigated plants. Significant increase in WUE, root to shoot ratio and stomata resistance for water diffusion were observed as a result of such treatment. Leaf transpiration was reduced substantially while the rate of photosynthesis and leaf water content was not significantly altered. The results were also compared to root-divided plants of which irrigation was fixed to one container only and showed that a better WUE, root development and distribution, shoot biomass production were achieved by the alternate drying and rewetting. They concluded that the controlled alternate irrigation (CAI) is an effective and water saving irrigation method and may have the potential to be used in the field.

Ramalan and Nwokeocha (2000) conducted a field experiment during the dry season of 1993/1994 at the Irrigation Research Farm, Institute for Agricultural Research, Samaru, Nigeria to evaluate water management options on the performance of tomato. The trial involved three furrow irrigation methods (conventional furrow, conventional furrow with cutback, and alternate furrow), two mulch treatments (without mulch and straw mulch), and three irrigation schedules (5-day interval, irrigation at 30 and 60 kPa soil moisture suction). The 18 treatments were laid out in a split-plot design in three replications. The irrigation method was assigned to the main plot while the mulch and irrigation schedule were in the subplots. Days to 50% flowering and fruiting of tomato were unaffected by furrow irrigation methods. But, the applications of mulch and irrigation at the specified suction levels have had influence on growth of tomato. The rice straw mulch on furrows significantly delayed the attainment of 50% fruiting by 6 days compared to the un-mulched plots. Fruit sizes at the ages of 17, 19 and 21 weeks after planting, marketable fruit yield, crop water use and water use efficiency were significantly affected by all the three factors. Fruit weight was affected only by soil water suction. The interaction of furrow irrigation method, mulch and soil water suction had significant effect on water use efficiency (WUE) of the crop. Use of alternate furrow method was statistically at par, in terms of WUE with the conventional furrow method if it was mulched and irrigated at 5-days interval.

Dominguez et al., (2003) conducted a research to compare deficit irrigation (DI) with partial root zone drying (PRD) for their effects on yield and fruit quality of ‘Petopride’, a processing tomato cultivar. The treatments were: full watering of both sides of the root system (RS) at each irrigation considered as the control (C), half of irrigation water in C divided equally to both sides of the RS with each watering (DI), and half of irrigation water in C given only to one side of the RS with each irrigation (PRD). There were no significant differences in fruit dry mass among treatments at P _ 0:06, and the following treatment effects were observed at P _ 0:05. Fruit number and fruit water content (FWC) were reduced in DI and PRD relative to C, and fruit were redder in the former two treatments. Concentration of soluble solids was higher in DI and PRD fruit than in C fruit. Maturity in PRD fruit was advanced by one week compared to DI and C fruit. But dry mass yield and fruit quality attributes were the same between DI and PRD treatments. DI and PRD are feasible water saving practices for areas with limited water supply.

Abbas et al., (2005) conducted a field study during 1997 and 1998 summer season to find out the effect of 4 irrigation schedules, based on actual evapotranspiration (ET), and 4 rates of nitrogen on maize. Averaged over the two seasons, the response of total dry matter (TDM) and I3 (-8 bars) based on crop evapotranspiration was greater than control (I_1) or I_2 (-4 bars) irrigation schedule. The study showed that seasonal water requirements of the maize crop under irrigated conditions vary from 181 mm to 220 mm after due account of rainfall. Average response varied at 5.90 $gm^{-2}mm^{-1}$ and 2.37-3.01g $mm^{-2}mm^{-1}$ for TDM and grain yield, respectively.

Sepaskhah and Khajehabdollahi (2005) conducted an experiment to determine the yield and water-use efficiency of maize under fixed and variable alternate furrow irrigation (fixed AFI, variable AFI) and every furrow irrigation (EFI) at different irrigation intervals in areas with shallow and deep groundwater. In variable AFI, water was applied to the furrow, which was dry in the previous irrigation cycle. The results indicated that even at 4-day irrigation intervals the water needs of maize on a fine textured soil in both areas (with deep and shallow water table) are not met by AFI. The decrease in grain yield due to water stress was mainly due to the decrease in the number of grains per cob and to a lesser extent to the decrease in 1000-grain weight. At the Kooshkak site with shallow groundwater (between 1.31 and 1.67 m), grain yields in AFI at 4- and 7-day intervals were comparable to those obtained in EFI at 7- and 10-day intervals, respectively. This might be due to the contribution of groundwater to the water use of the plant (about 5-10%). In the Badjgah area, with deep water depth, grain yield in AFI at 7-day intervals was statistically lower than that obtained in EFI at 10-day interval. In AFI, a shorter irrigation interval (4-day) may alleviate the water stress and result in no yield reduction compared with that in EFI at 7-day intervals even though water application was reduced. Furthermore, in the area with a shallow water table, AFI at 7-day intervals may be superior to EFI at 10-day irrigation intervals. When seasonal irrigation water is less than 700 mm, it may be preferable to use AFI at 10-day intervals to increase water-use efficiency, especially in areas with shallow groundwater. In general, when water was insufficient for full irrigation, the relative grain yield (yield per unit water applied) of maize under AFI was higher than those under EFI.

Shahnazari et al., (2007) conducted an experiment in potato (*Solanum tuberosum* L. cv. Folva) under open field conditions in 2004 and under a mobile rainout shelter in 2005. Two subsurface irrigation treatments were studied: full irrigation (FI) receiving 100% of evaporative demands, 50.1 and 201 mm of irrigation water in the 2 years, to keep it close to field capacity; and PRD, which received 21.7 and 140 mm of irrigation in 2004 and 2005 respectively. Due to rain in 2004, the PRD treatment was imposed over a short period only during the late tuber filling and maturing stages. In 2005, the PRD treatment was imposed during the whole period of tuber filling and tuber maturation. The PRD treatment was shifted from one side to the other side of potato plants every 5–10 days. Especially in 2005 it was apparent that stomatal conductance was generally lower in the PRD than in the FI plants, whereas leaf water potential tended to be lower in only a few instances. During the treatment period, plants were harvested five times, and no significant difference was found between the treatments in leaf area index, top dry mass and tuber yield. At final harvest, tubers were graded based on size into four classes C1–C4, of which the yield of the important marketable class (C2) was significantly higher (20%) in the PRD than in the FI treatment. Compared with FI, the PRD treatment saved 30% of irrigation water while maintaining tuber yield, leading to a 61% increase of irrigation water use efficiency. The limited data of 2004 support these results. In summary, PRD is a promising water-saving irrigation strategy for potato production in areas with limited water resources.

Quanqi et al., (2008) conducted a study in the Shandong province in North China to investigate the effects of different planting patterns on water potential characteristics of soil-plant-atmosphere continuum (SPAC) and yield of summer maize. Three planting patterns were applied, i.e. bed planting (BE), furrow planting (FU) and flat planting (FL). The results showed that although soil moisture content in 0–20 cm soil layer in BE decreased, soil temperature increased; as a result, soil water potential in BE increased. Compared with FL, leaf water potential in BE and FU enhanced, but water transfer resistance between soil-leaf and leaf-atmosphere decreased; feasible water supply conditions were thus created for crops colony. Maize yield of BE and FU significantly (LSD, $P < 0.05$) higher than that of FL, by 1326.45 and 1243.76 kg/ha, respectively. These results obtained in field crop conditions support the idea that planting patterns affect soil water potential, leaf water potential, water transfer resistance between soil-leaf and leaf-gas of summer maize in North China.

Nasri et al., (2010) conducted a split-plot field experiment on corn. Irrigation was applied through furrows in three ways as the main plots: alternate furrow irrigation (AFI), fixed furrow irrigation (FFI), and conventional furrow irrigation (CFI). AFI means that one of the two neighboring furrows was alternately irrigated during consecutive watering. FFI means that irrigation was fixed to one of the two neighboring furrows. CFI was the conventional way where every furrow was irrigated during each watering. Each irrigation method was further divided into five sub-treatments with different fertilizer combinations: (1) P+N (control) (2) P+N+K (3) P+N+K+Zn (4) P+N+K+Zn+B (5) P+N+K+Zn+B+Fe. The results indicate that water stress effects caused by furrow irrigation on yield may be alleviated by more frequent irrigation intervals. We concluded that AFI is a way to save water in arid areas where maize production relies heavily on repeated irrigation. Fertilized combinations influenced dry matter partitioning to seed filling. Thus, sufficient both macro and micro nutritional elements increased harvest index which was mostly due to more number of seeds per row than higher individual grain weight. Complete fertilizer combination increased total above ground biomass through more radiation use efficiency and by increasing leaf area. In order to utilize the water sources efficiently and increase corn production under limited water supply, we propose the use of circular irrigation care along with instance, K, Zn, B and Fe fertilizer.

Masoud and Ghodratolah (2010) carried out an experiment for increasing water use efficiency in corn (*Zea mays* L.) crop at different planting densities and decrease water wastes in usual methods of surface irrigation in Khorramabad, Iran. Three irrigation methods include: conventional furrow irrigation (CFI), fixed every other furrow irrigation (FFI) and alternate every other furrow irrigation (AFI) and three different plant densities (7, 8 and 9 plant m^{-2}) were used. The results showed that there were no difference between both FFI and AFI, but the performance of them decreased irrigated water at the rates of 26.2% and 23%, respectively comparing with control and then yield at the rates of 11% and 13.6%, respectively. In this respect, FFI resulted in the highest water use efficiency for biological yield of 4.4 kg m^{-3} and economical (grain) yield of 1.91 kg m^{-3}. Higher planting density resulted in higher irrigated water in spite of lower grain yield, but the highest economical water use efficiency was found in lower plant population of 7 plant m^{-2}.

Taisheng et al., (2010) conducted a field experiment to investigate the effect of (1) spatial deficit irrigation on spring maize in arid Inland River Basin of northwest China during 1997 2000; (2) temporal deficit irrigation on winter wheat in semi-arid Haihe River Basin during 2003–2007 and (3) temporal deficit irrigation on winter wheat and summer maize in Yellow River Basin during 2006–2007. Results showed that alternate furrow irrigation (AFI) maintained similar photosynthetic rate (Pn) but reduced transpiration rate (Tr), and thus increased leaf WUE of maize. It also showed that the improved WUE might only be gained for AFI under less water amount per irrigation. The feasible irrigation cycle is 7d in the extremely arid condition in Inner River Basin of northwest China and less water amount with more irrigation frequency is better for both grain yield and WUE in semi-arid Haihe River Basin of north China. Field experiment in Yellow River Basin of north China also suggests that mild water deficit at early seedling stage is beneficial for grain yield and WUE of summer maize, and the deficit timing and severity should be modulated according to the drought tolerance of different crop varieties. The economical evapotranspiration for winter wheat in Haihe River Basin, summer maize in Yellow River Basin of north China and spring maize in Inland River Basin of northwest China are 420.0 mm, 432.5 mm and 450.0 mm respectively. Their study in the three regions in recent decade also showed that AFI should be a useful water-saving irrigation method for wide-spaced cereals in arid region, but mild water deficit in earlier stage might be a practical irrigation strategy for close-planting cereals. Application of such temporal and spatial deficit irrigation in field-grown crops had greater potential in saving water, maintaining economic yield and improving WUE.

Tang et al., (2010) conducted a study to investigate how the biomass distribution and reproductive development of cotton are affected under PRI. A three-year field irrigation experiment was conducted with a 30% reduction in irrigation amount on cotton in an arid area of Xinjiang in northwest China. Three treatments included conventional furrow irrigation (CFI) as control, alternative furrow irrigation (AFI) and fix furrow irrigation (FFI). PRI decreased stomatal conductance on the days just after irrigation when cotton plants were not under water stress, but there was no difference in stomatal conductance among irrigation treatments when plants were under water stress on the days just before next irrigation. Non-hydraulic signals from the dried root zone inhibited the stomatal opening under well watered condition, but the moderate water deficit developed in the shoots under PRI may have played a more important role in biomass allocation and yield formation. This moderate water stress reduced shoot biomass accumulation and increased root biomass. While the vegetative and reproductive parts of the shoot were reduced in the same proportion under the PRI, the final yield was much less reduced in PRI, indicating an increased reproductive efficiency of cotton. Furthermore, PRI advanced the development of the reproductive organs and led to earlier flowering. The early matured bolls produced seed-cotton yield with a higher market value. AFI plants consistently performed better than FFI in the 3 years. We conclude that AFI can be used as a better deficit irrigation method with positive regulative effects on stomatal opening and yield forming process.

Chang et al., (2011) were studied to investigate yield performance of in terms of quality and quantity under such practices. Two cultivars, Yangdao 6 (an indica hybrid cultivar) and Yangjing 4038 (a japonica cultivar) were field-grown and three treatments were employed from transplanting to maturity: farmers' traditional flooding as control (FTF), furrow irrigation (FI) and alternate wetting and drying (AWD, re-watered when soil water potential reached -15 kPa at 15-20 cm). Compared with FTF, both FI and AWD enhanced leaf membrane lipid peroxidation, photosynthetic rate, root activity and contents of indole-3-acetic acid and zeatin+zeatinriboside in roots, and significantly increased yield by 9.43%-11.6% and 6.16%-9.94%, respectively. Both FI and AWD either significantly increased the rates of brown rice, milled rice, head rice and contents of albumin and glutelin proteins, and peak viscosity and breakdown value of rapid visco-analyser (RVA) profiles, and reduced chalky kernels, chalk size, chalkiness and content of prolamin in grain and setback values. The two cultivars showed similar trends in quality and quantity of rice yield. Both FI and AWD could increase grain yield and quality. Improvement in root and canopy performance under FI and AWD contributed to a higher grain yield and better quality of rice.

Metwally (2011) conducted an experiment during 2004/2005 and 2005/2006 seasons to study the effect of irrigation regimes on vegetative growth of onion plants cv. Giza 6. Six water supplies were applied in the field. The water quantity ranged between 350 to 3750 m3 /fed with 15 or 30 days irrigation interval. Results indicated that the higher water supply resulted in higher vegetative parameters: Plant height, number of leaves per plant, bulb and neck diameter. Bulbing ratio showed reverse as the lowest water supply resulted in higher bulbing ratio. Dry matter content showed high negative correlation with applied water quantity in both leaves and bulbs. Higher water supply increased double and bolter while decreased exportable bulbs. There were positive correlation between vegetative growth and total bulb yield.

Liang et al., (2013) conducted a pot experiment to study the effects of alternate partial root-zone irrigation on dry mass accumulation to investigate an efficient mode of water and fertilizer supply and yield and water use of sticky maize with fertigation. Three irrigation methods, i.e. conventional irrigation (CI), alternate partial root-zone irrigation (APRI) and fixed partial root-zone irrigation (FPRI), and three fertilization methods, i.e. 100% of total fertilizer (0.2 g N, 0.15 g P_2O_5 and 0.2 g K_2O kg^{-1} soil) as basal fertilizer (F_1), 100% of total fertilizer (0.2 g N, 0.15 g P_2O_5 and 0.2 g K_2O kg^{-1} soil) as basal fertilizer and topdressing with irrigation water (F_2), 80% of total fertilizer (0.16 g N, 0.12 g P_2O_5 and 0.16 g K_2O kg^{-1} soil) as basal fertilizer and topdressing with irrigation water (F3), were designed. Results showed that compared to CI, APRI decreased more water consumption than total dry mass of sticky maize, thus increased water-use efficiency (WUE) on the basis of total dry mass. Compared to F1, F2 increased dry seed yield of sticky maize under APRI, thus WUE on the basis of dry seed (WUEs) and WUEs per unit fertilizer were also increased. Therefore sticky maize with 100% of total fertilizer as basal fertilizer and topdressing with irrigation water is an efficient mode of water and fertilizer supply under APRI in this study.

Halim (2013) conducted two field experiments in the Middle Nile Delta area of Egypt during the 2010 and 2011 seasons to investigate the impact of alternate furrow irrigation with 7-d (AFI_7) and 14-d intervals (AFI_{14}) on yield, crop water use efficiency, irrigation water productivity, and economic return of corn (*Zea mays* L.) as compared with every-furrow irrigation (EFI, conventional method with 14-d interval). Results indicated that grain yield increased under the AFI_7 treatment, whereas it tended to decrease under AFI_{14} as compared with EFI. Irrigation water saving in the AFI_7 and AFI_{14} treatments was approximately 7% and 17%, respectively, as compared to the EFI treatment. The AFI_{14} and AFI_7 treatments improved both crop water use efficiency and irrigation water productivity as compared with EFI. Results also indicated that the AFI_7 treatment did not only increase grain yield, but also increased the benefit-cost ratio, net return, and irrigation water saving. Therefore, if low cost water is available and excess water delivery to the field does not require any additional expense, then the AFI_7 treatment will essentially be the best choice under the study area conditions.

Kuscu and Ali (2013) studied the responses of maize grain and dry matter yields to timing and severity of water deficit in a sub-humid environment in the field for two seasons. Seventeen irrigation treatments were applied to maize grown on clay-loam soil, at three critical development stages: vegetative, flowering and grain-filling. The grain and dry matter yields increased with the amount of irrigation water. In both seasons, the highest grain yields were obtained from full irrigation at each stage. Yields were reduced in all the other treatments in which water was limited in all or in part of the development stages. Yield response factor (ky) was separately calculated for the individual growth stages and for the total growing season, and was found to be 0.90, 1.12 (the highest value) and 0.87 (the lowest value) for the total growing season, flowering, and flowering and grain-filling combination stages, respectively. Maximum values of both water use efficiency and irrigation water use efficiency for grain yield under irrigation conditions were obtained as 2.05 kg m-3 and 1.62 kg m-3 from treatments of full irrigation at the flowering and grain-filling stages, and from full irrigation at the vegetative and flowering stages, respectively. Full irrigation during the total growing season was found to be the most appropriate choice for maximum grain yield under the local conditions, but these irrigation programs must be reconsidered in areas where water resources are more limited. Our data suggest that water stress should be scheduled on the grain-filling stage in the case of limited water or water scarcity. Withdrawal of irrigation water during the flowering stage was not a good strategy under the conditions of this study.

Yactayo et al., (2013) studied to test: two PRD treatments with 25% (PRD_{25}) and 50% (PRD_{50}) of total water used in full irrigation (FI, as control), and a deficit irrigation treatment with 50% of water restriction (DI_{50}). Two water restriction initiation timings were tested at: 6 weeks (WRIT6w) and 8 weeks (WRIT8w) after planting. Osmotic potential (∏), osmotic adjustment, relative water content and chlorophyll concentration were assessed in four dates during the growing period. PRD_{50} initiated at WRIT6w showed the highest WUE without a tuber yield reduction respect to the control. While plants under PRDs and DI_{50} showed lower ∏ than FI, PRDs treatments promoted higher osmotic adjustment particularly in WRIT6w. Our study suggests that early PRDs with mild water restriction allow drought hardiness (improving water stress response) and water saving avoiding a dramatic yield tuber reduction.

Nodehi (2015) conducted an experiment on maize as a split plot based on a randomized complete block design with three replications for a period of two years at Agriculture Center of Mazandaran. Treatments included three levels of 100, 80 and 60 percent water requirement as the main treatments, and three irrigation methods included fixed every-other furrow, alternative every-other- furrow and every-furrow irrigation as the subsidiary treatments. Statistical analysis of the results of two years' data showed that treatment with 100% water requirement with every-furrow irrigation and treatment with 60% irrigation water requirement with fixed every-other-furrow had the highest and lowest yield, respectively. The highest water use efficiency was in 60 percent irrigation water requirement with a fixed every-other furrow treatment and the lowest water use efficiency was related to the treatment with 100 percent irrigation water requirement with alternative every-other- furrow. The value of ky was obtained 0.8 for the total growth stage.

Arshad and Ibrahim (2014) conducted an experiments on partial root zone drying irrigation consisted of a factorial combination of irrigation regimes and soil types laid in a randomized complete block design with eight treatments. Irrigation regimes were at four levels namely: I100, I75, I50 and I25 and the soil types were at two levels namely: Rhu Tapai and Rengam series soil. The treatments were randomly assigned to experimental pots and replicated four times. All agronomic practices starting from planting of sorghum to harvesting were adhered to and photosynthesis, photosynthetic active radiation and yield parameters were recorded for the experiment. The result of the study shows that, sorghum performed better under partial root zone drying technique. The results further revealed that, irrigation regimes I100 and I75 performed better in terms of photosynthesis, photosynthetic active radiation and yield parameters compared to I50 and I25 irrigation regimes. The study also revealed that there was no significant different between the two types of soil used for the study. The study, therefore, recommended the use of I75 percent regulated deficit irrigation for optimizing sorghum yield production in semi-arid regions.

Sun et al., (2014) conducted an investigation on comparative effects of PRD and DI on fruit quality of tomato (*Solanum lycopersicum* L.). The results showed that the irrigation treatments had no effect on tomato yield but significantly affected several organic and mineral quality attributes of the fruits. Compared to DI, PRD significantly increased the fruit concentrations of Ca and Mg, and fruit juice concentrations of total soluble solid, glucose, fructose, citric and malic acid, P, K and Mg. It is concluded that PRD is better than DI in terms of improving fruit quality, and could be a promising management strategy for simultaneous increase of water use efficiency and fruit quality in tomatoes.

Akbar et al., (2015) conducted an experiment to study the effect of deficit irrigation by method of furrow irrigation grain yield and yield components of sweet corn, in a randomized complete block design in 4 treatments with four replications, in research farm of the faculty of agriculture of birjand, including: 1-an alternative furrow irrigation (AFI) 2- a fixed furrow irrigation (FFI) 3- double furrow irrigation in 14 time duration (DFI) 4- a critical furrow irrigation of all tracks treatment control (CFI) time constant irrigation to 7 time duration were considered. AFI means that one of the two neighboring furrows. CFI was the conventional method where every furrow was irrigated during each irrigation. The time for irrigation is calculated from the infiltration equation of Kostiakov Lewis and other treatments of deficit irrigation are planned on this basis. In this test, crop yield and 15 effective treats was analyzed are analyzed. The results of variance analysis showed a significant difference at the 1% level different irrigation types irrigation in measured treats. Alternative furrow irrigation treatment was a better solution for water saving in arid and semi-arid region with 50% saving compare to control treat only with 6.5% reduction on yield.

Hernandez et al., (2015) conducted a research to elucidate whether N supply affects WUEg in water limited environments; and to clarify the expected response to N supply of maize ET and its components under contrasting soil water availability. Maize crops were grown at Balcarce, Argentina during three seasons. Treatments included two water regimes (i.e. rain-fed and irrigated) and two rates of N (i.e. 120 kg N ha−1or non-fertilized). Measurements included (i) soil water content and intercepted pho-to synthetically active radiation (iPAR) during the whole crop season, and (ii) grain yield and shoot dry matter at physiological maturity. Crop ET was calculated by means of a water balance and soil evaporation was estimated by means of micro-lysimeters. Our results show that N supply did not influence WUEg in water limited environments; but N supply significantly increased ET (2–8%) under all water availability conditions. Maize seasonal ET increments were closely related to the improvement of seasonal iPAR in non-water limited environments, but not in water limited environments. In non-waters limited environments, ET response to N supply was mediated by the concomitant effects of iPAR increments on increasing transpiration while reducing evaporation. In water limited environments, ET slightly increased in response to iPAR increments due to N supply. The low ET increment in water limited environments with frequent low superficial soil water content (i.e. ≤ 2 mm cm^{-1}) was probably not influenced by reductions in evaporation (E); but associated with stomata closure in response to water deficiencies. This is consistent with the fact that N supply did not promote improvements in radiation use efficiency for biomass production (RUEb) in these environments.

Kresovic et al., (2016) investigated the effects of different irrigation levels with sprinkler irrigation system on crop yield, yield components, water use, water (WUE) and irrigation water use (IWUE) efficiency of maize (*Zea mays* L.) in Vojvodina (northern Serbia), on a Calcaric Chernozem soil in temperate environment for 3 consecutive years (2006–2008). Maize was subjected to four irrigation regimes, as follows: non-limited irrigation (I100), 75% of non-limited irrigation (I75), 50% of non-limited irrigation (I50), and rainfed (non-irrigated) as the control (I0). The irrigation treatments were arranged in a complete randomized block design with 4 replicates. Results showed that maize grown in rainfed conditions had high annual variability, mainly due to amount of rainfall and its distribution during the crop-growing seasons. A significant irrigation effect was found for yield, yield components and others investigated parameters under study. Water stress had significant impact on yield response: as an average of the three years, a grain yield increase of 47.8, 32.8, and 22.9% was observed in I100, I75 and I50 treatments compared to rains fed (I0) treatment, respectively. Yield increased linearly with seasonal crop evapotranspiration and irrigation amount. Furthermore, WUE is maximized with a moderate water deficit (I50), while IWUE is the highest in I100 treatment. The deficit irrigation stress index, DISI, decreased with increasing irrigation rate. The results revealed that irrigation is necessary for maize cultivation because rainfall is insufficient to meet the crop water needs in Vojvodina. In addition, the study indicated that the irrigation regime of 25% water saving (I75) could ensure satisfactory grain yield of maize and increment of WUE

Qi et al., (2017) carried out a field experiment to investigate the effects of varying nitrogen (N) supply and irrigation methods on the root growth and distribution of maize (*Zea mays* L.) in Wuwei, northwest China in 2011 and 2012. The irrigation treatments included alternate furrow irrigation (AI), fixed furrow irrigation (FI) and conventional furrow irrigation (CI). The N supply treatments included alternate N supply (AN), fixed N supply (FN) and conventional N supply (CN), were applied at each irrigation method. The root growth across the plant row was measured in 0-100 cm soil profile (20 cm as an interval) at maturity. The results showed that root distribution of two sides of the row was uniform for AI or CI coupled with CN or AN. Root length density (RLD) in 0-40 cm soil depth was significantly increased by AI compared to other irrigation methods while decreased by FN compared to other N supply treatments. Though RLD decreased more with soil layer deepening under AI, RLD in 60-100 cm soil depth in AI treatment was still larger than that in CI and FI treatments. In general, total fine root (diameter<2 mm) length, root dry weight, root surface area, and grain yield of maize were significantly increased by AI coupled with CN or AN when compared to other treatments. These results indicate that alternate partial root zone irrigation coupled with conventional or alternate nitrogen supply is useful to improve the root growth and grain yield of maize in the arid area.

Mohammadpour et al., (2012) conducted the surface area under cultivation can be increased by the deficit irrigation in the condition of water restriction through water savings. The management of deficit irrigation is one of the savings strategies in water resources in agricultural sector. In the condition of deficit irrigation, the amount of product per unit area is less than the maximum production per unit of area, but the profit is increased. A factorial experiment with a randomized complete block design with three replicates was conducted in the 1389-90(AHS) crop year in order to study the yield functions toward the deficit irrigation of maize in the hot and dry climate of Dezful. The first factor included four levels of water I100%, I80%, I60% and I120% crop water requirement and the second factor consisted of three levels of nitrogen fertilizer, N200, N150 and N250 kg nitrogen per hectare. The result of this research showed that in irrigation treatments 60%, 80%, 100% and 120% water requirement in the fertilizer level of 150 kg of nitrogen per hectare, the slope reduction of yield was 0.14, in fertilizer level of 200 kg of nitrogen per hectare, the slope reduction of yield was 0.15 and in 250 kg fertilizer level of nitrogen per hectare, the slope reduction of yield was 0.44. The investigation also indicated that because there is no significant difference in the grain yield between the water level of 80% and 100% water requirement, in conditions which we have to apply mild deficit irrigation, the irrigation treatment of 80% water requirement for corn is recommended.

Ibrahim et al., (2016) conducted to determine the best irrigation scheduling and the proper period for injecting fertilizers through drip irrigation water in a sandy soil to optimize maize yield and water productivity. Four irrigation levels (0.6, 0.8, 1.0 and 1.2) of the crop evapotranspiration and two fertigation periods (applying the recommended fertilizer dose in 60 and 80% of the irrigation time) were applied in a split-plot design, in addition to a control treatment which represented conventional irrigation and fertilization of maize in the studied area. The results showed that increasing the irrigation water amount and the fertilizer application period increased vegetative growth and yield. The highest grain yield and the lowest one were obtained under the treatment at 1.2 and of 0.6 crop evapotranspiration, respectively. The treatment at 0.8 crop evapotranspiration with fertilizer application in 80% of the irrigation time gave the highest water productivity (1.631 kg m-3) and saved 27% of the irrigation water compared to the control treatment. Therefore, this treatment is recommended to irrigate maize crops because of the water scarcity conditions of the studied area.

Elzubeir and Mohamed (2011) conducted an experiment on maize for two consecutive summer seasons; 2005/06 and 2006/07, at Dongola area- Northern State (Sudan). The objectives were to investigate the effect of irrigation regimes; irrigation water amounts and irrigation intervals, on maize (*Zea mays* L.) growth and yield in addition to their effect on the soil moisture content. Irrigation water amounts were determined using FAO Penman- Monteith equation (1998) for estimating crop evapotranspiration (ET_c). Three levels of ET_c were used; 100%, 75%, and 50% ET_c. Three irrigation intervals were imposed; 10, 15, and 20 days. The application of irrigation treatments was started at the third irrigation. The results indicated that maximum plant population and field water use efficiency were obtained at irrigation water amount of 50% ET_c in both seasons. Also, 10 days irrigation interval gave the highest values of plant height, cob length, 100-seed weight, grain yield, stover yield, and field water use efficiency.

Albasha et al., (2015) studied to evaluate the grain yield (GY) and Irrigation Water Productivity (IWP) performances of subsurface drip irrigation (SDI) for maize under a Mediterranean (Lavalette station) and temperate Oceanic climatic (La Mirandette station) conditions. Irrigations were conducted to fulfill 80-85% of the maximum crop requirements using SDI compared to fully-irrigated sprinkler treatments (SI). Dripline spacing used for SDI was “narrow” of 100 cm (SDI-100) and 120 cm (SDi-120) and “large” spacing of 150 cm (SDI-150) and 160 cm (SDI-160) at La Mirandette and Lavalette stations, respectively. The results indicate that reducing irrigation quantities by 15-20% with SDI significantly affected GY at Lavalette station but had less effect at that of La Mirandette. SDI slightly increased IWP compared to sprinkler-irrigated treatments at Lavalette (8% increase) whereas it had less and erratic effect in the case of La Mirandette, depending on rainfall. We conclude that under both climatic conditions, deficit irrigation with SDI would not allow to significantly increasing water productivity for maize compared to the more conventional technique of sprinkler without impacting yield.

Hayrettin et al., (2013) carried out experiment to determine the effect of irrigation amount applied with drip irrigation on field maize (*Zea mays* L.) evapotranspiration (ET), yield, water use efficiency, yield response factor (ky) and net return in a sub–humid environment of Turkey. Irrigation management treatments were created as 125%, 100%, 75%, 50%, 25% and 0% replenishment of water depleted in the 90 cm root zone from 100% replenishment treatment in every seven days. Irrigation amounts ranged from 76 to 1120 mm in 2007 and from 91 to 997 mm in 2008. The treatments resulted in seasonal ET of 311–1078 mm and 298–1061 mm in 2007 and 2008, respectively. The average grain yields varied from 5570 to 16535 kg ha–1. In both seasons, irrigation significantly affected yields, which increased with irrigation up to a level (1100 mm of irrigation water amount), but additional amounts of irrigation did not increase it any further. Yields increased linearly with seasonal ET. The yield response factor (ky) averaged 0.89 over the two seasons. Maximum water use efficiency (WUE) and irrigation water use efficiency (IWUE) values were obtained for the treatment of 25% deficit irrigation. A further increase in water amount from reference irrigation (T–100) increased grain yield but reduced both the WUE and IWUE. The reference irrigation treatment gave the highest net return of $3212 ha–1. The results revealed that the full irrigation is the best choice for higher yield and net income. The results also suggest that 25% deficit irrigation approach may be a good strategy for increase water use efficiencies when full irrigation is not possible.

CHAPTER III

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The field experiments were conducted at the research field of ARS, BARI, Rajbari, Dinajpur during the Rabi (dry) season of 2015-2016 to study the effect of alternate furrow irrigation on the growth and yield of maize. Details of different materials used and methodologies followed in conducting the experiment and processing the data have been presented in this chapter.

3.1 Description of the experimental site

3.1.1 Location

The experimental site is located in the agro-ecological zone (AEZ) 1 that lies at $20^{0}34^{/}$ to $26^{0}38^{/}$N latitude and $88^{0}01^{/}$ to$92^{0}41^{/}$E longitude. The elevation of the experimental site is 37.5 m above mean sea level.

3.1.2 Soil

The soil of the experimental field was clay loam and it belongs to the Old Himalayan Piedmont plain (BARC, 2005). The organic matter content of the experimental soil was medium (1.81%). Top soils were moderately acidic but sub-soils were neutral in reaction. The field capacity and permanent wilting point of the soil of the experimental field were 30 and 16.37 % (v/v), respectively and the bulk density was 1.43 g cm^{-3}. The chemical properties of initial soil samples of the experimental field determined in the Regional Soil Test Laboratory of Soil Research Development Institute (SRDI) are given in Table 3.1.

Table 3.1: Soil properties in the experimental sites of the study area during 2014-2015 (before sowing of maize)

Soil depth (cm)	p^H	OM (%)	Total N (%)	P (ug/gm soil)	K (meq/100g soil)	S (ug/gm soil)	Zn (ug/gm soil)	B (ug/gm soil)
0-10	6.2	2.33	0.12	36.47	0.19	10.81	0.80	0.22
10-20	6.83	1.49	0.08	23.99	0.12	12.16	0.68	0.28
20-30	7	1.60	0.08	13.93	0.14	12.76	0.57	0.23
Avg	6.68	1.81	0.09	24.8	0.15	11.91	0.68	0.25

3.1.3 Climate

The climate in the study area follows tropical monsoon climate with three distinct seasons: Winter (November to February) which is cool and almost dry: pre monsoon or summer (March to May) which is hot and characterized by periodic thunderous shower and monsoon or rainy season (June to October) which is warm, humid and more than 85% annual precipitation occurs during this time. The temperature becomes warmer from the beginning of pre monsoon (March) and reaches to its peak at the beginning of monsoon (June). The weather begins to cool down from the beginning of the winter season (February).

The temperature data of the study area of last five years shows that the maximum temperature occurs in the month of April which is 33.55^0c and minimum temperature in January which is 11.22^0c. (Source: BMD). The rainy season is one of the three seasons in the study area and about 85% of the total rainfall occur in this season (May to September). The months from November to February enjoy a very little rainfall and it increases in March, April and May when less than 20% of the total rainfall occurs. The average rainfall of Bangladesh is very high. But rainfall does not occur uniformly in all seasons.

The relative humidity varies with season. In the study area the highest monthly average humidity recorded is 86% in the month of July and lowest is 61% in the month of March during the period of (2010-2014). From the humidity data, it can be said that in rainy season the humidity is high and in winter season the humidity is low (Source: BMD).

From the record of evaporation data it is clear that a large amount of water from the open water bodies, like ponds, river etc. and rain water evaporation in every evaporates. From

March to May, the evaporation rate is high and during the monsoon the evaporation rate is low. Weather information on rainfall, temperature, relative humidity and evaporation at the experimental site during the period of the study is presented in Table 3.2.

Table 3.2: Average monthly rainfall, temperature, humidity and evaporation (2010-2014)

Month	Rainfall (mm)	Temperature ^{0}c	Humidity (%)	Evaporation (mm)
January	5.20	16.79	84	51
February	13,08	20.80	76	62
March	7.86	24.43	65	78
April	58.92	27.64	61	96
May	185.76	24.48	71	106
June	369.40	28.78	85	100
July	318.40	29.68	84	98
August	281.40	29.19	86	82
September	261.80	28.21	87	89
October	100.44	26.90	83	53
November	0.86	22.24	79	49
December	0.08	18.85	85	44

3.2 Experimental Materials

3.2.1 Plant material

Maize variety "BARI Hybrid maize-9" was used in conducting the experiment. This variety was developed by Bangladesh Agricultural Research Institute (BARI) and released in 2010. It is a high yielding, resistance to diseases and pests and moderate drought tolerant variety. This variety attains a height of 130−135 cm and takes 140−145 days to complete life cycle in rabi season and takes 110-115 days in kharif season. It takes 65−70 days to flowering and yield varies between 9−10 t ha^{-1}.

3.2.2 Collection of soil samples

Soil samples were collected by using a hand auger from five sampling points. Sampling points were selected covering the whole experimental field and samples were collected at 20 cm increments to a depth of 60 cm from the maize field before setting up of experiments to know the initial status of soil.

3.3 Experimental techniques

3.3.1 Treatments

The experiment comprising of two factors viz. different levels of irrigation as main factor and different irrigation methods as sub factor.

Factor A: Three irrigation levels (main plot treatment):

I_1: Irrigation water applied to 100% FC

I_2: Irrigation water applied to 80% FC

I_3: Irrigation water applied to 60% FC

Factor B: Three irrigation methods (subplot treatment):

M_1: Alternate wetting and drying furrow irrigation (AWDFI)

M_2: Fixed wetting and drying furrow irrigation (FWDFI)

M_3: Traditional furrow irrigation (TFI)

AWDFI indicates that one of the neighboring furrows was alternately irrigated during consecutive watering. Irrigation water was applied only one side of the root system for wetting the root with each irrigation while the other side of the root kept for drying (Fig. 1 and 2). FWDFI means that it was fixed to one furrow of the neighboring two furrows from first irrigation to last irrigation (Fig. 1 and 2). TFI indicates that traditional furrow irrigation was the traditional way where all furrows were irrigated for each irrigation (Fig. 1 and 2). It means that irrigation water was applied on both sides of the root system for each irrigation. Irrigation water was applied at different growth stages of maize according to the soil moisture content measurements. Total four irrigations were applied in all treatments during the different growth stages of maize. The stage which irrigation was scheduled as initial growth (25-30 DAS), tasselling (55-60 DAS), silking (85-90 DAS) and grain filling (110-115 DAS) stages of maize which also followed by plant and soil moisture observation method depending on rainfall or soil moisture.

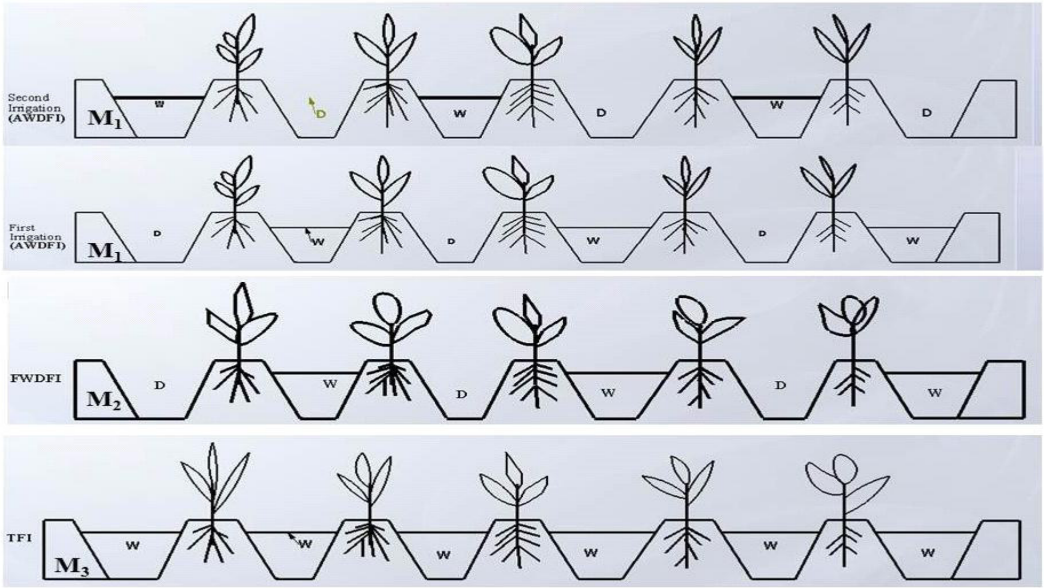

Fig. 1: Schematic view of irrigation methods: Alternate wetting and drying furrow irrigation

(AWDFI) method (M_1), fixed wetting and drying furrow irrigation (FWDFI) method (M_2) and traditional furrow irrigation (TFI) method (M_3). Here, W and D indicate half of the root system of the plant being exposed to wetting and drying soil.

Fig. 2: Photographic view of irrigation water applied at the experimental field plots: Alternate wetting and drying furrow irrigation (AWDFI) method (M_1), fixed wetting and drying furrow irrigation (FWDFI) method (M_2) and traditional furrow irrigation (TFI) method (M_3).

3.3.2 Layout and design of the experiment

The experiment was laid out in a split-plot design with three replications. The land was divided into three equal blocks, representing the replications. Each block was divided into 3 sub-blocks., then each sub block was divided into 3 unit plots. The size of a unit plot was 6.0m x 4.2m. The distance between plots and blocks were 1.0m and 1.5m respectively. Irrigation treatments were assigned to each sub block while irrigation methods were assigned to each unit plot randomly. There were nine plots in each block.

I_1M_1		I_2M_2		I_3M_3	
I_1M_3		I_2M_3		I_3M_1	R_1
I_1M_2		I_2M_1		I_3M_2	
I_2M_2		I_3M_3		I_1M_1	
I_2M_3		I_3M_1		I_1M_3	R_2
I_2M_1		I_3M_2		I_1M_2	
I_1M_3		I_1M_1		I_1M_2	
I_3M_1		I_3M_3		I_3M_3	R_3
I_2M_2		I_2M_2		I_2M_1	

Fig 3: Layout of the experiment

3.3.3 Fertilizer application

The fertilizers were applied in the experimental plots @ 250, 55, 100, 40, 4 and 1.4 kg ha^{-1} in the form of urea, triple super phosphate, muriate of potash, sulfur, zypsum and boron. The fertilizers were applied in the experimental plots at 5 ton per hectare cowdung. These were the recommended doses for Maize production in Bangladesh (BARC, 1989). Two-thirds of urea and entire dose of triple super phosphate, muriate of potash and zypsum were applied to the plots as a basal dose. The rest one-third of urea was top-dressed at 20 days after sowing just before the first irrigation. A summary of applied fertilizer doses is given in Table 3.3.

One third of Nitrogen and all phosphorous, potassium, sulfur, zinc and boron were applied during final land preparation. Remaining nitrogen was applied in two spilts as side dressing in maize rows at 30-35 and 55-60 DAS. Application of organic manure at the rate of tones cow dung per hectare.

Table 3.3: Doses of fertilizers applied in the experimental plots

Nutrient	Quantity (Kg ha^{-1})	Source
N	250	Urea
P	55	Triple super phosphate
K	100	Muriate of potash
S	40	Zypsum
Zn	4	Zinc
B	1.4	Boron

Table 3.4: Calendar of operation during the growing season

Operations	Date of operation
Sowing date	24 November 2015
Re-sowing, Gap filling	10 December2015
Weeding	01 January 2016
First irrigation	05 January 2016
Second irrigation	26 February 2016
Harvest	22 April2016

3.3.4 Sowing of seeds

At a good tilth condition of the soil, called the 'Joe' condition, 2–3 cm deep furrows were made with hand rakes for sowing. The distance between adjacent furrows was 60 cm. Seeds were sown at the rate of 30 kg ha^{-1} in the furrows on 24 November 2015 keeping 2 seeds per hill in the soil at 'Joe' condition to ensure satisfactory germination.

3.3.5 Intercultural operation

After germination of seeds, various kind of intercultural operations were accomplished for better growth and development of the plants.

3.3.5.1 Thinning and gap filling

After germination of seeds, continuous observation was maintained to keep required number of plants in the plots. Any gap caused by damaged plants/ungerminated seeds in the plots was filled up to maintain required plant population. Thinning was done at 20 DAS keeping one plant per hill.

3.3.5.2 Weeding and furrowing

Various weeds grew in the experimental plots that were uprooted by weeding. First weeding was done after 20 days of sowing. Subsequent weeding was done followed by application of irrigation. Furrows were also made at the time of weeding.

3.3.5.3 Plant protection measures

In order to control insect pests, Marshall 20 EC was sprayed properly at the rate of 2 ml per litre.

3.4 Measurement of soil moisture

Soil moisture was measured gravimetrically before each irrigation to find out the depth of water required to replenish the deficit. For this, soil samples were collected with a soil auger up to the depth of 75 cm each at 15 cm interval. They are collected in air tight aluminum containers. The samples are then weighed and dried in an oven at 105^{o} C for about 20 hours, until all the moisture is driven off (Michael, 1978). After removing from oven they are cooled slowly to room temperature and weighed again. Then the soil moisture on weight basis was calculated by the following formula:

$$\text{Soil moisture content (percent by weight)} = \frac{\text{Weight of moist sample} - \text{Weight of oven dry sample}}{\text{Weight of oven dry sample}} \times 100$$

Soil water content was recorded at sowing, before irrigation, 24 hours after each irrigation or rainfall, every 10 days interval and at the time of harvesting.

3.5 Irrigation practices

Irrigation was scheduled on the basis of crop stages like seeding (CRI), vegetative, silking and grain filling stages. Amount of irrigation water needed to bring the soil to field capacity was calculated using the following formula (Michael, 1978):

$$d = \sum_{i=1}^{n} \frac{M_{fci} - M_{bi}}{100} \times A_i . D_i$$

where, d = net amount to be applied during an irrigation, mm

M_{fci} = field capacity moisture content in the ith layer of the soil, %

B_{bi} = moisture content before irrigation in the ith layer of the soil, %

A_i = bulk density of the soil in the ith layer, gm/cu-cm

D_i = depth of the ith soil layer within the root zone, cm, and

n = number of soil layers in the root zone, D

The amount of applied irrigation water was the depth of water needed to refill the soil profile (0-45, 60 and 75 cm depending on growth stages) to different levels of field capacity. The amount was controlled to 100%, 80% and 60% FC for irrigation to each plot. Field capacity was determined by ponding water method on the soil surface which was suggested by Michael (1978). The amount of irrigation water was determined by volumetric measurement and supplied to the experimental plots using a polythene hose pipe from water supply source to the plots.

3.6 Determination of effective rainfall

Effective rainfall means useful or utilizable rainfall (Michael, 1985). Effective rainfall was estimated by using the USDA Soil Conservation Method (Smith, 1992). The equations are as follows:

$$P_{effective} = \frac{P_{total}(125 - 0.2 \times P_{total})}{125} \quad (3.2)$$

for $P_{total} < 250$ mm, and

$$P_{effective} = 125 + 0.1 \times P_{total} \quad (3.3)$$

for $P_{total} > 250$ mm

Where $P_{effective}$=Effective rainfall, mm

P_{total}=Total rainfall, mm.

An amount of 13.13 cm rainfall was recorded during the growing period of wheat. The effective rainfall was estimated as 10.4 cm by using equations 3.2 and 3.3.

3.7 Determination of water requirement (WR)

The water requirement was computed by adding the applied irrigation water, effective rainfall during the growing season and contribution of moisture from the soil.

Mathematically, water requirement is expressed by the following relationship (Mandal and Dutta 1995; Michael 1978; Majumdar, 2004):

$$WR = IR + ER + \sum_{i=1}^{n} \frac{M_{si} - M_{hi}}{100} \times A_i . D_i \qquad (3.4)$$

Where WR= seasonal water requirement, cm

IR = total irrigation water applied, cm

ER = seasonal effective rainfall, cm

M_{si} = moisture content (%) at the sowing time in the i^{th} layer of the soil

M_{hi} = moisture content (%) at the harvest time in the i^{th} layer of the soil

A_i = apparent specific gravity i.e. bulk density of the i^{th} layer of the soil

D_i = depth of the i^{th} layer of the soil within the root zone, cm

n = number of the i^{th} layers in the root zone

Total seasonal crop water use (SCWU) was calculated as the sum of irrigation input between first irrigation to last irrigation, effective rainfall and soil water contribution (SWC) between sowing (moisture percentage at the beginning of the season in the soil layers) to harvest (moisture percentage at the end of the season in the soil layers). Rainfall was monitored and recorded in the study area. Effective rainfall was calculated which was suggested by Reddi and Reddy (2009) and Smith (1992).

3.8 Determination of field water use efficiency (FWUE)

The water use of the crop field is generally described in terms of field water use efficiency (FWUE), which is the ratio of crop yield to the total amount of water used in the field during the entire growing period of the crop. FWUE was calculated as follows:

$$FWUE=Y/WR \qquad (3.5)$$

Where, FWUE= field water use efficiency, kg ha^{-1} cm^{-1}

Y= grain yield, kg ha^{-1}

WR= seasonal water requirement in the crop field, cm

3.9 Harvesting, data recording and processing

Maturity of crops was determined when 100% of the spikes became straw color. The crop was harvested on 22 April 2016. After maturity, a harvest area of 1m x 1m was selected in the middle portion of each unit plot. In addition to 1 m^2 area, the crop of the whole plot was also harvested. The harvested crop of each plot was bundled separately and tagged properly. After recording data on plant height and length of spike of each plant, the plant materials were then sun dried for grain collection. Finally, grain and straw yields and yield contributing parameters were recorded separately.

3.10 Collection of data at harvest

Data were recorded on the following crop characteristics at and after harvest:

- Plant height at harvest
- Length of the cob
- Diameter of the cob
- Grain / cob
- Thousand grain cob
- Grain / Yield
- Yield
- Seasonal water use
- Water productivity

(j) Water use efficiency

3.11 Procedure of recording data

A brief outline of the data recording procedure is given below:

Plant height at maturity: Plant height was measured from the ground level to the tip of the longest leaf.

Length of cob: Cob length was recorded from the basal code of the rachis to the apex of each cob.

Grains / cob: Presence of any food materials in the grain was considered as grain. The total number of grains present on each cob was counted.

Weight of 1000−grains: One thousand clean dried grains were counted from the seed stock and weighed by using an electronic balance.

Grain yield: Grains obtained from each plant were sun dried and weighed. The dry weight of grains of 10 sample plants was allotted to the respective unit plot yield to record the final grain yield per plot; the grain yield was finally converted to t ha^{-1}.

Straw yield: Straw obtained from each plot including the straw of 10 sample plants of respective plot was dried in the sun and weighed to record the straw yield/plot and finally that was converted to t ha^{-1}.

Biological yield: Grain yield and straw yield altogether are regarded as biological yield. The biological yield was recorded for g m^{-2} and it was finally converted to t ha^{-1}.

Harvest index: The harvest index was calculated with the following formula (Gardner *et al.,* 1985):

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100 \qquad (3.6)$$

Dry matter

Crop dry matter (DM) was measured at different intervals during the crop growing seasons from each treatment with three replications. The plant biomass of roots and shoots samples were collected during 2015-2016. The roots were collected to a depth of 20 cm from the sampling area 20 cm x 20 cm. The roots were cleaned and washed with clean water. Plant biomass was dried at 60^0 C to constant weight using oven dry method.

3.12 Statistical analysis

Data on yield contributing characters, dry matter and water productivity were statically analyzed to test the effect of irrigation levels and methods by the analysis of variance using R-Foundation for Statistical Computing Platform (R version 3.1.2: 2014-10-13). All the treatment means compared for any significant differences using statistical models at 5% probability level of significant ($P \leq 0.05$).

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Crop performances

4.1.1 Crop growth rate

Crop growth rate (CGR) was influenced by the treatments (Fig. 4). The effect of irrigation levels and methods significantly ($P \leq 0.01$) affected the CGR among the treatments at the different growth stages of maize dry biomass (Fig. 4). CGR was significantly lower when the irrigation level was drastically reduced (Fig.4a). The effect of irrigation levels showed that the level I_1 (100% field capacity) produced significantly higher crop growth rate during grain filling (119 DAS) and maturity stages (149 DAS) compared to the lower level of irrigation I_2 (80% FC) and I_3 (60% FC) (Fig. 4a). The results indicate that CGR was not significantly different when furrows were irrigated alternately (M_1) and every furrow (M_3) irrigated with the irrigation level up to 100% FC (Fig. 4b).

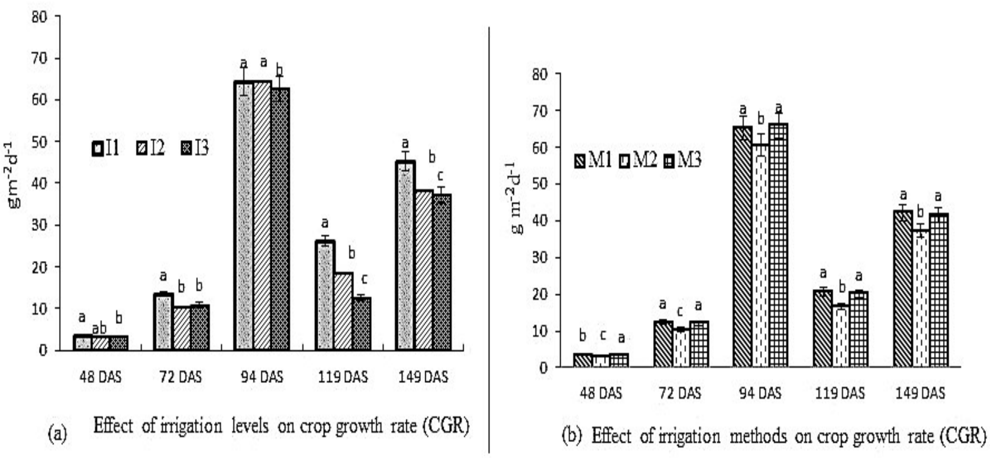

Fig 4: Effect of irrigation levels and methods on crop growth rate (CGR, g m^{-2} d^{-1}) of maize at different growth intervals. Mean values at different days after sowing (DAS) by different letters (a-c) are significantly ($P \leq 5\%$) different within treatments. Values are mean of three replication of each treatment. Here: I_1, I_2, & I_3 indicate irrigation up to 100%, 80% and 60% field capacity, respectively; M_1: Alternate furrow irrigation, M_2: Fixed furrow irrigation, M_3: Traditional furrow irrigation (TFI).

Alternate wetting and drying furrow irrigation(M_1) and traditional furrow irrigation technique (M_3) produced significantly better growth rate of maize compared to the fixed wetting and drying furrow irrigation method (M_2) (Fig.4b). Dry biomass of alternate furrow irrigation system was not significantly lower compared to every furrow irrigation due to fulfill shifting water demands using the signal system of water transpiration through shoot and the control of stomata during the entire growing season. The interactive effect of irrigation level and method showed that less amount of irrigation water also significantly reduced crop growth rate in the crop biomass among the treatments while the same level of irrigation produced dry matter insignificantly different between the irrigation method M_1 and M_3, but the effect was so apparent with the method of M_2. The result thus indicates that AWDFI irrigation may reduce excess transpiration loss without reducing the photosynthesis rate by slightly limiting stomata opening on maize grown.

4.1.2 Yield and yield contributing parameters

Yield and yield components of maize under different irrigation levels and methods are given in Table 4.1. There was a significant interaction between irrigation level and method (Table 4.1 and Table 4.2). The interactive effect of irrigation levels and methods showed that total grain yield in traditional furrow irrigation treatment (M_3) was higher compared to other methods when irrigated with 100% FC. The yield contributing parameters viz. as cob length, cob perimeter, no of grain and grain yield per plant or cob were found non-significant between the methods of AWDFI (M_1) and TFI (M_3) but better than that of FWDFI (M_2) at different levels of irrigation. Results showed that yields were significantly different among the methods when irrigated to 100% field capacity (I_1). There was a consistent trend for similar yield on AWDFI (M_1) and TFI (M_3) and lower yield on fixed wetting and drying furrow irrigation (M_2) when irrigation level was drastically reduced. Crop yield in treatment of fixed furrow irrigation (M_2) was found lower than AWDFI (M_1) and TFI (M_3) due to limited root growth, water and nutrient uptake for prolonged soil drying on one side root of the plant. The yield results indicated that when less amount of irrigation water was applied, AFI (M_1) had insignificantly reduced yield but yield reduction was significant with FFI at different levels of irrigation. AFI could maintain approximately similar grain yield compared to TFI with almost 50% reduction in irrigation water. This technique involves alternately half of the root system being exposed to drying soil while the remaining half is irrigated normally with each irrigation.

Table 4.1: Effect of irrigation levels and methods on yield contributing characters and yield of maize

£Treatments		Cob		Grain/cob (no.)	*TGW (g)	*Yield/cob (g)	¥Yield (kg/ha)
Level	Method	Cob length (cm)	Cob perimeter (cm)				
I_1	M_1	18.0 abc	4.90 a	510.3 a	333.3ab	157.4 a	9488 b
	M_2	17.0 abc	4.61 c	497.0 a	330.2abc	141.7 b	8731 c
	M_3	18.9 a	4.82ab	529.7 a	339.2ab	164.4 a	9894 a
I_2	M_1	17.5abc	4.78abc	487.3 a	342.5 a	145.1 b	8184 d
	M_2	17.2 c	4.67bc	486.7 a	314.7bc	135.1 b	7800 e
	M_3	18.1abc	4.61 c	510.0 a	333.5ab	143.1 b	8313 d
I_3	M_1	18.6ab	4.67bc	517.0 a	342.1 a	144.2 b	7668 e
	M_2	17.3bc	4.71abc	493.7 a	306.2c	135.4 b	7096 f
	M_3	17.5abc	4.76abc	520.0 a	326.9abc	141.6b	7609 e

£Treatments: I_1, I_2, & I_3 indicate irrigation up to 100%, 80% and 60% field capacity, respectively; M_1: Alternate wetting and drying furrow = irrigation, M_2: Fixed wetting and drying furrow irrigation, M_3: Traditional furrow irrigation (TFI).

*TGW & total yield weight was measured at14% grain moisture content.

¥Whole plot yield was measured and expressed in tons per hectare (t/ha).

In a column, same letter (s) do not significant differ at $P_{0.05}$ level within treatments. Values are mean of three replication of each treatment.

4.1.3 Plant height

Table 4.2 reveals that irrigation water quality had significant effect on plant height. In 100%, 80% and 60% FC irrigation water on traditional furrow irrigation, the plant height were found to be 137cm, 135cm and 134cm respectively. Then 100%, 80% and 60% FC irrigation water on alternate wetting and drying furrow irrigation, the plant height were found to be 134cm, 132cm, 130cm respectively and on the fixed wetting and drying furrow irrigation those were found to be 130cm, 129cm and 125cm respectively. So the plant height in traditional furrow irrigation was comparatively larger than alternate wetting and drying furrow irrigation and fixed wetting and drying furrow irrigation.

Table 4.2: Effect of irrigation on plant height

Levels	Method	Plant Height (cm)
I_1	M_1	134
	M_2	130
	M_3	137
I_2	M_1	132
	M_2	129
	M_3	135
I_3	M_1	130
	M_2	125
	M_3	134

4.1.4 Number of Grain per Cob

Table 4.1 shows the number of grains per cob at different moisture content levels. At 100% field capacity (FC) using M_1, M_2 and M_3 methods, the number of grains per cob were found to be 510, 497 and 530 respectively. For 80% FC and 60% FC using methods M_1, M_2 and M_3 the number of grains per cob were found to be 487, 486, 510 and 517, 493 and 520 respectively. The results revealed that the highest number of grains per cob were found in 100% FC in method M_3 and the lowest number of grains per cob were found at 60% FC in method M_2. Therefore, more number of grains were found in traditional furrow irrigation than alternate wetting and drying furrow irrigation and fixed wetting and drying furrow irrigation.

4.1.5 Length of cob

There were significant difference in cob length was found among three irrigation levels and three irrigation treatments. Table 4.1 reveals that applying irrigation at 100% FC and M_1, M_2 and M_3 methods, the lengths of cob were found to be 18cm, 17cm and 18.9 cm respectively and applying irrigation at 80 % FC and 60% FC on the same methods, the lengths of cob were found to be 17.5cm, 17.2cm, 18.1cm and 18.6cm, 17.3cm and 17.5cm respectively. The result reveals that the highest length of cob was found while applying irrigation at 100% FC using M_3 method. On the other hand, the lowest length of cob was found while applying irrigation at 60% FC using M_2 method. So, the traditional furrow irrigation gave larger length of cob than alternate wetting and drying furrow irrigation and fixed wetting and drying furrow irrigation.

4.1.6 Thousand Grain Weight

Table 4.1 reveals that while applying irrigation at 100% FC and M_1, M_2 and M_3 methods, the weights of thousand grain were found to be 333.3gm, 330.2gm and 339.2gm respectively and while applying irrigation at 80% FC and 60% FC on the same methods, the weights of thousand grain were found to be 342.5gm, 314.7gm 333.5gm and 342.1gm, 306.2gm and 326.9gm respectively. The result reveals that the highest weight of thousand grain was found while applying irrigation at 100% FC using M_1 method and the lowest weight was found applying irrigation at 60% FC using M_2 method. So, the weight of thousand grain was more at alternate wetting and drying furrow irrigation than fixed wetting and drying furrow irrigation and traditional furrow irrigation.

4.1.7 Weight of Grain Yield

Table 4.1 reveals that the weights of grain yield applying irrigation at 100% FC using M_1, M_2 and M_3 methods were found to be 9488kg/ha, 8731kg/ha and 9894kg/ha respectively and applying irrigations at 80% FC and 60% FC using same methods, the weights of grain yield were found to be 8184kg/ha, 7800kg/ha, 8313kg/ha and 7668kg/ha, 7096kg/ha, 7609kg/ha respectively. The result reveals that the highest weight of grain yield was found applying irrigation at 100% FC using M_3 method and the lowest weight of grain yield was found applying irrigation at 60% FC using M_2 method. So the traditional furrow irrigation gave more grain yield than alternate wetting and drying furrow irrigation and fixed wetting and drying furrow irrigation.

4.1.8. Cob length and cob perimeter

Fig. 5 shows that the cob length was found greater using M_3 method than $M_1$and M_2 method applying irrigation at 100%, 80% and 60% FC. So the traditional furrow irrigation gave larger cob length than the fixed wetting and drying furrow irrigation and alternate wetting and drying furrow irrigation. On the other hand, cob perimeter was found larger using M_1 method than M_2 and M_3 method applying irrigation at 100%, 80% and 60% FC. So, alternate wetting and drying furrow irrigation gave larger cob perimeter than fixed wetting and drying irrigation and traditional furrow irrigation.

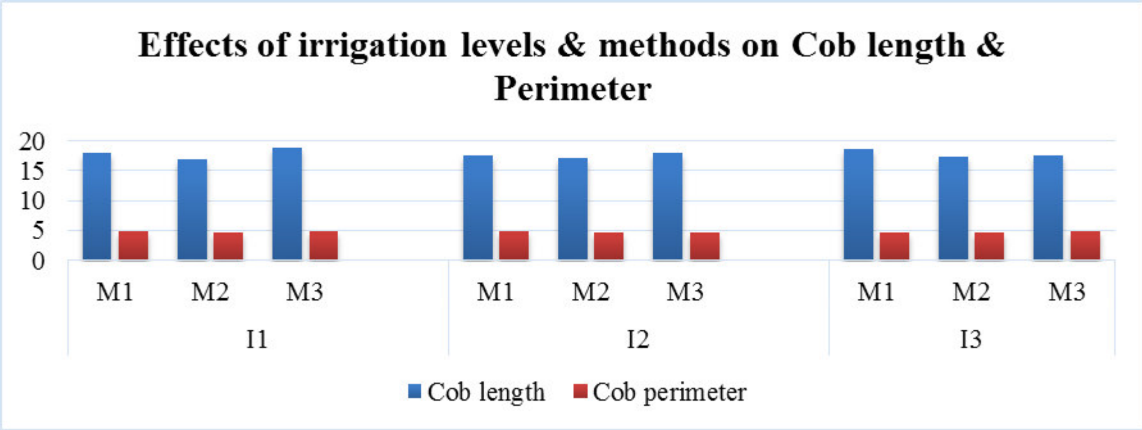

Fig 5: Effects of irrigation levels and methods on cob length and cob perimeter

4.1.9. Number of grain per cob and thousand grain weight

Fig. 6 shows that the number of grain per cob was found greater using M_3 method than $M_1$and M_2 method applying irrigation at 100%, 80% and 60% FC. So, the traditional furrow irrigation gave more number of grains per cob than the fixed wetting and drying furrow irrigation and alternate wetting and drying furrow irrigation. On the other hand, the weight of thousand grain was found lower using M_1 method than M_2 and M_3 method applying irrigation at 100%, 80% and 60% FC. So, the lower weight of thousand grain was resulted in alternate wetting and drying furrow irrigation gave lower weight of thousand grain than fixed wetting and drying furrow irrigation and traditional furrow irrigation.

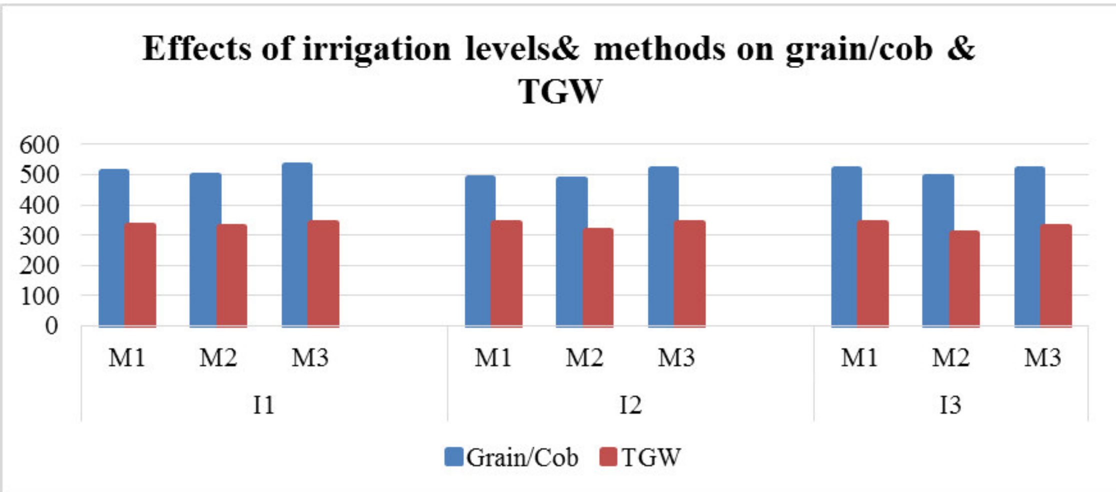

Fig 6: Effects of irrigation levels and methods on grain per cob and thousand grain weight

4.1.10. Yield per cob and yield

Fig. 7 shows that yield per cob was highest while applying irrigation water at 100% FC using M_3 method and while applying irrigation at 80% FC and 60% FC using M_1 method was higher than M_2 and M_3 method. Hence, alternate wetting and drying furrow irrigation gave more yield per cob than fixed wetting and drying furrow irrigation and traditional furrow irrigation. On the other hand, yield component was highest while applying irrigation water at 100% FC and 80% FC using M_3 method and for applying irrigation at 60% FC using M_1 method, yield per cob was higher than M_2 and M_3 method.

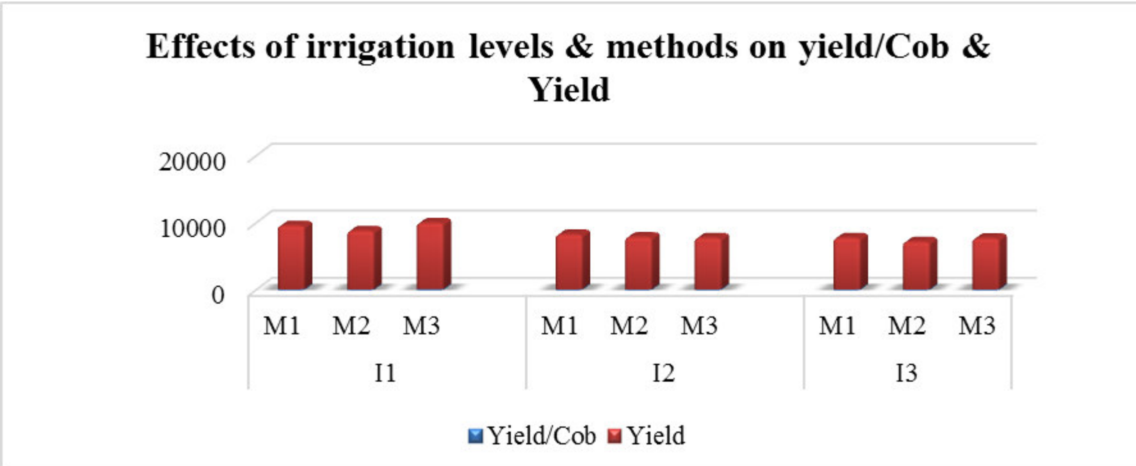

Fig 7: Effects of irrigation levels and methods on yield per cob and yield.

4.2. Seasonal water saving and water use efficiency

The component of seasonal water use (SWU) and water productivity (WP) of maize is shown in Table 4.3. SWU and WUE varied among the treatments due to the variation of irrigation water use. AWDFI method and irrigation levels greatly affected the field water use efficiency for maize production (Table 4.3).

Table 4.3: Seasonal water use (SWU) and water productivity (WP) of maize grown.

IR timing (DAS)[b]	Treatment		IR water amount (cm)	Effective rainfall (cm)	SWC (cm)	SWU (cm)	Grain yield (Kg/ha)	WP (kg/m3)	% water saving of M_1 over M_3
	IR level	IR Method							
39, 63, 98	I_1	M_1	8.7	18	-3.3	23.4	9488	4.05	27
		M_2	8.7	18	-3.2	23.5	8731	3.72	
		M_3	17.3	18	-3.5	31.8	9894	3.11	
	I_2	M_1	7.0	18	-3.0	22.0	8184	3.72	24
		M_2	7.0	18	-2.6	22.4	7800	3.48	
		M_3	14.0	18	-3.1	28.9	8313	2.88	
	I_3	M_1	5.3	18	-2.4	20.9	7668	3.67	19
		M_2	5.3	18	-2.2	21.1	7096	3.36	
		M_3	10.5	18	-2.9	25.6	7609	2.97	

[¥]IR indicates irrigation

[£] Treatments: I_1, I_2, & I_3 indicate irrigation up to 100%, 80% and 60% field capacity, respectively; M_1: Alternate wetting and drying furrow irrigation, M_2: Fixed wetting and drying furrow irrigation, M_3: Traditional furrow irrigation (TFI).

"-" sign indicates that soil moisture appeared more (unused) at harvest than sowing period of maize cultivation.

Results show that alternate furrow irrigation (M_1) technique had highest WUE compared to traditional furrow irrigation system (M_3) due to both lower irrigation application and higher grain yield (Table 4.3). AFI system gave higher WP compared to other methods of TFI (M_3) and FWDFI (M_2) at same level of irrigation due to produce nearly similar yield and lower application of irrigation water (Table 4.3) for maize cultivation. AWDFI (M_1) saved 27, 24 and 19 % SWU compared to TFI when irrigation water applied up to 100, 80 and 60% FC, respectively (Table 4.3). Data showed that water productivity (WP) varied 2.88 to 4.05 kg/m^3. The highest WUE was found in alternate wetting and drying furrow irrigation (M_1) as expected from yield and seasonal water use. Traditional furrow irrigation system (M_3) noticeably produced the lowest WUE (Table 4.3) but M_3 technique did not produce significantly higher yield at the different levels of irrigation amount. The results indicated that AWDFI (M_1) system maintained desired yield when re-watering irrigation was applied alternatively. As a result, WUE was substantially improved by AWDFI (M_1). Therefore, WUE was higher around 23, 22 and 19% in AWDFI (M_1) system than TFI (M_3) when irrigating with I_1, I_2 and I_3 level of irrigation amount. Alternate wetting and drying furrow irrigation (M_1) is an effective water-saving irrigation method which efficient soil moisture utilization improves soil enzymatic activities and crop water use. However, AFI had the potential to save water and may be an useful irrigation water application method where water and water supply methods are limited to irrigation for crop production.

4.3. Irrigation Water Amount and Effective Rainfall

Table 4.3 reveals that the effectiveness of rainfall was same in all of three irrigation levels and three irrigation methods. Effective rainfall was 18 cm. and this amount of irrigation water was applied in the field using M_1, M_2, M_3 methods varying with irrigation level (100% FC, 80% FC, and 60% FC). The highest amount of water (17.3 cm) was applied using M_3 method at 100% FC.

4.4. Percentage of Saving Water

The table 4.3 shows the percentage of water saving in alternate wetting and drying furrow irrigation over traditional furrow irrigation. The highest amount of water was saved (27%) when irrigation was applied at 100% field capacity.

4.5. Seasonal water use and water productivity:

Fig. 8 shows that the usage of the seasonal water was the highest while applying irrigation using M_3 method at 100% FC, 80% FC and 60%. Hence, the usage of the seasonal water was more in traditional furrow irrigation than alternate wetting and drying furrow irrigation and fixed wetting and drying furrow irrigation. But the water productivity was more in M_1 method than M_2 and M_3 methods at 100% FC, 80% FC and 60%. So, water productivity was greater in alternate wetting and drying furrow irrigation than fixed wetting and drying furrow irrigation and traditional furrow irrigation.

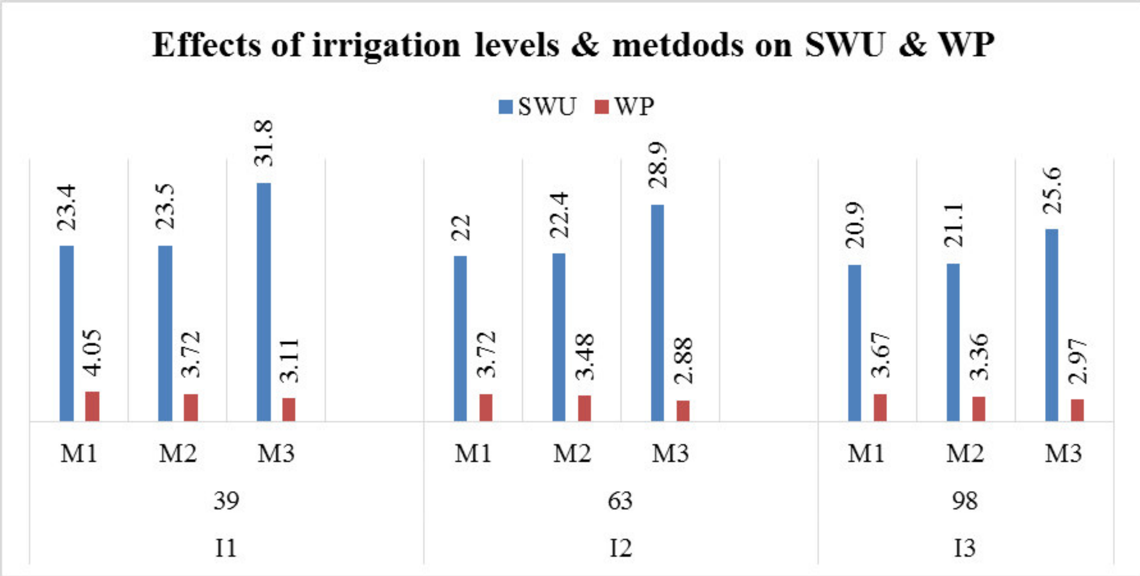

Fig 8: Effects of irrigation levels and methods on seasonal water use and water productivity

CHAPTER V

CONCLUSION

CHAPTER V

CONCLUSION

Experiment was conducted to assess the improvement of maize cultivation through the response of alternate wetting and drying furrow irrigation method.

- The field experimental plan yielded nine treatments (3 × 3) by randomized complete block in a spilt plot design replicated thrice, having twenty seven plots.
- The layout of split plot design involved three irrigation (IR) levels such as I_1 (Irrigation water applied to 100% FC), I_2 (Irrigation water applied to 80% FC) and I_3 (Irrigation water applied to 60% FC) main plot and three IR methods such as M_1 (Alternate wetting and drying furrow irrigation (AWDFI)), M_2 (Fixed wetting and drying furrow irrigation (FWDFI)) and M_3 (Traditional furrow irrigation (TFI)) subplot treatment in three replications.
- Total four irrigations were applied in all treatments during the different growth stages of maize. The stage which irrigation was scheduled as initial growth (25-30 DAS), tasselling (55-60 DAS), silking (85-90 DAS) and grain filling (110-115 DAS) was also followed by plant and soil moisture observation method depending on rainfall or soil moisture.
- As this is a one year study, it suggests that alternate wetting productivity and drying furrow irrigation (AWDFI) has the potential to improve both yield and water. AWDFI and traditional furrow irrigation (TFI) with irrigation to 100% field capacity produced maize yield around 9.5 and 9.9 t/ha. Compared to the TFI, AWDFI technique saved seasonal irrigation water use by 27 % and reduced total grain yield by around 4 % when irrigated to 100% field capacity.
- However, alternate furrow irrigation may be used in practice by alternately irrigating one part of the root zone of the plant each time and may improve water productivity of maize crop production without significant reduction of yield and yield attributes.

Further study is necessary to confirm the results of the present experiments for several seasons and other crops.

REFERENCES

REFERENCES

Abbas, G. Hossain, A. Ahmed, A. and Wajid, S.A. 2005. Water Use Efficiency of Maize as Affected By Irrigation Schedules and Nitrogen Rates. Journal of agriculture & social sciences 1813–2235/2005/01–4–339–342.

Akbar, T. Hashemi, R. Abbaskhasei and Alishahidi. 2015. The effect of deficits irrigation method of alternate furrow irrigation on yield of sweet corn. Research journal of fisheries and hydrobiology.

Alam, M. S., Mridha, M. A. K., Rashid, M. H., Roy, K. C. 2003. Waterlogging tolerance of Maize cultivation, Journal of the Institution of Engineers, Vol. 0/AE. No. 1, Dec, 2003.

Albasha, R., Dejean, C. Mailhol, J.-C., Weber, J.-J., Bollègue, C. and Lopez, J.-M. 2015. Performances of subsurface drip irrigation for maize under Mediterranean and temperate oceanic climate conditions. International Commission on Irrigation and Drainage. 6(1): 1-4.

Amiruzzaman, M., and Hossain, G.M. 2015. Climate resilience technologies for maize production, Training manual on Agricultural Technologies for Adaptation to climate change, held on h10-11 June at BARC, Farmgate, Dhaka.

Arshad, A.M. and Ibrahim W. 2014. Effect of Partial Root zone Drying Irrigation on Nutrient Concentration in Leaves, Photosynthesis, Photosynthesis Active Radiation and Yield of Sorghum Cultivar. Journal of Biology, Agriculture and Healthcare ISSN 2224-3208 (Paper) ISSN 2225-093X (Online)Vol.4, No.2, 2014.

Biswas, M., Sarkar, S., Goswami, S.B., 2002. Rate of irrigation frequencies and water application methods on evapotranspiration rate and water use efficiency of cauliflower. J. Indian Soc. Soil Sci. 54: 339–341.

Chang, Z.Z., Hongwei, L. and Tingting, C. 2011. Effect of furrow irrigation and alternate wetting and drying irrigation on grain yield and quality of rice. China Agriculture Science. 44(24): 4988-4998

Dominguiz, J.A.Z. Behboudian, M.H. Lang, A. and Clothier, B.E. 2003. Deficit irrigation and partial rootzone drying maintain fruit dry mass and enhance fruit quality in 'Petopride' processing tomato (*Lycopersicon esculentum*, Mill.). J. Scientia Horticulturae. 98 (2003) 505–510.

Elzubeir, A.O. and Mohamed, A.E. 2011. Irrigation scheduling for maize (*Zea mays* L.) under desert area conditions- North of Sudan. Agric. Biol. J. N. Am., , 2(4): 645-651

Grimes, D.W. Walhood, V.T. and Dickens, W.L. 1968. Alternate-furrow irrigation for San Joaquin Valley Cotton. J. *California Agriculture* 22(5):4-6.

Halim, A.E. 2013. Impact of alternate furrow irrigation with different irrigation intervals on yield, water use efficiency, and economic return of corn. *Chilin Journal of Agricultural Research*, **73**, 175-180.

Hayrettin, KUSCU. Abdullah, KARASU. Mehmet, OZ. Ali Osman, DEMIR. İlhan, TURGUT. 2013. Effect of irrigation amounts applied with drip irrigation On maize evapotranspiration, yield, water use efficiency, And net return in a sub–humid climate, 18(1), 13-19

Hernández, M., Echarte, L., Della Maggiora, A., Cambareri, M., Barbieri, P. and Cerrudo, D. 2015. Maize water use efficiency and evapotranspiration response to N supply under contrasting soil water availability. *Field Crops Research*, *178*, 8-15.

Ibrahim, M.M., El-Baroudy, A.A. and Taha, A.M. 2016. Irrigation and fertigation scheduling under drip irrigation for maize crop in sandy soil. *International Agrophysics*, 30(1): 47-55.

Islam, M.S. and Hossain, M.A. 2009. Determination of crop co-efficient of hybrid maize by lysimeter study. Bangladesh J. Agril. Res. 35(1): 77-82.

Jat, M. L., Sharma, S.K., Rai, H.K., Srivastava, A. and Gupta, R.K. 2006. Effect of tillage on performance of winter in Maize in Northern India, Maize Association of Australia 6th Triennial Conference, Grifith, NSW, Australia February 21-23.

Kang, S. and Zhang, J. 2004. Controlled alternate partial root-zone irrigation: its physiological consequences and impact on water use efficiency, Journal of Experimental Botany 55 (407): 2437–2446.

Kang, S. Liang, Z. Hu, W. and Zhang, J. 1998. Water use efficiency of controlled alternate irrigation on root-divided maize plants. J. Agricultural Water Management 38: 69-76.

Khan, B. R., Alam, M. S., Hossain, M. M., Parh, D. K. 1992. Irrigation requirement of maize. Annual Research Report 1992, IWM Division, BARI, Gazipur.

Kresović, B., Tapanarova, A., Tomić, Z., Životić, L., Vujović, D., Sredojević, Z. and Gajić, B. 2016. Grain yield and water use efficiency of maize as influenced by different irrigation regimes through sprinkler irrigation under temperate climate. *Agricultural Water Management*, 169: 34-43.

Kusco, H. and Demir, A.O. 2013. Yield and Water Use Efficiency of Maize under Deficit Irrigation Regimes in a Sub-humid Climate. J. Philipp Agric. Scientist Vol. 96 No. 1, 32–41.

Li, F., Liang, J., Kang, S., and Zhang, J. 2007. Benefits of alternate partial root-zone irrigation on growth, water and nitrogen use efficiencies modified by fertilization and soil water status in maize, Plant Soil 295:279–291.

Liang, H. Li,F. and Nong, M. 2013. Effects of alternate partial root-zone irrigation on yield and water use of sticky maize with fertigation. J. Agricultural Water Management 116 (2013) 242– 247.

Liu, F. Jensen, C.R. Anderson, M.N. 2003. Hydraulic and chemical signals in the control of leaf expansion and stomatal conductance in soybean exposed to drought stress. Functional Plant Biology, 30: 65-73.

Masoud, R. and Ghodratolah, S. 2010. Water Use Efficiency of Corn as Affected by Every Other Furrow Irrigation and Planting Density11 (7): 826-829, 2010

Metwally A. K.2011. Effect of Water Supply on Vegetative Growth and Yield Characteristics in Onion (*Allium Cepa* L.). Australian Journal of Basic and Applied Sciences, 5(12): 3016-3023, 2011 ISSN 1991-8178.

Mohammadpour, M., Afrous, A. and Palangan, A. P. 2013. The yield functions of maize toward the deficit irrigation in the tropical climate of Dezfoul. *Bulletin of Environment, Pharmacology and Life Sciences*, *2*(2), 1-4.

Nasri, M. Khalatbari, M. and Farahani, H.A. 2010. The effect of alternate furrow irrigation under different nutritional element supplies on some agronomic traits and seed qualitative parameters in corn (*Zea mays* L.). Journal of Cereals and Oilseeds Vol. 1(2), pp. 17 – 23.

Nodehi, D.A. 2015. Effect of Furrow Irrigation Methods and Deficit Irrigation on Yield and Water Use Efficiency of Maize in Mazandaran. J. Sci. & Technol. Agric. & Natur. Resour., Water and Soil Sci., Vol. 18, No. 70.

Qi, D. Hu, T. and Niu, X. 2017. Responses of root growth and distribution of maize to nitrogen application patterns under partial root-zone irrigation. International Journal of Plant Production 11 (2), April 2017 ISSN: 1735-6814 (Print), 1735-8043 (Online).

Quanqi, L., Yuhai, C., Mengyu, L., Xubo, Z., Baodi, D., Songlie, Y. 2008. Water potential characteristics and yield of summer maize in different planting patterns. Plant Soil Environ. 54 (1): 14-19.

Ramalan, A.A. and Nwokeocha, C.U. 2000. Effects of furrow irrigation methods, mulching and soil water suction on the growth, yield and water use efficiency of tomato in the Nigerian Savanna. J. Agricultural Water Management 45 (2000) 317-330.

Reddi, G.H.S. Reddy, T.Y. 2009. Efficient Use of Irrigation Water. 1st ed. Kalyani Publishers, New Delhi. pp. 110-112.

Roy, K. C., Anwar, T. M. K., Mainuddin, M. and Islam, S. 1992. Research on maize for irrigation based on climatological approach. Annual Research Report 2012, IWM Division, BARI, Gazipur.

Sarkar, K.K. Akanda, M.A.R. Biswas, S.K. Roy, D.K. Khatun, A. and Goffer, M.A. 2012. Field performance of alternate wetting and drying furrow irrigation on tomato crop growth, yield, water use efficiency, quality and profitability. Journal of Integrative Agriculture 15(10): 2380–2392.

Sepaskhah, A. R. and Khajehabdollahi, M. H. 2005. Alternate furrow irrigation with different irrigation intervals for maize (Zea mays L.). *Plant production science*, 8(5): 592-600.

Sepaskhah, A.R. and Khajeabdullahi, M.H. 2005. Alternate Furrow Irrigation with Different Irrigation Intervals for Maize (*Zea mays* L.). Journal Plant Production Science Volume 8(5).

Sepaskhah, A.R. Sichani, S.A. Bahrani, B. 1976. Subsurface and furrow irrigation evaluation for bean production. Transactions of the American Society of Agricultural Engineers, 19: 1089-1093.

Shahnazari, A. Liu, F. Andersen, M.N. Jacobsen, S. and Jensen, C.R. 2007. Effects of partial root-zone drying on yield, tuber size and water use efficiency in potato under field conditions. J. Field Crops Research 100: 117–124.

Sun, Y. Holm, P.E. and Liu, F. 2014.Alternate partial root-zone drying irrigation improves fruit quality in tomatoes. J. Hort. Sci. (Prague), 41(4): 185–19.

Taisheng, D., Kang, S., Sun, J., Zhang, X. and Zhang, J. 2010. An improved water use efficiency of cereals under temporal and spatial deficit irrigation in north China. *Agricultural Water Management*, 97(1): 66-74.

Tang, L. Li, Y. and Zhang, J. 2010. Biomass allocation and yield formation of cotton under partial root zone irrigation in arid zone. J. Plant Soil. 337: 413–423.

Yactayo, W. Ramírez, D.A. Gutiérrez, R. Mares, V. Posadas, A. and Quiroz, R. 2013. Effect of partial root-zone drying irrigation timing on potato tuber yield and water use efficiency. J. Agricultural Water Management 123: 65–70.

Zegbe, J.A. Behboudian, M.H. Clothier, B.E. 2004. Partial root zone drying is a feasible option for irrigating processing tomatoes. Agricultural Water Management, 68: 195-206.