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Effects of different irrigation levels on yield and water productivity of maize

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ABSTRACT

This study was conducted in the experimental farm of Bangladesh Agricultural University (BAU), Mymensingh, during 1 January 2012 to 10 May 2012 with a view to evaluate the effects of different irrigation levels on yield and yield contributing attributes of maize. The experiment consisted of 5 irrigation treatments, such as I_0: no irrigation (control), I_1: irrigation at IW (Irrigation Water applied)/CPE (Cumulative Pan Evaporation) = 0.4, I_2: irrigation at IW/CPE = 0.6, I_3: irrigation at IW/CPE = 0.8, I_4: irrigation at IW/CPE = 1.0. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Each replication was divided into 5 plots (7.0 m × 4.5 m) having 1.5 m buffer zone between them. Maize was grown with three irrigations applied at 43, 63 and 83 days after sowing (DAS) and recommended fertilizer doses. There was no significant (α = 0.05) effect of irrigation on the grain yield of maize. Treatment I_4 produced the highest grain yield (10.30 t/ha) and I_1 produced the lowest grain yield (6.81 t/ha). The irrigation treatments exerted different degrees of influence; some attributes differed significantly while others differed insignificantly. The water use efficiency (WUE) differed significantly among the irrigation treatments. The maximum stressed treatment (I_0) provided the highest WUE (6291 kg/ha/cm for grain production and 30050 kg/ha/cm for biomass production). The maximum irrigated treatment (I_4), on the other hand, provided the lowest WUE (459.3 kg/ha/cm for grain production and 110.7 kg/ha/cm for biomass production).

INTRODUCTION

Maize (*Zea mays* L.) is the most important food grains in the world as well as in developing countries like Bangladesh. It is becoming an important crop in the rice based cropping system and continues to expand rapidly at average rate of 20% per year (CIMMYT, 2008). Maize are planted in Bangladesh has risen from just a few thousand hectares in 1993-1994 to a total of 312 thousand hectares in the 2012-2013 cropping year and approximately 2078 thousand metric tons of maize grain was produced (DAE, 2014). Currently it is grown one about 0.355 million hectare of land with a production of 2.361 million metric tons and average yield of 6.65 tons per hectare (Krishi Diary, 2016). Every part of the plant and its products can be used in one form or the other and can supply food and fuel in relatively large quantities as compared to other cereal crops. Its grain has high nutritive value containing 66.20% starch, 11.10% protein, 7.12% oil and 1.50% minerals. Moreover, it contains 90g carotene, 1.80mg thiamin and 0.10mg riboflavin per 100g grains (Thakur, 1980; Chowdhury and Islam, 1993). Maize can be consumed directly as green cob, popped grain and flour satu (a type of local food). It is also used for manufacturing starch, corn flakes, alcohol, salad oil, soap, varnishes, paints, printing and similar products (Ahmed, 1994). The green part of the crop is a good source of animal feed. Now-a-days, the green part of the maize is popularly used to produce chitagour as animal feed. At present, a good number of maize varieties are available in Bangladesh; most of them are hybrid varieties like BHM-5, BHM-7, BHM-8, BHM-9, Chamak, Pacific-984 and Monesha are used at field level. Maize grows well in sandy loam and clay loam type of soils having pH in between 5.5 and 8.5. A temperature range of 12 to 29˚C is favorable for its growth.

Maize is grown in Bangladesh during the driest months when rainfall is almost inadequate. Proper growth and development of maize needs formable soil moisture in the root zone. The moisture

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content in the soil gradually decreases with elapsed time during dry season. Limited water supply during growing season results in soil and plant water deficits and reduces maize yield (Gordon et al. 1995). In relation to crop yield, proper time and supplemental irrigation should be realized in irrigation scheduling for the most effective use of available water in optimizing maize production. Water deficit had little effect on timing of emergence and number of leaves per plant but it delays tasseling initiation and silking, reduces plant height and vegetative growth of maize (Abrecht and Carberry, 1993). Heading to milking stage is the most sensitive period of water stress and has ultimate impact on grain yield (Shaozhong and Minggang, 1992). Improper scheduling of irrigation results not only in wastage of water but also reduces the crop growth and yield. Maize has high irrigation requirements and is very sensitive to water stress. Only about 15.7 million-acres of land is irrigated which is not enough to fulfill the 35.72 million-acre requirements (BBS, 2010). Water scarcity is the main constraint for maize production in Rabi season. Sustainable use of water resources is increasingly becoming an acute world-wide problem. Traditional irrigation practices influence on water productivity and contribute greatly to the labour cost for excess irrigation and lower yield resulting in lower economic returns. Maize cannot tolerate more than 24 hours water logging conditions (Amiruzzaman and Hossain, 2015). Thus, adequate irrigation management of maize is important not only for saving water but also improving crop profitability. Therefore, an attempt has been made to find out the influence of different levels of irrigation on growth yield and water productivity of maize.

MATERIALS AND METHODS

Experimental site

The experimental site was located at the farm near the office of Chief Farm Superintendent (CFS) of the Bangladesh Agricultural University at Mymensingh. The rainfall and evaporation data for the study area were collected from the weather station at the BAU farm.

Experimental design

The experiment consisted of five irrigation treatments. Irrigation was scheduled based on the ratio of irrigation water applied (IW) to the cumulative pan evaporation (CPE). The irrigation treatments were: I_0: no irrigation (control), I_1: IW/CPE = 0.4, I_2: IW/CPE = 0.6, I_3: IW/CPE = 0.8, and I_4: IW/CPE = 1.0. In all treatments, irrigation was given at 43, 63 and 83 DAS. The timing of irrigation was selected based on physiological development stages of maize. The 43 (vegetative stage), 63 (silking stage) and 83 (tasselling stage) DAS were designated as the stage when a maize plant contained 3−5, 8−10 and 20−22 leaves on average, respectively. The variety of the maize was BARI hybrid maize 5 (BHM−5).

Land preparation and field layout

The land of the experimental field was opened on 15 December 2011 with a tractor and subsequently prepared thoroughly by ploughing and laddering. Weeds, stubble and crop residues were collected and removed from the field. The field was laid out on 20 December 2011 following a Randomized Complete Block Design (RCBD). It was divided into 3 blocks to represent three replications of the treatments. The spacing between the adjacent blocks was 1.5m. Each block was divided into five equal plots having 1.50 m buffer between them in a block.

Fertilizer application and seed sowing

The recommended doses of urea, triple super phosphate, muriate of potash, gypsum and zinc sulphate at the rate of 540, 240, 240, 15 and 5 kg/ha, respectively were applied. One-third of urea and the entire doses of the other fertilizers were applied at the time of final land preparation. The rest two-third of urea was top dressed in two equal splits at 50 and 83 DAS. For sowing the seeds, 5−6 cm deep furrows were made by using single tine hand rakes at a spacing of 75 cm. The seeds were sown on 1January 2012 at a depth of 5 to 6 cm, and 2 seeds were dropped per hill. The seed to seed distance was 25 cm.

Quantification and application of irrigation

Irrigation was applied based on the IW/CPE ratios of 0, 0.4, 0.6, 0.8 and 1.0. The amount of water applied in different treatments in each irrigation was quantified based on pan evaporation and rainfall.

Harvesting and data recording

At full maturity, the maize was harvested on 10 May 2012. A 3-m^2 area containing 16 plants was selected at the middle of each plot for harvesting. These plants were harvested to the ground level. The plants were bundled and tagged separately for each plot. The data was collected from sample plants are plant height, number of cobs per plant, cob length, cob perimeter, number of row of grains per cob, number of grains per cob, grain yield, straw yield and hundred (100)-grain weight.

Harvest index

Harvest index (HI) is the ratio between the grain yield and biological/biomass yield. The biological yield is the sum of the grain and straw yields. The HI is expressed as

$$\text{Harvest Index (HI)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

Water use efficiency

The water use of a crop field is generally described in terms of field water use efficiency (FWUE), which is the ratio of the crop yield to the total amount of water used in the field during the entire growing period of the crop. The FWUE demonstrates the productivity of water in producing crop yield. FWUE for maize was calculated by: FWUE=Y/WU; Where, FWUE = field water use efficiency, kg/ha/cm, Y = grain yield, kg/ha, WU = seasonal water use in the crop field, cm. The WU was calculated by summing up the water applied in irrigation (taking into account the rainfall) and soil moisture contribution. The soil moisture contribution was determined by subtracting the soil moisture at harvest from that at sowing.

Data analysis

The collected data were analyzed using analysis of variance (ANOVA) technique with MSTAT statistical package.

RESULTS AND DISCUSSION

Effect of irrigation on growth and yield attributes

Plant height

The mean plant heights for different irrigation treatments are listed in Table 1. The highest plant height of 299.6 cm was obtained at I_3 (IW/CPE = 0.8) and the lowest was 287.9 cm at I_0 (no irrigation). Due to different irrigation treatments at different growth stages, the plant heights, although varied to some extent, were statistically identical in the treatments. Niazuddin et al. (2002), Hossain et al. (2009) and Alam (2011) also reported different plant heights under different irrigation treatments.

Table 1
Growth and yield attributes of maize under different irrigation treatments.

Treatment	Plant Height, cm	Line/cob	Grain/line	Grain/cob	Cob length, cm	Cob perimeter, cm	Shell weight, t/ha	100 grain weight, g
I_0	287.9^b	15.2^a	35.3^a	540.3^a	16.6^a	15.7^b	2.280^a	20.19^a
I_1	293.3^{ab}	15.6^a	35.1^a	547.6^a	17.1^a	16.1^{ab}	2.167^a	19.71^a
I_2	295.5^a	14.7^{ab}	34.5^a	508.4^a	15.9^a	15.6^b	2.320^a	18.91^a
I_3	299.6^a	14.1^b	35.5^a	498.1^a	17.2^a	16.1^{ab}	2.205^a	21.91^a
I_4	297.3^a	15.2^a	37.8^a	574.1^a	17.5^a	16.3a	2.654^a	21.66^a
$LSD_{0.05}$	7.26	1.09	5.22	82.67	2.06	0.56	0.652	4.35

Grains per line of cob

The irrigation treatments did not have significant effects on the number of grains per line of cob (Table 1) although a trend of increased number of grains with increased level of irrigation was noticed. The highest value (37.84 grains/line) was observed at I_4 and the lowest value (34.54 grains/line) was at I_2.

Cob length and perimeter

The irrigation treatments did not affect the length and perimeter of cobs significantly (Table 1). Among all irrigation treatments, the highest cob length of 17.45 cm was obtained at I_4 and the lowest of 15.93 cm was obtained at I_2. A similar cob length was also reported by Niazuddin et al. (2002), Hossain et al. (2009) and Alam (2011). An increase in cob length by 3.19, 3.43 and 5.06% was observed in treatment I_1, I_3 and I_4, respectively and a decrease in cob length by 4.09% in I_2 was observed compared to the control treatment, I_0. In case of cob perimeter, the highest value of 16.29 cm was at I_4 and the lowest value of 15.63 cm was at I_2. Again, an increase in cob perimeter by 2.99, 2.61 and 3.95% in treatments I_1, I_3 and I_4, respectively and a decrease by 0.25% in I_2 was observed compared to the control.

Shell yield

The shell yield did not vary significantly among the irrigation treatments. The highest shell yield (2.654 t/ha) was obtained under maximum irrigation (I_4) and the lowest (2.167 t/ha) was obtained at I_1. The shell yield increased by 1.75 and 16.40% in treatment I_2 and I_4, respectively and decreased by 4.95 and 3.28% in I_1 and I_3, respectively compared to I_0.

Number of grains per cob

The number of grains per cob was identical among the irrigation treatments (Table 1). The highest number of grains per cob (574) was obtained at I_4 and the lowest (498) was at I_3. An increase in the number of grains per cob by 1.29 and 6.29% were obtained in I_1 and I_4, respectively and a decrease by 5.92 and 7.77% in I_2 and I_3, respectively compared to I_0. There was no trend in the number of grains per cob with the quantity of applied irrigation.

100-grain weight

The 100-grain weight of maize was statistically similar for different irrigation treatments (Table 1). The highest 100-grain weight (21.91 g) was obtained at I_3 and the lowest (18.91 g) was obtained at I_2. The 100-grain weight decreased by 2.13 and 6.33% in I_1 and I_2, respectively and increased by 8.51 and 7.28% in I_3 and I_4, respectively compared to the control treatment. The 100-grain weight had a relation with the number of grains per cob.

Effect of irrigation on yield

Grain yield

The treatment I_4 produced the highest grain yield of 10.301 t/ha and I_1 produced the lowest yield of 6.810 t/ha (Table 2). However, irrigation treatments had no significant effect on the production of grain yield of maize. As water stress was the lowest in I_4, the yield became the highest. The percentage increase in grain yield in treatment I_2, I_3 and I_4 was 11.83, 10.54 and 17.63, respectively over the control treatment. The grain yield however decreased by 22.23% in treatment I_1. In similar experiments, Talukder et al. (1999), Niazuddin et al. (2002), Hossain et al. (2009) and Alam (2011) reported obtaining the highest grain yield at I_4 and the lowest at I_0. In an experiment in a farmer's field, the highest grain yield (12.50 t/ha) was also reported under the highest irrigation level (BARI, 2005 – 2006). The grain yield of maize increased with the increase in total water use except for the treatment I_2.

Straw yield

Although irrigation played a positive role in increasing the straw yield of maize, its effect was insignificant (Table 2). The straw yield under various irrigation treatments ranged from 31.15 to 47.041 t/ha. Treatment I_3 produced the highest straw yield (47.041 t/ha) and I_2 produced the lowest (31.15 t/ha) yield. Hossain et al. (2009) and Alam (2011) however reported obtaining the highest straw yield at I_4 and the lowest at I_0.

Table 2
Grain, straw and biomass yield of maize under different irrigation treatments.

Treatment	Grain yield, t/ha	Straw yield, t/ha	Biomass yield, t/ha
I_0	8.757^a	33.071^b	45.731^b
I_1	6.810^a	33.282^b	43.903^b
I_2	9.793^a	31.150^b	44.872^b
I_3	9.680^a	47.041^a	60.571^a
I_4	10.301^a	31.491^b	46.072^b
$LSD_{0.05}$	3.481	11.530	13.160

Biological yield

No significant variation was observed in the biological yield of maize among the irrigation treatments apart from the I_3 treatment (Table 2). The highest biological yield (60.571 t/ha) was obtained at I_3 and the lowest (43.903 t/ha) was at I_0. These results are inconsistent with the findings of Niazuddin et al. (2002), Hossain et al. (2009) and Alam (2011) as all of them found the highest yield at I_4 and the lowest at I_o.

Effect of irrigation on harvest index and water use efficiency

Harvest index

As compared in Table 3, the irrigation treatments did not exert any significant influence on the harvest index (HI). Treatment I_4 provided the highest HI (21.83%) and I_1 provided the lowest HI (15.27%). Niazuddin et al. (2002) Hossain et al. (2009) and Alam (2011) also reported similar effects of irrigation levels on HI.

Table 3
Harvest index (HI) and water use efficiency for grain (WUE_g) and biomass (WUE_b) production under different irrigation treatments.

Treatment	Harvest Index,%	Total water use, mm	WUE_g, kg/ha/cm	WUE_b, kg/ha/cm
I_0	19.18^a	13.9^e	6291^a	30050^a
I_1	15.27^a	128.0^d	531.9^b	13130^b
I_2	22.00^a	164.1^c	596.7^b	2495^b
I_3	16.38^a	200.8^b	489.0^b	2877^b
I_4	21.83^a	246.2^a	459.3^b	110.7^b
$LSD_{0.05}$	6.778	13.06	1248	15990

Water use efficiency

The water use efficiency that demonstrates the productivity of water in producing crop yields did not differ significantly among the irrigation treatments apart from I_0. The highest water use efficiency for grain production, WUE_g (6291 kg/ha/cm), was obtained at I_0 and the lowest (459.3 kg/ha/cm) was obtained at I_4 (Table 3). The highest water use efficiency for biomass production, WUE_b (30050 kg /ha/cm), was at I_0 and the lowest (110.7 kg/ha/cm) was at I_4. Both water use efficiencies decreased with increasing quantity of applied irrigation. Hossain et al. (2009) and Alam (2011) also reported comparable effects of different irrigation levels on water use efficiencies of maize.

CONCLUSION

Most yield attributes of maize were significantly affected by different irrigation treatments. The highest grain yield was 10.301 t/ha for I_4 (IW/CPE = 1) and the lowest was 6.810 t/ha for I_1 (IW/CPE=0.4). The water productivity/water use efficiency (WUE) was the highest (6291 kg/ha/cm for grain production and 30050 kg/ha/cm for biomass production) for I_0 and the lowest (459.3 kg/ha/cm for grain production and 110.7 kg/ha/cm for biomass production) for I_4.

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