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ORIGINAL ARTICLE

Impacts of dairy farm's wastewater irrigation on growth and yield attributes of maize

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ABSTRACT

An experiment was conducted at the experimental field of the Bangladesh Agricultural University (BAU) to investigate the effects of dairy farm's wastewater irrigation on maize (*Zea mays* L. *cv.* BARI hybrid-9) production and soil health during 5 February 2016 through 14 May 2016. Two factors were involved in the experiment: irrigation and fertilizer. Irrigation had three treatments - I_1: Irrigation with fresh water, I_2: Irrigation with mixed water (fresh water: dairy farm's wastewater = 1:1) and I_3: Irrigation with raw wastewater. There were three fertilizer treatments - F_0: No fertilizer, F_1: Half of recommended dose fertilizer and F_2: Full dose fertilizer. The experiment was laid out in a split-plot design with three replications. The irrigation treatments were applied in the main plots and the fertilizer treatments in the sub-plots. Maize was grown with two irrigations applied at 28 and 86 days after sowing (DAS). Wastewater contained different nutrients and organic matter, which optimistically contributed to the growth and yield attributes of maize. Various growth and yield data of the crop were recorded. For the effect of irrigation water quality, the highest grain yield (10.89 t ha^{-1}) was obtained under I_3 and the lowest grain yield (7.95 t ha^{-1}) was obtained under I_0. For the effect of fertilizer, the highest grain yield (11.70 t ha^{-1}) was obtained under F_2 and the lowest yield (8.56 t ha^{-1}) was obtained under F_0. The interaction effect between irrigation and fertilizer exerted significant impact on grain yield of maize. The highest grain yield (11.41 t ha^{-1}) and water use efficiency (2125 kg ha^{-1} cm^{-1}) were obtained under I_3F_0 (wastewater irrigation with no fertilizer application) and I_3F_2, respectively. The lowest values of grain yield (7.657 t ha^{-1}) and water use efficiency for grain production (697.3 kg ha^{-1} cm^{-1}) were obtained under I_1F_0. The highest 1000-grain weight of 417.7 g was obtained under I_3F_2 and the lowest of 239.7 g was obtained under I_1F_0.

INTRODUCTION

The pressure on irrigated agriculture is increasing day by day to ensure food security. Irrigation water in Bangladesh is a limited resource. A dramatic increase in demand of water for dry season irrigation causes an acute shortage of water in many parts of the country. With the increase of global population, the gap between the supply and demand for water is widening and reaching such an alarming levels that in some parts of the world it is posing a threat to human existence. So, additional water source(s) for irrigation may be an important solution to this problem. The water demand already exceeds supply in many parts of the world. Awareness of the global importance of preserving water for ecosystem services has only recently emerged. This is because during the 20th century, more than half of the world's wetlands have been lost along with their valuable environmental services. Biodiversity-rich freshwater ecosystems are currently declining faster than marine or land ecosystems (Hoekstra 2006).

In Middle East and North Africa, water is a scarce commodity and its availability is declining to a crisis level. The reuse of wastewater for the purpose of agricultural irrigation can reduce the amount of water that needs to be extracted from environmental water sources (Heidarpour et al. 2007).

The important quality parameters of wastewater, from an agricultural point of view are: physical properties such as total dissolved solids (TDS), electrical conductivity, temperature, color/turbidity, hardness and sediments, and chemical properties such as acidity, type and concentration of cations and anions (calcium, magnesium, sodium, carbonate, bicarbonate, chloride, sulphate, sodium adsorption ratio, boron, trace metals,

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nitrate nitrogen and potassium) (Kandiah 1990).

Maize production in Bangladesh had increased gradually from 1997 to 2008 due to its higher profitability than other cereal crops. In 2008-2009, the affection of farmer was increased to other cereal crops because of their higher productivity and profitability. So, the production of maize had reduced drastically in 2008-2009, mainly for the affection of farmers to other crops and reduction of its profitability (BBS 2009).

An experiment was carried out by Khan et al. (2007) to evaluate the dairy manure amendments of soil for corn production under different tillage systems. The experiment showed that both tillage and dairy manure had significantly reduced bulk density with greater porosity and hydraulic conductivity than soils under no tillage and zero dairy manure. Kamar (2011) conducted an experiment to demonstrate the effects of deficit irrigation on yield and water use efficiency of maize and finally he found that the highest grain yield was obtained at I_4V_3: irrigation at IW (irrigation water applied)/CPE (cumulative pan evaporation) = 1.0 with Pacific 984 variety, and the water use efficiency differed significantly among the irrigation treatments but insignificantly among the varietal treatments. Niazuddin et al. (2002) conducted an experiment to demonstrate the effect of water stress and nitrogen levels on the yield of maize. A few research works have been studied nationally on the impacts of wastewater irrigation on growth and yield of potential crops, especially maize. So, it is necessary to evaluate the impacts of dairy farm's wastewater irrigation on maize cultivation in Bangladesh.

MATERIALS AND METHODS

Experimental site and soil

The experiment was conducted in the central farm of the Bangladesh Agricultural University (BAU), Mymensingh, under the department of Irrigation and Water Management (IWM), during the period from February 2016 through May 2016. It was carried out to investigate the effect of irrigation by dairy wastewater on maize production and soil health under different fertilizer doses. The experimental site was situated in the agro-ecological zone (AEZ) 9 that lies at 24.75° N latitude and 90.50° E longitude. The elevation of the experimental site is 18 m above mean sea level. The soil of the experimental field is silt loam underlain by sandy loam. Organic matter content of the soil was 0.48%. The top soils were moderately acidic but sub-soils were neutral in reaction. The average field capacity and permanent wilting point of the soil was 38.19 and 18.37% (v/v), respectively and the bulk density was 1.33 g cm^{-3}. The initial pH of the field sub-soils was 7.59, 7.73 and 7.85, respectively, and electrical conductivity was 0.23, 0.11 and 0.06 dS m^{-1} at 0−20, 20−40 and 40−60 cm depth, respectively (BARC 2005).

Plant material

The variety named BARI (Bangladesh Agricultural Research Institute) Hybrid-9 was used in the experiment. It had a potential to reach a height of 150-200 cm and take 115-130 days for completing the life cycle and is resistant to leaf rust and leaf spot diseases. Number of cob per plant is 2-3. The yield varies between 10-13.8 t ha^{-1} (BARI 2012).

Experimental treatments

The treatments of the experiment comprised two factors: irrigation with three different percentages of wastewater and fertilizer having three different doses. There were thus nine treatments combinations. The planned treatments were:

1) I_1F_0 = irrigation with fresh water (I_1) + No fertilizer dose (F_0)
2) I_1F_1= irrigation with fresh water (I_1) + application of one half of (standard recommended) fertilizer dose (F_1)
3) I_1F_2 = Irrigation with fresh water (I_1) + application of full dose of fertilizer (F_2)
4) I_2F_0 = Irrigation with mixed water (fresh water: dairy wastewater = 1:1) (I_2) + No fertilizer dose (F_0)
5) I_2F_1 = Irrigation with mixed water (fresh water: dairy wastewater = 1:1) (I_2) + application of half dose of fertilizer (F_1)
6) I_2F_2 = Irrigation with mixed water (fresh water: dairy wastewater = 1:1) (I_2) + application of full dose of fertilizer (F_2)
7) I_3 F_0 = Irrigation with raw dairy water (l_3) + No fertilizer dose (F_0)
8) I_3F_1 = Irrigation with raw dairy water (l_3) + application of half dose of fertilizer (F_1)
9) I_3F_2 = Irrigation with raw dairy water (l_3) + application of full dose of fertilizer (F_2)

Soil and water sample collection

Soil samples were collected from five sampling points with a hand auger to know the initial properties of the soil of the experimental field before setting up the experiment. The collected samples were air dried, crushed on the ground and sieved through a 2 mm mesh sieve. Dry roots, grasses and other substances were removed from the samples. For each depth and treatment, a 500 g sample was taken in polyethylene bag for analysis. Wastewater samples were collected from the drainage canal of dairy lean, BAU, Mymensingh at each time of irrigation. Half-litter plastic bottles were used to collect the samples that were previously cleaned with diluted hydrochloric acid followed by distilled water. Before taking samples, the containers were rinsed three times with water to be sampled. For collection of fresh water, sufficient water was pumped out prior to sampling. Wastewater samples were drawn from middle and few centimetres below the surface of wastewater.

Quality parameters of dairy wastewater

Some important quality parameters of wastewater of BAU dairy farm are presented in Table 1 along with the FAO standard and Bangladesh standard of water for irrigation. The EC of wastewater varied from 0.51 to 0.74 dS m^{-1}. The FAO (1992) recommended standard value of EC for irrigation is 0.70 dS m^{-1} and in Bangladesh standard, it is 1.2 dS m^{-1} shown in Table 1. Wilcox (1955) classified irrigation water as excellent, good, permissible, doubtful and unsuitable depending on EC values as <0.25, 0.25−0.75, 0.75−2.0, 2.0−3.0 and >3.0 dS m^{-1}, respectively. So, comparing with the standard values of EC for irrigation, the dairy farm's wastewater was suitable for irrigation. The pH of wastewater varied from 7.2 to 7.8. The FAO standard for acceptable range of pH for irrigation water is 6.5-8.0 and in respect to Bangladesh standard, it is 6.0-9.0 (Table 1). The concentrations of NH_3-N, PO_4, P_2O_5, P and K of wastewater were higher than the limits set by FAO. The concentration of NO_2-N was very low in the wastewater. The concentrations of NO_3-N, Zn and B were not detected in the wastewater.

Fertilizer application

The recommended doses of urea, triple super phosphate, muriate of potash, gypsum and zinc sulphate were applied at the rate of 540, 240, 240, 15 and 5 kg ha^{-1}, respectively (BARC 2005). One-third of urea and the entire doses of other fertilizers were applied at the time of final land preparation. The rest of two-third of urea was top dressed in two equal splits at 50 and 83 DAS, respectively.

Irrigation practices

Irrigation was provided based on soil moisture content and crop stages like booting, flowering and grain filling stages. Adequate soil moisture content was available in the field at booting stage due to rainfall. For this reason, the first irrigation was applied at 28 DAS with an amount of 3.58 cm at each plot. Similarly, second irrigation was applied at 86 DAS with an amount of 5.3 cm at each plot. Third irrigation was not applied because of excessive rainfall on that period.

Table 1. Some important quality parameters of wastewater of BAU dairy farm along with the FAO and Bangladesh standard for irrigation

Quality parameters of wastewater	Date			FAO standard	Bangladesh standard
	10 January 2016	25 January 2016	15 February 2016		
pH	7.20	7.80	7.35	6.5-8.0	6.0-9.0
EC (dS m^{-1})	0.510	0.70	0.74	0.7	1.2
BOD (mg L^{-1})	120	140	133	-	10
COD (mg L^{-1})	400	480	488	-	<400
NH_3-N (mg L^{-1})	55	22.10	33.6	-	-
NO_3-N (mg L^{-1})	Not detectable	Not detectable	Not detectable	10	-
NO_2-N (mg L^{-1})	0.0065	Not detectable	Not detectable	-	-
PO_4 (mg L^{-1})	30.15	41.11	30.5	10	
P_2O_5 (mg L^{-1})	22.22	31.2	29.1	-	-
P (mg L^{-1})	11.0	13.1	13.5	-	15
Zn (mg L^{-1})	Not detectable	Not detectable	Not detectable	2.0	10
K (mg L^{-1})	60.1	57.7	56.7	30	
B (mg L^{-1})	Not detectable	Not detectable	Not detectable	2.0	2.0

Leaf area index

Leaf area index (LAI) is the ratio of the area of leaf to its ground area. It is the functional size of a standard crop on unit land area. It depends on growth of leaf, number of leaf per plant, plant population density and leaf senescence.

It is expressed by the following formula:

$$\text{Leaf area index} = \frac{\text{Total leaf area of the crop}}{\text{Total ground area under the crop}} \ldots\ldots\ldots\ldots (1)$$

To determine LAI, leaves of ten representative plants were collected and their total area was measured by using a leaf area meter. Total area covered by those ten plants was calculated from the known density of plant population. Finally, the LAI was measured by using the above formula. The LAI was measured on 05 March 2016. The area of leaf was measured with an LI-3100 AREA METER (LI-cor. Inc. Lincoln. Nebraska, USA) in Professor Muhammad Hossain Central Laboratory at BAU.

Determination of yield and harvest index

Grain yield: The grains obtained from each sampling area were sun dried to 12% moisture content and weighed. The dry weight of grains of 1.0 m^2 was allotted to the respective unit plot yield to record the final grain yield per plot; the grain yield was converted to ton per hectare.

Straw yield: The straw obtained from 1.0 m^2 sampled area of each plot was dried in the sun (to 12% moisture content). At first, the plant weight was measured. Then the shell and cover weight were noted. Finally, they were added to record straw yield per plot that was converted to ton per hectare.

Biological yield: The grain and straw yields together are regarded as biological yield. The biological yield was recorded for each plot (ton per hectare).

Harvest index: A harvest index was calculated by the following formula (Gardner et al. 1995):

$$\text{Harvest index}(\%) = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100 \ldots\ldots\ldots\ldots (2)$$

Water use efficiency

The crop-water use for maize cultivation was computed by adding the applied irrigation water, effective rainfall during the growing season and contribution of soil moisture during the growing season. Mathematically, the crop-water use was expressed by the following relationship (Michael 1985):

$$WU = IR + ER + \sum_{i=1}^{n} \frac{(M_S - M_h)}{100} \times D_i \ldots\ldots\ldots\ldots (3)$$

Where,
WU = seasonal crop-water use, cm
IR = total irrigation water applied, cm
ER= seasonal effective rainfall, cm
M_S = soil moisture content (% volume) at sowing
M_h = soil moisture content (% volume) at harvest
D_i = depth of root zone layer, cm

Effective rainfall was calculated by using the USDA Soil Conservation Method. The equations are given below:

$$P_{\text{effective}} = \frac{P_{\text{total}} \times (125 - 0.2 \times P_{\text{total}})}{125} \quad \text{for } P_{\text{total}} < 250\text{mm} \ldots\ldots\ldots\ldots (4)$$

$$P_{\text{effective}} = 125 + 0.1 \times P_{\text{total}} \quad \text{for } P_{\text{total}} > 120\text{mm} \ldots\ldots\ldots\ldots (5)$$

Determination of field-water use efficiency (FWUE)

The water used by a crop field is generally described in terms of field water use efficiency (FWUE), also called crop-water-productivity, 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. It was calculated by the following relationship (Michael 1985):

$$FWUE = \frac{Y}{W_u} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where,
FWUE = field-water use efficiency or crop-water-productivity,

kg ha^{-1} cm^{-1}
WU = seasonal crop-water use in the crop field, cm
Y = grain yield, kg ha^{-1}

Statistical analysis

The growth and yield attributes of maize were tabulated in proper forms for statistical analyses. The analysis of variance (ANOVA) was done following the methods described by Gomez and Gomez (1984). MSTAT-C computer package (Russel and Eisensmith, 1983) was used to carry out the statistical analysis. The significance of difference among the means was compared by using the standard error. The standard error was computed by $s/\sqrt{n}$, where s is the standard deviation and n is the number of observation.

RESULTS AND DISCUSSION

The effects of different irrigation treatments, fertilizer doses and their interactions on maize cultivation have been elaborated.

Effect of irrigation on growth and yield parameters

The mean plant height under different irrigation treatments were presented in Table 2. The tallest plant (271.0 cm) was obtained with wastewater irrigation (I_3) and the shortest plant (250.7 cm) was obtained with fresh water irrigation (I_1). The mean plant height increased by 8.10 and 4.58% in treatment I_3 and I_2 (mixed water irrigation), respectively compared to the control, I_1. At 5% level of significance, the plant heights under the treatments I_2 and I_3 were statistically similar. Almost similar plant height was also reported by Niazuddin et al. (2002) and Hossain (2009). The number of cob per plant was not identical for different irrigation treatments as shown in Table 2. The highest number of cobs per plant (1.44) was obtained with treatment I_3. The lowest number of cobs per plant (1.22) was monitored for treatment I_1. Bala (2007) did an experiment and he found that the highest number of cob per plant was obtained at I_2 (irrigation amount equals to 75% of soil moisture deficit from field capacity) and the lowest at I_3 (irrigation amount equals to 100% of soil moisture deficit from field capacity). The leaf area index (LAI) under different irrigation treatments was presented in Table 2. The highest LAI (4.68) was found in treatment I_3 and the lowest LAI (4.04) in treatment I_1. As the co-efficient of variation was 4.80%, there was a small variation of LAI among different experimental plots under different irrigation treatments. At 5% level of significance, the LAI was statistically dissimilar under I_1, I_2 and I_3. The cob length and perimeter varied significantly among three irrigation treatments. The highest cob length (19.56 cm) and perimeter (14.43 cm) were obtained with treatment I_3. The lowest cob length (18.14 cm) and perimeter (14.14 cm) were gained for the treatment I_1 (Table 2). Almost similar cob length and perimeter were also reported by Niazuddin et al. (2002) and Hossain (2009). The number of grains and columns per cob were not identical and varied significantly among three different irrigation treatments. The largest number of grain per cob (466.5) and columns (15.32) were monitored for treatment I_3. The number of grains per cob was decreased by 5.92 and 8.64% in treatment I_2 and I_1, respectively compared to the control treatment, I_3. Kamar (2011) found the highest number of grains per cob was obtained at treatment I_4 : irrigation at IW (irrigation water applied)/CEP (cumulative pan evaporation) = 1.0. The highest (211.7 g) and lowest (181.2 g) plant weights were obtained for treatment I_3 and I_1 respectively. The highest (44.18 g) and lowest (33.19 g) (cover and shell) weights were found at treatment I_3 and I_1 as shown in Table 2. The highest plant weight was obtained at I_4 (irrigation amount equals to 125% of soil moisture deficit from field capacity) and the lowest one was obtained at I_1 (irrigation amount equals to 50% of soil moisture deficit from field capacity) by Bala (2007). The largest 1000-grain weight was obtained 352.6 g in irrigation treatment I_3. The smallest 1000-grain weight was found 301.2 g in irrigation treatment I_1. The 1000-grain weight was statistically identical for irrigation treatment I_2 and I_1 (Table 2).

Table 2. Plant height, LAI, cob length, no. of cobs per plant, columns per cob, perimeter of cob, no. of grains per cob, plant weight, (cover and shell) weight and 1000-grain weight of maize under three irrigation treatments

Irrigation treatment	Plant height (cm)	Leaf area index	Cob length (cm)	No. of cobs per plant	Columns per cob	Perimeter of cob (cm)	No. of grains per cob	Plant weight (g)	Cover and Shell weight (g)	1000-grain weight (g)
I_1	250.7^B	4.040^C	18.14^C	1.22^C	14.49^B	14.1^B	426.0^C	181.0^C	33.19^C	301.2^B
I_2	262.2^A	4.36^B	19.03^B	1.33^B	15.03^A	14.2^B	438.9^B	200.0^B	37.69^B	312.6^B
I_3	271.0^A	4.687^A	19.56^A	1.44^A	15.32^A	14.4^A	466.5^A	211.7^A	44.18^A	352.6^A
CV (%)	3.61	4.80	1.51	5.52	2.09	0.72	1.88	3.32	3.65	6.11
$LSD_{0.05}$	9.41	0.209	0.286	0.071	0.312	0.105	8.36	6.54	1.39	19.68
Level of significance	**	**	**	**	**	**	**	**	**	**

Common letter (s) within the same column does not differ significantly at 5% level of significance, ** = 1% level of significant. I_1 = Irrigation with fresh water, I_2 = Irrigation with mixed water (fresh water: dairy farm's wastewater = 1:1) and I_3= Irrigation with raw wastewater.

In an almost similar experiment, the largest 1000-grains weight was obtained at I_3 (IW/CEP = 1.0, Irrigation given at 70 and 100 days after sowing) and the lowest at I_2 (IW/CEP = 1.0, Irrigation given at 55 and 90 days after sowing) by Bala (2007).

Effect of irrigation on yield attributes

The treatment I_3 produced the largest amount of grain yield 10.89 t ha^{-1} and the treatment I_1 produced the lowest amount of grain yield 7.95 t ha^{-1}. All the three treatments were significantly dissimilar in grain production (Table 3). Almost similar results were obtained by Talukder et al. (1999), Niazuddin et al. (2002) and Hossain (2009). The straw yield was also not identical for the three treatments I_1, I_2 and I_3 (Table 3). The straw yield was the summation of plant weight, cover weight and shell weight.

Table 3. Grain yield, straw yield and biological yield of maize under three irrigation treatments

Irrigation treatment	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})
I_1	7.95^C	8.76^C	16.71^C
I_2	8.15^B	9.90^B	18.05^B
I_3	10.89^A	11.98^A	22.87^A
CV (%)	3.82	3.80	3.35
$LSD_{0.05}$	0.618	1.01	1.43
Level of significance	**	**	**

Other details are same as Table 2.

Treatment I_3 provided the largest amount of biological yield 22.87 t ha^{-1} and the treatment I_1 provided the smallest amount of biological yield 16.71 t ha^{-1} (Table 3). All the three irrigation treatments were significantly dissimilar and I_3 provided the best result. These results are almost similar with the reports of Niazuddin et al. (2002) and Hossain (2009).

Effect of irrigation on harvest index and water use efficiency

Table 4 represents that wastewater irrigation significantly reduced the harvest index of maize. The harvest index increased by 0.2 and 5.10% in I_2 and I_1, respectively compared to the treatment I_3. The values of harvest index of maize were 37.94, 36.16 and 36.10 % under I_1, I_2 and I_3, respectively. The observed harvest index implied that mixed water contributed more in producing straw yield than in producing grain yield. Niazuddin et al. (2002) and Hossain (2009) gave almost similar reports of harvest index.

Table 4. Harvest index (%), water use efficiency for grain production (WUE_g) and biomass production (WUE_b) of maize under three irrigation treatments

Irrigation treatment	Harvest index (%)	WUE_g (kg ha^{-1} cm^{-1})	WUE_b (kg ha^{-1} cm^{-1})
I_1	37.94^A	1332.00^C	3522.00^C
I_2	36.16^B	1587.98^B	3857.00^B
I_3	$36.10A^B$	1666.00^A	4347.00^A
CV (%)	3.55	3.25	3.29
$LSD_{0.05}$	1.31	47.90	128.60
Level of significance	*	**	**

* = 5% level of significant, other details are same as Table 2.

The water use efficiency that demonstrates the productivity of water in producing crop yields differed significantly among the three irrigation treatments in case of grain and biomass production (Table 4). The highest water use efficiency for grain production, WUE_g (1666.00 kg ha^{-1} cm^{-1}) was obtained under treatment I_3 and the lowest WUE_g (1327.00 kg ha^{-1} cm^{-1}) was obtained under treatment I_1. The highest water use efficiency for biomass production, WUE_b (4347.00 kg ha^{-1} cm^{-1}), was obtained under the treatment I_3 and the lowest WUE_b (3522.00 kg ha^{-1} cm^{-1}) was obtained under the treatment I_2. The water use efficiency for biomass production, WUE_b, increased by 9.51 and 23.42% in I_2 and I_3, respectively compared to the treatment I_1. These results are almost similar with the findings of Niazuddin et al. (2002) and Hossain (2009).

Effect of fertilizer on growth and yield parameters

At 5% level of significance, the plant heights under the treatments F_0, F_1 and F_2 were statistically dissimilar. The tallest plant (280.0 cm) was obtained with fertilizer treatment (F_2) and the shortest plant (240.9 cm) was obtained with fertilizer treatment (F_0). The mean plant heights under different fertilizer treatments are listed in Table 5. The mean plant height increased by 9.17 and 16.23% in treatment F_1 and F_2, respectively compared to the control, F_0. In a similar experiment, the tallest plant heights were obtained at F_3 (N_{375}, P_{60}, K_{180}, S_{30}, Zn_5 kg ha^{-1}) and the lowest at F_2 (N_{125}, P_{60}, K_{60}, S_{30}, Zn_5 kg ha^{-1}) by Bala (2007). In another experiment, Gope (2001) found the tallest plant heights at N_1 (70 kg ha^{-1}). The highest number of cobs per plant (1.778) was obtained with treatment F_2. It decreased by 31.27% at treatment F_1. The lowest number of cobs per plant (1.0) was monitored for treatment F_0. The number of cob per plant was not identical for different fertilizer treatments as shown in the Table 5. In a similar experiment, the highest number of cobs per plant was obtained at F_1 (N_{250}, P_{60}, K_{120}, S_{30}, Zn_5 kg ha^{-1}) and the lowest at F_2 (N_{125}, P_{60}, K_{60}, S_{30}, Zn_5 kg ha^{-1}) by Bala (2007). As the co-efficient of variation is 3.61%, there was a small variation of LAI among different experimental plots under different fertilizer treatments. At 5% level of significance, the LAI was statistically dissimilar under F_0, F_1 and F_2. The leaf area index (LAI) under different fertilizer treatments is listed in Table 5. The highest LAI (5.041) was found in treatment F_2 and the lowest LAI (3.727) was found in treatment F_0. The highest cob length (21.92 cm) and perimeter (14.91 cm) were obtained with treatment F_2. The lowest cob length (15.39 cm) and perimeter (13.11 cm) were gained for the treatment F_0. The cob length and perimeter varies significantly among three fertilizer treatments. Gope (2001) found the highest cob length and perimeter at N_2 (100 kg ha^{-1}) and N_3 (120 kg ha^{-1}). The highest cob length and perimeter were obtained at F_1 (N_{250}, P_{60}, K_{120}, S_{30}, Zn_5 kg ha^{-1}) and the lowest cob length and perimeter were gained for the treatment F_2 (N_{125}, P_{60}, K_{60}, S_{30}, Zn_5 kg ha^{-1}) by Bala (2007). The number of grains per cob was decreased by 8.02 and 38.2% in the fertilizer treatment F_1 and F_0, respectively compared to the treatment, F_2. The number of grains per cob was not identical and was varied significantly among three different irrigation treatments. The largest number of grains per cob (524) was monitored for treatment F_2. The largest number of columns per cob (15.80) was monitored for treatment F_2 (Table 5). The highest (50.21 g) and lowest (28.16 g) (cover and shell) weight per square meter was found at treatment F_2 and F_0 as shown in Table 5. The highest (235.0 g) and lowest (141.1 g) plant weight per square meter were obtained for treatment F_2 and F_0 respectively. Bala (2007) found that the highest and lowest plant weights per square meter were obtained at F_3 (N_{375}, P_{60}, K_{180}, S_{30}, Zn_5 kg ha^{-1}) and F_2 (N_{125}, P_{60}, K_{60}, S_{30}, Zn_5 kg ha^{-1}). The 1000-grains weight was statistically not identical for fertilizer treatments F_2, F_1 and F_0. The largest 1000-grains weight was obtained 388.2 g for fertilizer treatment F_2. The smallest 1000-grains weight was found 261.6 g for fertilizer treatment F_0 (Table 5). Bala (2007) also found that the largest 1000-grains weight was obtained at F_3 (N_{375}, P_{60}, K_{180}, S_{30}, Zn_5 kg ha^{-1}) and F_2 (N_{125}, P_{60}, K_{60}, S_{30}, Zn_5 kg ha^{-1}).

Effect of fertilizer on yield attributes

The mean grain yield obtained under different fertilizer treatments were presented in Table 6. Treatment F_2 produced the highest grain yield of 11.70 t ha^{-1} and F_0 produced the lowest grain yield of 8.56 t ha^{-1}. For the addition of plant nutrients to the soil by the application of fertilizer, which caused the maximum number of plants, highest 1000-grain weight and the treatment F_2 gave the maximum grain yield. The grain yield increased by 18.22 and 36.68% in F_1 and F_2, respectively compared to the treatment F_0. The treatments F_0, F_1 and F_2 put statistically dissimilar impacts on the grain yield of maize. The highest grain yield was obtained at F_1 (N_{250}, P_{60}, K_{120}, S_{30}, Zn_5 kg ha^{-1}) and the lowest grain yield was obtained at F_2 (N_{125}, P_{60}, K_{60}, S_{30}, Zn_5 kg ha^{-1}) by Bala (2007). Gope (2001) found that the highest grain yield was obtained at N_2 (100 kg ha^{-1}) and the lowest grain yield was obtained at N_3 (120 kg ha^{-1}).

The straw yield under the three fertilizer treatments ranged from 9.67 to 11.00 t ha^{-1}. Treatment F_2 produced the highest straw yield (11.00 t ha^{-1}) and treatment F_0 produced the lowest straw yield (9.67 t ha^{-1}). The straw yield increased by 9.10 and 13.75% in F_1 and F_2, respectively compared to the treatment F_0; both the half and full dose fertilizer increased straw yield significantly compared to no application of fertilizer (Table 6). Full dose fertilizer produced the highest biological yield of 22.70 t ha^{-1} while no application of fertilizer produced the lowest biological yield of 18.23 t ha^{-1} (Table 6). The biological yield increased by 13.38 and 24.52% in F_1 and F_2, respectively compared to the treatment F_0. The biological yield under F_1 and

F_2 increased significantly over that under F_0 implying absolute necessity of fertilizer requirement for good biological yield of maize. Niazuddin et al. (2002) and Hossain (2009) gave almost similar reports of biological yield.

Table 5. Plant height, LAI, cob length, no. of cobs per plant, columns per cob, perimeter of cob, no. of grains per cob, plant weight, (cover and shell) weight and 1000-grain weight of maize under different fertilizer treatments

Fertilizer treatment	Plant height (cm)	Leaf area index	Cob length (cm)	No. of cobs per plant	Columns per cob	Perimeter of cob	No. of grains per cob	Plant weight (g)	Cover and shell weight (g)	1000-grain weight (g)
F_0	240.9^C	3.727^C	15.39^C	1.000^C	13.58^C	13.11^C	324.6^C	141.1^C	28.16^C	261.6^C
F_1	263.0^B	4.320^B	19.42^B	1.222^B	15.47^B	14.77^B	482.6^B	216.9^B	36.68^B	316.6 ^{B}
F_2	280.0^A	5.041^A	21.92^A	1.778^A	15.80^A	14.91^A	524.4^A	235.0^A	50.21^A	388.2 ^{A}
CV (%)	3.61	4.80	1.51	5.52	2.09	0.72	1.88	3.32	3.65	6.11
$LSD_{0.05}$	9.41	0.209	0.286	0.071	0.312	0.105	8.36	6.54	1.39	19.68
Level of significance	**	**	**	**	**	**	**	**	**	**

F_0 = No fertilizer, F_1 = Half of recommended dose fertilizer and F_2 = Full dose fertilizer. Other details are same as Table 2.

Table 6. Grain yield, straw yield and biological yield of maize under three fertilizer treatments

Fertilizer treatment	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})
F_0	8.56^C	9.67^C	18.23^C
F_1	10.12^B	10.55^B	20.67^B
F_2	11.70^A	11.00^A	22.70^A
CV (%)	3.82	3.80	3.35
$LSD_{0.05}$	0.618	1.01	1.43
Level of significance	**	**	**

Other details are same as Table 5.

Effect of fertilizer on harvest index and water use efficiency

Table 7 shows the application of fertilizer exerted significant influence on the harvest index of maize. Treatment F_2 provided the highest harvest index of 40.49% and F_0 provided the lowest harvest index of 33.12%. The harvest index increased by 13.19 and 22.25% in the treatments F_1 and F_2, respectively compared to the treatment F_0. At 5% level of significance, the harvest index of maize under F_0, F_1 and F_2 were statistically dissimilar. Niazuddin et al. (2002) and Hossain (2009) gave almost similar reports of harvest index.

Table 7. Harvest index (%), water use efficiency for grain production (WUE_g) and biomass production (WUE_b) of maize under different fertilizer treatments

Fertilizer treatment	Harvest index (%)	WUE_g (kg ha^{-1} cm^{-1})	WUE_b (kg ha^{-1} cm^{-1})
F_0	33.12^C	848.60^C	2544.0^C
F_1	37.49^B	1581.0^B	4205.0^B
F_2	40.49^A	1994.0^A	4978.0^A
CV (%)	3.55	3.25	3.29
$LSD_{0.05}$	1.31	47.90	128.60
Level of significance	**	**	**

Other details are same as Table 5.

The water use efficiency that demonstrates the productivity of water in producing crop yields significantly differed among the three fertilizer treatments both for grain and biomass production (Table 7). The highest water use efficiency for grain production, WUE_g (1994.00 kg ha^{-1} cm^{-1}), was obtained under full dose fertilizer application (F_2) and the lowest WUE_g (848.60 kg ha^{-1} cm^{-1}) was obtained under no application of fertilizer (F_0). The water use efficiency for grain production increased by 86.31 and 134.98% under F_1 and F_2, respectively compared to F_0. The highest water use efficiency for biomass production, WUE_b (4978.0 kg ha^{-1} cm^{-1}), was obtained under F_2 and the lowest WUE_b (2544.0 kg ha^{-1} cm^{-1}) was obtained under F_0. This water use efficiency increased by 65.29 and 96.68% under the treatments F_1 and F_2, respectively compared to that under the treatment F_0. Both water use efficiencies increased significantly with the increasing quantity of fertilizer application. Kamar (2011) gave almost similar reports of water use efficiency.

Interaction effects of irrigation and fertilizer on growth and yield parameter

The mean plant heights obtained under the interaction effect of irrigation and fertilizer treatments are listed in Table 8. The tallest plant of 283.4 cm was obtained under I_3F_2 (wastewater irrigation with full dose fertilizer) and the shortest plant of 232.7 cm was obtained under I_1F_0 (fresh water irrigation with no fertilizer). The interaction effect of irrigation and fertilizer on the plant height was significant for most treatment combinations. The plant heights increased by 19.63% in I_2F_2 (mixed water irrigation with full dose fertilizer) compared to I_1F_0 (fresh water irrigation with no fertilizer). Also, the plant heights increased by 1.80% in I_3F_2 compared to that in I_2F_2 (mixed water irrigation with full dose fertilizer). In a similar experiment, the tallest plant heights were obtained at I_3 (IW/CEP = 1.0, Irrigation given at 70 and 100 days after sowing) F_2 (N_{125}, P_{60}, K_{60}, S_{30}, Zn_5 kg ha^{-1}) and the lowest at I_1 (IW/CEP = 1.0, Irrigation given at 35 and 70 days after sowing) F_2 (N_{125}, P_{60}, K_{60}, S_{30}, Zn_5 kg ha^{-1}) by Bala (2007). The number of cobs per plant was not identical for different combination of irrigation and fertilizer treatments as shown in the Table 8. The highest number of cob per plant (2.0) was obtained with I_3F_2 (wastewater irrigation with full dose fertilizer). The lowest number of cob per plant (1.0) was monitored with the combination I_1F_0, I_1F_1, I_2F_0 and I_3F_0. The highest number of cob per plant was obtained at I_2 (IW/CEP = 1.0, Irrigation given at 55 and 90 days after sowing) F_3 (N_{375}, P_{60}, K_{180}, S_{30}, Zn_5 kg ha^{-1}) and the lowest at I_1 (IW/CEP = 1.0, Irrigation given at 35 and 70 days after sowing) F_1 (N_{250}, P_{60}, K_{120}, S_{30}, Zn_5 kg ha^{-1}) by Bala (2007). The LAI under the interaction effect of irrigation and fertilizer treatment is listed in Table 8. The highest LAI (5.41) was found under the treatment combination I_3F_2 (wastewater irrigation with full dose fertilizer) and the lowest LAI (3.50) was found under the treatment combination I_1F_0 (fresh water irrigation with no fertilizer). At 5% level of significance, the LAI was statistically dissimilar under different treatment combinations. The highest cob length (22.64 cm) and perimeter (15.09 cm) were obtained with the combination I_3F_2 (wastewater irrigation with full dose fertilizer). The lowest cob length (14.44 cm) and perimeter (13.01 cm) were gained with the combination I_1F_0 (fresh water irrigation with no fertilizer) (Table 8). The cob length and perimeter varies significantly among the different combination treatments. The highest cob length and perimeter were obtained at I_4 (IW/CEP = 1.0, Irrigation given at 35, 55, 70 and 100 days after sowing) F_1 (N_{250}, P_{60}, K_{120}, S_{30}, Zn_5 kg ha^{-1}) and I_3 (IW/CEP = 1.0, Irrigation given at 70 and 100 days after sowing) F_2 (N_{125}, P_{60}, K_{60}, S_{30}, Zn_5 kg ha^{-1}) by Bala (2007). The lowest cob length and perimeter were gained for the treatment I_2 (IW/CEP = 1.0, Irrigation given at 55 and 90 days after sowing) F_1 (N_{250}, P_{60}, K_{120}, S_{30}, Zn_5 kg ha^{-1}) and I_4 (IW/CEP = 1.0, Irrigation given at 35, 55, 70 and 100 days after sowing) F_3 (N_{375}, P_{60}, K_{180}, S_{30}, Zn_5 kg ha^{-1}) by Bala (2007). The number of grains per cob was not identical and was varied significantly among the different combination treatments. The largest number of grains per cob (536) was monitored with the combination I_3F_2 (wastewater irrigation with full dose fertilizer). The number of grains per cob was decreased by 43.1% in the combination I_1F_0 (fresh water irrigation with no fertilizer) compared to the combination I_3F_2 (wastewater irrigation with full dose fertilizer). The lowest number of grains per cob (305.1) was gained with the combination I_1F_0 (fresh water irrigation with no fertilizer). The largest number of columns per cob (15.77) was monitored with the combination I_2F_2 (Irrigation with mixed water and application of full dose of fertilizer) (Table 8). The highest (261 g) and lowest (138.3 g) plant weights were obtained with the combination I_3F_2 (wastewater irrigation with full dose fertilizer) and I_1F_0 (fresh water irrigation with no fertilizer) respectively. The highest (53.44 g) and lowest (22.46 g) (cover and shell) weight was also found with the combination I_3F_2 (wastewater irrigation with full dose fertilizer) and I_1F_0 (fresh water irrigation with no fertilizer) as shown in Table 8. The mean 1000-grains weight obtained under the interaction effect of irrigation and fertilizer treatments is listed in Table 8. The highest 1000-grains weight of 417.7 g was obtained with the treatment combination I_3F_2 (wastewater irrigation with full dose fertilizer) and the lowest of 239.7 g was obtained with I_1F_0 (fresh water irrigation with no fertilizer). The wastewater irrigation with half dose fertilizer significantly improved 1000-grain weight of maize. In a similar experiment, the largest 1000-grains weight was obtained at I_4 (IW/CEP = 1.0, Irrigation given at 35, 55, 70 and 100 days after sowing) F_2 (N_{125}, P_{60}, K_{60}, S_{30}, Zn_5 kg ha^{-1}) and the lowest at I_2 (IW/CEP = 1.0, Irrigation given at 55 and 90 days after sowing) F_2 (N_{125}, P_{60}, K_{60}, S_{30}, Zn_5 kg ha^{-1}) by Bala (2007).

Interaction effects of irrigation and fertilizer on yield attributes

The interaction between irrigation and fertilizer treatments had significant effect on the grain yield of maize (Table 9). The treatment combination I_3F_2 (wastewater irrigation with full dose fertilizer) produced the highest grain yield of 11.10 t ha^{-1} and I_1F_0 (fresh water irrigation with no fertilizer) produced the lowest grain yield of 7.657 t ha^{-1}. The grain yield increased by 30.1% under I_1F_2 compared to that under I_1F_0. Also, the grain yield increased by 11.45% in I_3F_2 compared to that in I_1F_2 (mixed water irrigation with full dose fertilizer). The interaction effect of irrigation and fertilizer on the grain yield was statistically significant in most treatment combinations compared to I_1F_0. The highest grain yield was obtained at I_3 (IW/CEP = 1.0, Irrigation given at 70 and 100 days after sowing) F_1 (N_{250}, P_{60}, K_{120}, S_{30}, Zn_5 kg ha^{-1}) and the lowest grain yield was obtained at I_1 (IW/CEP = 1.0, Irrigation given at 35 and 70 days after sowing) F_2 (N_{125}, P_{60}, K_{60}, S_{30}, Zn_5 kg ha^{-1}) by Bala (2007).

Table 8. Plant height, LAI, cob length, no. of cobs per plant, columns per cob, perimeter of cob, no. of grains per cob, plant weight (cover and shell) weight and 1000-grain weight of maize under the interaction of three irrigation treatments and three fertilizer doses

Treatment combination	Plant height (cm)	Leaf area index	Cob length (cm)	No. of cobs per plant	Columns per cob	Perimeter of cob	No. of grains per cob	Plant weight (g)	Cover and shell weight (g)	1000-grain weight (g)
I_1F_0	232.7^C	3.500^C	14.44^C	1.00^D	12.82^A	13.01^A	305.1^E	138.3^E	22.46^F	239.7^A
I_1F_1	241.2^{BC}	4.210^B	18.52^E	1.00^D	15.11^A	14.70^A	461.9^C	192.6^D	29.71^E	295.7^A
I_1F_2	278.0^A	4.410^B	21.47^B	1.67^B	15.55^A	14.71^A	511.5^B	212.7^C	47.39^B	368.3^A
I_2F_0	235.4^C	3.530^C	15.85^F	1.00^D	13.73^A	13.03^A	316.3^E	141.7^E	27.67^E	256.7^A
I_2F_1	272.8^A	4.250^B	19.59^D	1.33^C	15.60^A	14.71^A	474.6^C	227.5^B	35.61^D	302.3^A
I_2F_2	278.4^A	5.303^A	21.64^B	1.67^B	15.77^A	14.94^A	525.8^{AB}	230.8^B	49.79^B	378.7^A
I_3F_0	254.6^B	4.150^B	15.88^F	1.00^D	14.19^A	13.28^A	352.3^D	143.3^E	34.36^D	288.3^A
I_3F_1	274.9^A	4.500^B	20.15^C	1.33^C	15.71^A	14.92^A	511.2^B	230.5^B	44.73^C	351.7^A
I_3F_2	283.4^A	5.410^A	22.64^A	2.00^A	16.07^A	15.09^A	536.0^A	261.5^A	53.44^A	417.7^A
CV (%)	3.61	4.80	1.51	5.52	2.09	0.72	1.88	3.32	3.65	6.11
$LSD_{0.05}$	16.31	0.363	0.495	0.122	0.541	0.181	14.48	11.34	2.41	34.09
Level of significance	*	**	**	**	NS	NS	*	**	**	NS

Other details are same as Table 2 and 5.

The treatment combination I_3F_2 (raw wastewater irrigation with full dose fertilizer) produced the highest straw yield of 13.88 t ha^{-1} and I_2F_1 (mixed water irrigation with half dose fertilizer) produced the lowest straw yield of 9.53 t ha^{-1} (Table 9). The straw yield increased by 41.60% under the treatment combination I_3F_2 compared to that under the treatment combination I_1F_1. Also, the straw yield increased by 39.1% in I_3F_2 compared to that in I_1F_0 (fresh water irrigation with no fertilizer). The treatment combinations of I_2F_2 and I_3F_1 provided the identical straw yields. The treatment combination I_3F_2 (wastewater irrigation with full dose fertilizer) produced the highest biological yield of 524.98 t ha^{-1} and I_1F_0 (fresh water irrigation with no fertilizer) produced the lowest biological yield of 17.64 t ha^{-1} (Table 9). The biological yield increased by 10.68% under the combination I_3F_2 compared to that under I_2F_2. Also, the straw yield increased by 41.61% in I_3F_2 compared to that in I_1F_0 (fresh water irrigation with no fertilizer).

Interaction effects of irrigation and fertilizer on harvest index and water use efficiency

The interaction effects of irrigation and fertilizer exerted significant influence on the harvest index of maize in most treatment combinations (Table 10). Treatment combination I_2F_1 (mixed water irrigation with half dose fertilizer) provided the highest harvest index of 47.22% and I_1F_0 (fresh water irrigation with no fertilizer) provided the lowest harvest index of 30.63%. The treatment combinations I_1F_1, I_2F_1, I_3F_0, and I_3F_2 are identical in providing harvest index. An experiment was carried out by Kamar (2011) gives similar result of harvest index. The water use efficiency significantly differed among the combinations of irrigation treatments and fertilizer doses for both grain and biomass production (Table 10).

Table 9. Grain yield, straw yield and biological yield of maize under the interaction of three irrigation treatments and three fertilizer doses

Treatment combination	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})
I_1F_0	7.657^H	9.98^F	17.64^H
I_1F_1	8.31^E	10.56^D	18.87^E
I_1F_2	9.96^{BC}	10.98C^D	20.94^C
I_2F_0	7.77^G	11.75^{EF}	19.52^G
I_2F_1	8.45^D	9.53^C	17.98^D
I_2F_2	8.88^B	13.69^B	22.57^B
I_3F_0	11.41^F	12.67^E	24.08^F
I_3F_1	11.0^C	13.00^B	24.00^C
I_3F_2	11.10^A	13.88^A	24.98^A
CV (%)	3.82	3.80	3.35
$LSD_{0.05}$	1.07	1.75	2.49
Level of significance	**	**	*

Other details are same as Table 2 and 5.

Table 10. Harvest index (%), water use efficiency for grain production (WUE_g) and biomass production (WUE_b) of maize under the interaction of three irrigation treatments and three fertilizer doses

Treatment combination	Harvest index (%)	WUE_g (kg ha^{-1} cm^{-1})	WUE_b (kg ha^{-1} cm^{-1})
I_1F_0	30.63^D	697.3^H	2273.0^H
I_1F_1	35.98^C	1364.0^E	3791.0^E
I_1F_2	47.22^A	1920.0^B	4501.0^C
I_2F_0	32.11^D	809.3^G	2520.0^G
I_2F_1	36.92^C	1546.0^D	4187.0^D
I_2F_2	39.46^B	1936.0^B	4865.0^B
I_3F_0	36.62^C	1039.0^F	2837.0^F
I_3F_1	39.56^B	1834.0^C	4636.0^C
I_3F_2	34.78^C	2125.0^A	5567.0^A
CV (%)	3.55	3.25	3.29
$LSD_{0.05}$	2.27	82.96	222.70
Level of significance	**	**	*

Other details are same as Table 2 and 5.

The highest water use efficiency for grain production, WUE_g (2125.0 kg ha^{-1} cm^{-1}), was obtained under the treatment combination I_3F_2 (wastewater irrigation with full dose fertilizer) and the lowest WUE_g (697.3 kg ha^{-1} cm^{-1}) was obtained under the treatment combination I_1F_0 (fresh water irrigation with no fertilizer). The water use efficiency for grain production increased by 204.72% under I_3F_2 compared to that under I_1F_0. The treatment combination I_3F_2 provided significantly higher WUE_g than other treatment combinations. The highest water use efficiency for biomass production, WUE_b (5567.0 kg ha^{-1} cm^{-1}), was obtained under I_3F_2 (wastewater irrigation with full dose fertilizer) and the lowest WUE_b (2273.0 kg ha^{-1} cm^{-1}) was obtained under I_2F_0 (mixed water irrigation with no fertilizer). The highest water use efficiency should obtain at I_3F_0 treatment as the highest grain yield obtained at I_3F_0. But we don't know any specific reason for occurring highest water use efficiency at I_3F_0 treatment as we got it practically. The water use efficiency for biomass production increased by 144.92% under I_3F_2 compared to that under I_2F_0. The WUE_g and WUE_b were found by Kamar (2011) which is almost similar to this result.

CONCLUSIONS

The following conclusions were drawn from the study:

1. The yield and yield contributing characters were significantly affected by the application of wastewater irrigation at different growth stages of maize.
2. The highest grain yield (10.89 t ha^{-1}) of maize and water use efficiency for grain production (1666 kg ha^{-1} cm^{-1}) were obtained under the treatment of I_3 (wastewater irrigation). The lowest grain yield (7.95 t ha^{-1}) was obtained under the treatment of I_2 (mixed water irrigation; FW: WW = 1:1) and the lowest water use efficiency for grain production (1332 kg ha^{-1} cm^{-1}) was obtained under the treatment of I_1 (fresh water irrigation), respectively.
3. For the interaction effects between irrigation and fertilizer, the highest grain yield (11.41 t ha^{-1}) and water use efficiency for grain production (2125 kg ha^{-1} cm^{-1}) were obtained under the treatment combination of I_3F_0 (wastewater irrigation with no fertilizer application) and I_3F_2 (wastewater irrigation with full dose fertilizer application), respectively. The lowest grain yield (7.66 t ha^{-1}) and water use efficiency for grain production (697.3 kg ha^{-1} cm^{-1}) were obtained under the treatment combination of I_1F_0 (fresh water irrigation with no application of fertilizer).
4. Different nutrients and organic matter of wastewater significantly contributed to the growth and yield of maize. So, it can be used as a source of irrigation and fertilizer for maize cultivation in Bangladesh.

CONFLICTS OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this paper.

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