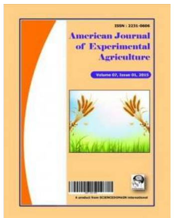

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Assessment of Irrigation Water Requirement of Maize Crop for Different Tillage Practices in Bangladesh

Md. Mashiur Rahman[1], Md. Golam Ambia Mahmud[2], Hossain Md. Ferdous[3], Naznin Sultana[4] and Abu Sayed[5*]

[1]Department of Farm Machinery and Post-harvesting Process Engineering, Bangladesh Agricultural Research Institute, Gazipur-1701, Bangladesh.
[2]Department of Water Resource Engineering, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh.
[3]Department of Agronomy, EXIM Bank Agricultural University Bangladesh, Chapainawabgonj-6300, Bangladesh.
[4]Department of Biotechnology, Ser-e-Bangla Agricultural University, Dhaka, Bangladesh.
[5]Department of Agricultural Engineering, EXIM Bank Agricultural University Bangladesh Chapainawabgonj-6300, Bangladesh.

Authors' contributions

This work was carried out in collaboration with all authors. Author MGAM initiated the research and conducted it. Authors MMR and AS designed the study and supervised the research. Authors HMF and NS managed the literature searches, reviewed the manuscript drafts and participated in the data collection. Authors AS and MGAM analyzed statistical analyses. All authors read and approved the final manuscript.

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ABSTRACT

A study was conducted to assess the irrigation water requirement of maize crop for different tillage practices. Irrigation water was applied at three-growth stages viz. treatment one (I_1), 20-25 days after sowing (DAS), treatment two (I_2), 45-50 DAS and treatment three (I_3), 80-85 DAS. Under I_1

**Corresponding author: E-mail: abu_982@yahoo.com;*

irrigation treatment with zero (T_1), minimum (T_2) and traditional (T_3) tillage practices, the seasonal water requirement was 26.3, 29.3 and 31.0 cm respectively. In I_2 treatment with T_1, T_2 and T_3 tillage practices, water requirement was 34.5, 37.5 and 42.5 cm respectively and in I_3 treatment with T_1, T_2 and T_3 tillage practices, water requirement were 46.3, 51.3 and 60.0 cm respectively. The highest yield was in I_3 treatment (8.3 t ha^{-1}) which was similar to I_2 treatment (8.2 t ha^{-1}) and the lowest was in I_1 treatment (7.3 t ha^{-1}). In this study, no significance different was found in I_2 and I_3 treatment but in I_3 treatment required more 42 cm water than I_2. From the economical analysis, the highest net return (USD/ha 1501.45) and the highest benefit cost ratio (3.1) were found in T_2I_2 treatment combination. Therefore, T_2I_2 (minimum tillage with two-time irrigation) treatment combination is the best suit for maximum water resources saving in maize cultivation without compromising with yield in Bangladesh at dry season (Rabi).

Keywords: Maize; irrigation water; tillage; yield; Bangladesh.

1. INTRODUCTION

Maize (*Zea Mays*) originates in the Andean region of Central America. It is one of the oldest and most important cereals crop in the world both for human and animal consumption and highest yielding grain crop having multiple uses [1]. In Bangladesh, maize is the third most important cereal crop having with 14.09 million hectares (ha) of cultivated land and it is estimated that nearly 2.8 million ha are suitable for maize cultivation [2]. Due to expansion of poultry and fish feed industries market demand for maize in Bangladesh has significantly increased in the last decade [3,4]. As a result, maize area has increased substantially where cultivated land area with maize jumped from 0.05 M ha in 2000 to >0.31 M ha in 2012–2013 [5]. The maize production has also increased in recent years from 0.93 M ton to 1.54 M ton [6].

Proper growth and development of maize needs favorable soil moisture up to its root zone. Limited water supply during the growing season results in soil and plant water deficits and reduces maize yields [7,8]. Water deficit has little effect on timing of emergence of maize seedlings, number of leaves per plant but delayed teaseling initiation and silking, reduced plant height and vegetation growth of maize [9,10]. Heading to milking stage is the most important sensitive period of water stress and has ultimate impact on grain yield [11,12].

Water scarcity problem in Bangladesh becomes worse, mainly due to expansion and diversification of agricultural crops while maintaining self-sufficiency in food grain production. So, more emphasis should be given to adapt cropping pattern which require less water [13]. Maize is a crop that requires far less water than Boro rice and produces consistently much higher yield. The optimum use of irrigation water should be an important strategy for increasing maize production [14]. To ensure sustainable development, yield and soil health, appropriate irrigation management and conservation tillage practices has no alternative. A little amount of work has been done in Bangladesh on application of irrigation water in concerning engineering view with the combination of tillage practices for water saving purpose on maize crop cultivation. Therefore, an attempt has been made to determine the optimum water requirement on different tillage practice and to determine the effects of irrigation on maize yields.

2. MATERIALS AND METHODOLOGY

The experiment was conducted during the Rabi season in Bangladesh Agricultural Research Institute (BARI), Gazipur. The farm area of BARI, Gazipur is mainly leveled with solely permeable soils and clay loam to loam soil. The others part of farm is high land and soil dominate with clay to silty- clay textures all over the area. The amount of potassium and phosphorus in the soil is below the critical limit for maize cultivation and the soil is low in organic matter (0.7%) and slightly acidic to neutral (ph 6.3). The minimum and maximum average monthly temperature varies between 10℃ to 30.5℃. The monthly humidity level ranges from 64% in May to 90% in April. Annual average rainfall is 1875 mm and rainfall during the Rabi season (dry period of the year) is only 310 mm. the information on ETo of an area will be a very useful guide for development of irrigation schedules for crops. The reference evapotranspiration (ETo) for the maize was computed by using CROPWAT software [15] and shown in Fig. 1.

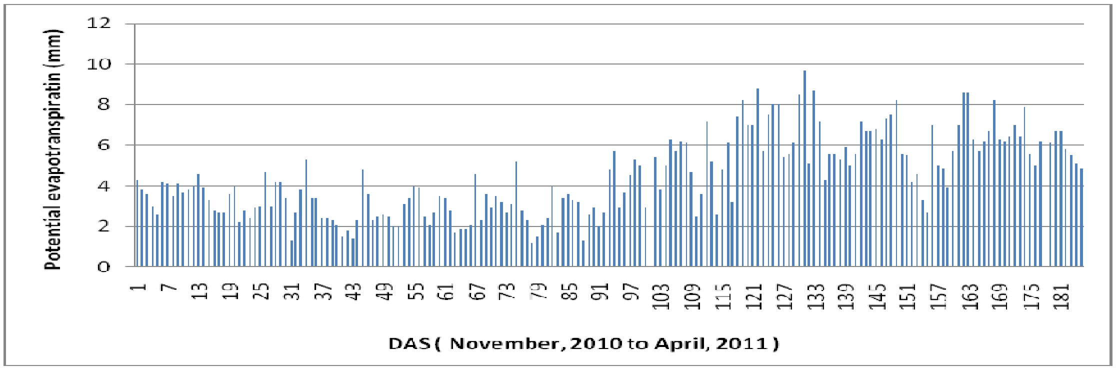


Fig. 1. Daily potential evapotranspiration (ETo) during experiment season

Data on physical and chemical properties of initial and post harvest soils were collected from 0-30 cm depth. The experiment was set up in a split Block Design (SBD) for tillage with a split plots arrangement with nine treatment combinations with three replications. The unit plot size was 3 m x 4 m. Since water resources saving are the main concern tillage practices have been assigned in the main plot and irrigation has been applied in the sub plots intensively. Irrigation was applied to reach the soil moisture up to field capacity. Three irrigation treatments I_1, I_2 and I_3 were applied for each tillage practice T_1, T_2 and T_3. 'Bari Vutta -6' seed were planted on 08 November, 2010 with the spacing line to line distance 70 cm × 70 cm and plant to plant distance 25 cm × 25 cm. Fertilizer was applied at the rate of 250-100-40-5-1 kg ha^{-1} of NPKSZnB at the time of final land preparation except nitrogen. One third Nitrogen was applied during final land preparation and remaining nitrogen was applied in two equal splits at 30 and 55 days after sowing. The water requirement for maize cultivation was determined by measuring the soil moisture by digital moisture method. The depth or water requirement was determined by the following equation. Irrigation depth,

$$d = \frac{FC\ \% - MCi\ \%}{100} \times \rho \times D \text{..........} \quad \text{......}(1)$$

Where,

d= Depth of water to be applied, cm
FC= Field capacity of the soil, %
MC_i= Moisture content of the soil at the time of irrigation, %
ρ = Bulk density of the soil, gm/cc
D= Root zone depth, cm

The maize was harvested on 06 April, 2011. The yield contributing characters were collected after harvest. The yield contributing characters are plant height, cob diameter, grain per cob, cob length, 100 grains weight; plant dry weight, numbers of plant per plot, line of grain per cob and number of cob per plant were evaluated. The yield of maize per hectare was determined after threshing the maize.

In agricultural production the most important factors are the Net Return (NR) and Benefit Cost Ratio (BCR) because these two factors governs the farmer's attitude towards cultivation for any specific crop. For this reason, a simple economic analysis was done based on total production. Production cost included labor cost and input cost. Price of the produce was collected from local market to compute total production cost, gross return, net return and benefit-cost ratio. Finally the collected data were analyzed with MSTATC software.

3. RESULTS AND DISCUSSION

3.1 Effect of Irrigation on Maize Yield Contributing Characters

The effects of irrigation on the yield and yield contributing characters of maize have shown in Table 1. Maximum yield of maize was 8.3 t ha^{-1} recorded in I_3 treatment and the lowest yield 7.1 t ha^{-1} was recorded in I_1 treatment, in I_2 treatment the maize yield was recorded as 8.2 t ha^{-1} that was the nearest value of I_3 treatment. A statistically significant effect identified in 100-grain weight of maize grain. The highest yield t ha^{-1} were obtained in I_2 and I_3 treatment where 2 and 3 irrigations were applied on the dated of 25 and 50 days after sowing (DAS). Highest level of significance found in plant height, maximum plant height 214.7 cm and 207.3 cm were in I_3 and I_2

irrigation treatment respectively and lowest plant height 193.7 cm was in I_1 irrigation treatment. Maximum height of maize plant is discouraged because long height plant has a lodging tendency, which decreases maize yield. The maximum number of cob per plot were found in I_2 and I_3 treatments as 75.3 pieces and 77.7 pieces respectively and the lowest in I_1 treatment 62.3 pieces shown in Table 1. Shirazi et al. [16] had conducted a field experiment in Bangladesh that was carried out to find out the response on yield and yield contributing parameters of maize to water stress and nitrogenous fertilizer. They found the highest grain yield of 6.77 t ha^{-1} and lowest 5.61 t ha^{-1}. Yenesew and Tilahun [17] found that maximum maize biomass yield, grain yield and stover yield are obtained by applying optimum amount of water throughout the growing season.

3.2 Effect of Irrigation on Different Tillage Practices

For T_1, T_2 and T_3 tillage practices 3-types of irrigation water I_1, I_2 and I_3 were applied. In T_1 tillage practices maize yield were 6.6 t ha-1, 7.5 t ha-1 and 7.6 t ha-1 and in T_2 tillage practices maize yield were 7.2 t ha-1, 8.6 t ha-1 and 8.6 t ha-1 for I_1, I_2 and I_3 irrigation treatments respectively (Table 2). In both cases, Maize yield of I_2 irrigation was statistically similar with I_3 irrigation. On the other hand, I_1 irrigation treatment practice was not acceptable because in this treatment maize yield was much lower than I_2 and I_3 treatment.

In T_3 tillage practices there were also three type of irrigation water applied. Here a significance difference found in I_1 irrigation practices with I_2 and I_3 irrigation practices (Fig. 3). The maize yield were 7.5 t ha-1, 8.4 t ha-1 and 8.7 t ha-1 for I_1, I_2 and I_3 irrigation treatments respectively. The maize yield of I_2 and I_3 is statistically identical. Therefore, it observed that maize yields are not dependent on tillage practices. It is dependent on irrigation practices. All the three tillage practices the maize yields of I_2 and I_3 irrigation practices are slightly difference. So between two treatments I_2 irrigation practices are acceptable because it's required less amount of irrigation water. The effects of irrigation on maize yields with different tillage are presented in Fig. 2. Islam et al. [18] reported that the highest marketable yield 7.60 t ha^{-1} and 7.9 t ha^{-1} was recorded with tillage (T_3) and irrigation (I_3), respectively. In case of the interaction effects of tillage and irrigation, the highest yield 7.89 and 7.83 t ha^{-1} were recorded at 2006-07 and 2007-08, respectively from $T_3 I_3$. Lamm et al. [19] found Strip tillage and no tillage had approximately 8.1% and 6.4% greater grain yields than conventional tillage, respectively. They recommended that increasing the plant population from 26,800 to 33,300 plants /acre was beneficial at all three irrigation capacities. Rahman et al. [20] observed for maize, the effect of different tillage treatments on the yield and yield contributing characters were not significant. The highest grain yield 8.29, 8.35 and 8.40 t ha^{-1} of maize were obtained from treatment T_4 (tillage at 18-20 cm depth) during the year 2005-06, 2006-07 and 2007-08, respectively, which was statistically insignificant.

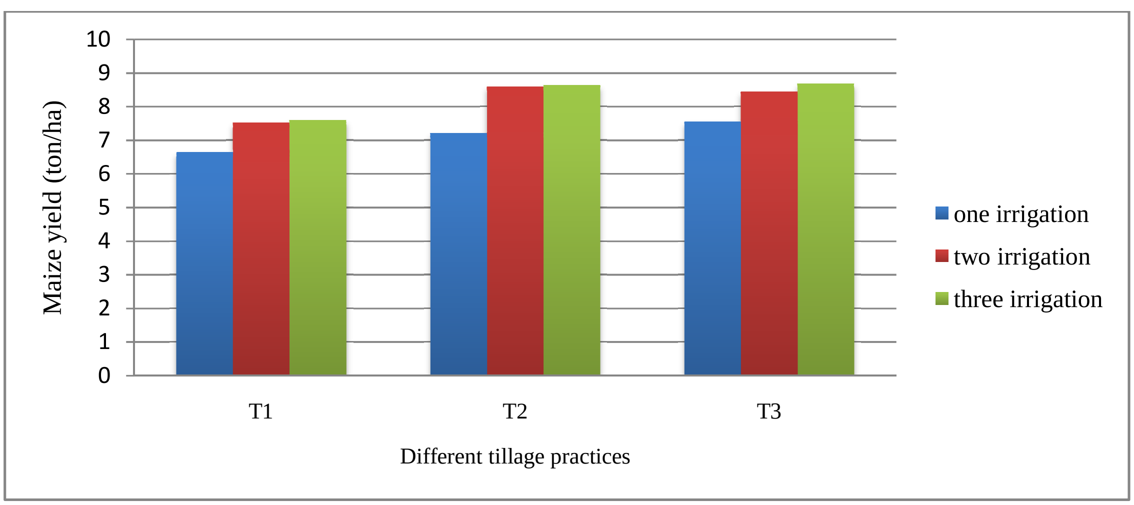


Fig. 2. Effect of irrigation on maize yields with different tillage practices

Table 1. Effect of irrigation water on the yield and yield contributing characters of maize

Treatment	Plant height (cm)	Plant/ plot	Cob/ plot	Grain/cob	100-grain weight (g).	Yield t ha^{-1}
I_1	193.7	66.3	62.3	358.0	14.9	7.1
I_2	207.3	75.3	75.3	416.7	15.2	8.2
I_3	214.7	75.0	77.7	426.0	15.7	8.3
Level of significance	HS	**	**	**	**	**
CV (%)	3.0	5.3	6.9	3.1	2.5	5.0

*** indicate significant difference, HS- high level of significant*

Table 2. Maize yield under different levels of irrigation and tillage treatment combination

Treatment combination	Average applied water (cm)	Average soil water contribution (cm)	Effective rainfall+ water required for seedling establishment (cm)	Total average water used (cm)	Maize yields (t ha^{-1})	Water use efficiency (t ha^{-1}cm^{-1})
T_1I_1	9.00	3.3	17.3	26.3	6.6	**0.3**
T_1I_2	17.3	3.3	17.3	34.5	7.5	0.2
T_1I_3	29.0	3.3	17.3	46.3	7.6	0.2
T_2I_1	12.0	1.0	17.3	29.3	7.2	**0.3**
T_2I_2	20.3	1.0	17.3	37.5	8.6	**0.2**
T_2I_3	34.0	1.0	17.3	51.3	8.6	0.2
T_3I_1	13.7	-1.0	17.3	31.0	7.5	**0.2**
T_3I_2	25.2	-1.0	17.3	42.5	8.4	0.2
T_3I_3	42.8	-1.0	17.3	60.0	8.7	0.1

3.3 Effect of Irrigation on Different Maize Yields Parameters

Highly significant variations were observed in plant height and grains per cob parameters. Fig. 3 shows that similar impact recorded in plant height, cob per plot and grains per cob in I_2 and I_3 irrigation treatments. Maximum number of plant per plot found in I_2 irrigation practices followed by I_3 irrigation practices lowest number of plant was in I_1 irrigation practices. 100-grain weight was height in I_3 irrigation practices (15.7 g) which is very similar to I_2 irrigation practices (15.2 g) and lowest was in I_1 irrigation practices (14.9 g). From the above discussions it may be concluded among three irrigation practices, I_2 irrigation practice (irrigation applied two times, after 25 days after sowing and 50 days after sowing) is optimum for maize cultivation in dry season of Bangladesh. I_1 irrigation practices are not sufficient for optimum yield and I_3 irrigation is sufficient but has no statistically significant difference with I_2 irrigation practices. Therefore, I_2 irrigation practice is suitable and optimum in each tillage practice for maize cultivation.

3.4 Water use Efficiency in Irrigation and Tillage Treatment Combination

The total water use was varied from 26.3 cm to 60.0 cm. The lowest amount of water was applied in T_1I_1 tillage treatment and the highest total water used was 60.0 cm in T_3I_3 treatment combination (Table 2). Total water use increased with maximum number of irrigation. Minimum number of irrigation with zero tillage produced lowest yields. The highest maize yields was found in T_3I_3 (8.7 t ha-1) and T_2I_2 (8.6 t ha-1) treatment combination. Yields were increased with maximum number of irrigation and lowest in minimum number of irrigation. Maize yields were independent of tillage but dependent on irrigation. Statistically significant different was found in irrigation treatment for maize yields. No significant difference was found in tillage treatment. A significant difference was found in combined treatment on maize yields. In zero tillage treatment, three irrigations were applied but significant yields did not increase. Maize yields were increased significantly minimum and traditional tillage treatment with increased number of irrigation (Fig. 4). No significant difference was found in T_2I_2, T_2I_3, T_3I_2 and T_3I_3 treatment combinations in maize yields and yields contributing characters.

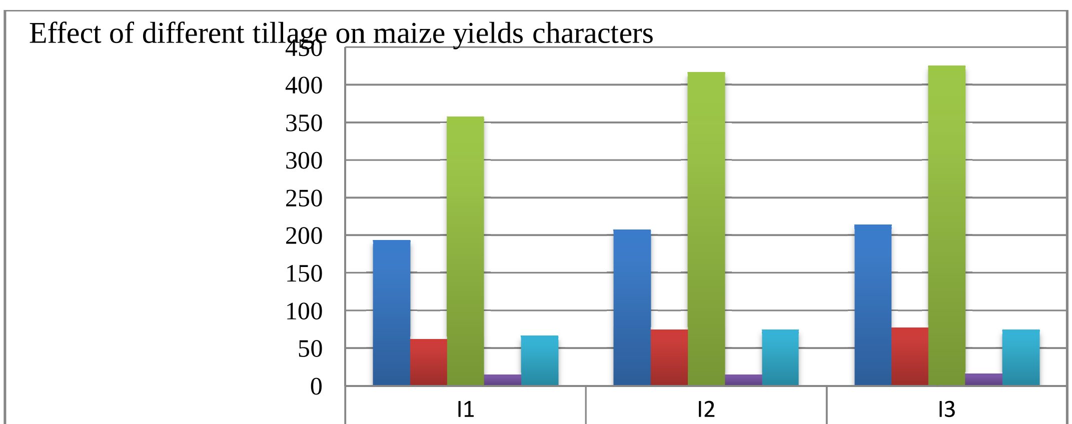
The highest water use efficiency (0.3 t ha^{-1}cm^{-1}) was found in T_1I_1 treatment combination and lowest water use efficiency (0.1 t ha^{-1}cm^{-1}) was found in T_3I_3 treatment combination (Table 2). Then the higher water use efficiency was found in T_2I_1, T_2I_2 and T_3I_1 treatment combination.

Though higher water use efficiency was found in T_2I_1 and T_3I_1 treatment combination but these treatment combinations were not acceptable because yields was lower in these treatments combination. T_3I_3 treatment combination has the higher yields but water efficiency was lower. This treatment combination was not cost effective method for maize cultivation. In T_2I_2 treatment combination, both water use efficiency and yields are high. Therefore, T_2I_2 treatment combination is most acceptable for maize cultivation. That means minimum tillage (T_2) and two irrigations (irrigation application after 25 days of sowing and after 50 days of sowing) is optimum treatment for maize production. Tariq et al. [21] found the average water use efficiency of maize ranged from 0.7 to 1.8 kg m^{-3} and they concluded that optimum yield of maize can be obtained when crop is irrigated with a depth of 0.75 Epan (pan evapotranspiration).

3.5 Total Irrigation Water used in Different Irrigation Treatment

A high-yields maize crop requires average 50 cm of water, with a range of 45.0 cm to 80.0 cm for acceptable yields. About 35-41 cm of water is enough to produce a low yield, but that depends on the season the water is availability or unavailable. In general, higher yields need more water but factors like temperature affect this to some extent. Shahidi et al. [22] found one centimeter of water per hectare is about 100.3 m^3 of water per hectare of land, so maize crop uses average 50x100.3 = 5015 m^3 of water per hectare [22]. The maximum amount of water was applied in I_3 (105 cm) irrigation treatment and minimum amount of irrigation water was applied in I_1 (35 cm) irrigation treatment. In I_2 (62.7 cm) irrigation treatment a moderate amount of water was applied (Table 3). However, substantial difference of applied water was found in I_1, I_2 and I_3 irrigation treatment but a little amount of yields difference was observed in I_1, I_2 and I_3 irrigation treatment.

From the above results and discussions, T_2I_2 treatment combination is rational for maize cultivation at dry season (Rabi) in Bangladesh. That means I_2 irrigation practices is best suitable for maize cultivation in regarding the yield and water use efficiency. I_2 irrigation treatment is the optimum irrigation practices for acceptable maize yields. In I_1 irrigation treatment satisfactory yields were not founds. In I_2 and I_3 irrigation treatment the yields was satisfactory in Bangladeshi context. In I_3 irrigation treatment a huge amount of valuable water was used but yields was not significantly different from I_2 irrigation treatment. Therefore, I_1 and I_3 irrigation treatments may not scientifically accepted. On the other hands, I_2 irrigation treatment is deemed as scientifically accepted for maize cultivation in Bangladesh.



	I1	I2	I3
Plant height (cm)	193.7	207.3	214.7
No. of cobs per plot	62.33	75.33	77.67
grains per cob	358	416.7	426
100-grains weight (gm)	14.93	15.23	15.73
Plant population per plot	66.33	75.33	75

Fig. 3. Effect of different irrigation level on various maize yields parameters

3.6 Water Savings by I_2 Irrigation Treatment over I_3

Water saving in one hectare of land for maize cultivation by adopting I_2 irrigation treatment over I_3 irrigation treatment is 10532.9 m^3 – 6289.6 m^3 = 4243.3 m^3 (Table 4). I_2 irrigation treatment (irrigation applied after 25 days of sowing and after 50 days of sowing) saves 4243.3 m^3 of water per hectare of land for maize cultivation than I_3 irrigation treatment (irrigation applied after 25 days of sowing, after 50 days of sowing and after 85 days of sowing). Therefore, I_2 irrigation treatment is optimum irrigation practices for maize cultivation considering yields and water saving aspect.

3.7 Economic Analysis

For economic analysis the benefit cost ratio (BCR), gross return and net return were determined (Table 5). The highest BCR was observed in T_2I_2 treatment combination (3.1) that means only two irrigations with minimum tillage treatment. The lowest BCR was observed in T_3I_3 treatment combination (1.9) followed by T_3I_2 (2.0) and T_3I_1 (2.2) treatment combination. Yields were increased with the increase of irrigation but BCR is not increased with the increase of irrigation. The highest gross return (USD/ha 2235.97) was found in T_3I_3 treatment combination which was very much similar to T_2I_3 (USD/ha 2228.24) T_2I_2 (USD/ha 2215.36) and treatment combination and the lowest gross return (USD/ha 1713.40) was found in T_1I_1 treatment combination (Table 5).

Fig. 4 shows maize yields, BCR and gross returns with different treatment combination. This Figure also shows that the highest benefit cost ratio and higher yields were found in T_2I_2 (3.1) treatment combination. Although the highest yields was in T_3I_3 treatment combination the lowest BCR was found in this treatment combination. This treatment is not cost effective treatment combination for maize cultivation in Bangladesh.

The highest net return (USD/ha. 1501.45) was found in T_2I_2 treatment combination which was nearest to T_2I_1 (USD/ha 1228.65) and T_1I_3 (USD/ha 1198.77) treatment combination. The lowest net return was found in T_3I_2 (USD/ha 1076.41) treatment combination which was very much similar to T_3I_3 (USD/ha 1084.14) and T_1I_1 (USD/ha 1086.97) treatment combination (Table 4 and Fig. 5).

Table 3. Total irrigation water applied in different irrigation treatment

Irrigation treatment	Water used in zero tillage (T_1)	Water used in minimum tillage (T_2)	Water used in traditional tillage (T_3)	Total water applied (cm)	Total irrigation water use (m^3/hectare)
I_1	9.0	12.0	14.0	35.0	3510.9
I_2	17.3	20.3	25.2	62.7	6289.6
I_3	29.0	34.0	42.0	105.0	10532.9

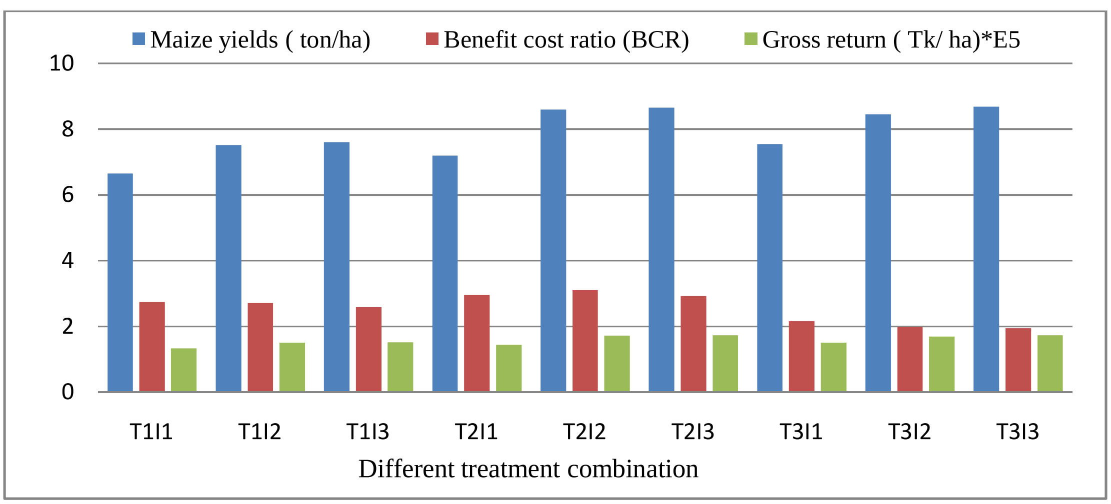


Fig. 4. Maize yields, BCR and gross returns with different treatment combination

Table 4. Water savings by I_2 over I_3 irrigation treatment

Variables	Irrigation treatment (I_2)	Irrigation treatment (I_3)
No. of irrigation	2	3
Total applied water (m^3/ha)	6289.6	10532.9
Yields (t ha^{-1})	8.20	8.31
Water use efficiency (t ha^{-1}-cm)	0.102	0.068

Table 5. Economic effect of tillage and irrigation on the yield

Cost items	Treatment combination								
	T_1I_1 (usd/ha)	T_1I_2 (usd/ha)	T_1I_3 (usd/ha)	T_2I_1 (usd/ha)	T_2I_2 (usd/ha)	T_2I_3 (usd/ha)	T_3I_1 (usd/ha)	T_3I_2 (usd/ha)	T_3I_3 (usd/ha)
Human labors	111.80	122.36	10000	8680	122.36	128.80	341.32	354.20	367.08
Fuel	38.64	38.64	38.64	38.64	38.64	38.64	193.20	193.20	193.20
Manure	128.80	128.80	128.80	128.80	128.80	128.80	128.80	128.80	128.80
Urea	25.76	25.76	25.76	25.76	25.76	25.76	25.76	25.76	25.76
TSP	123.80	123.80	123.80	123.80	123.80	123.80	123.80	123.80	123.80
MP	137.25	137.25	137.25	137.25	137.25	137.25	137.25	137.25	137.25
Gypsum	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50
Irrigation	51.52	10000	13000	51.52	128.80	167.44	51.52	128.80	167.44
Total variable cost	626.07	713.91	758.99	626.07	713.91	758.99	898.73	1100.31	1151.83
Gross return	1713.04	1937.15	1957.76	1854.72	2215.36	2228.24	1944.88	2176.72	2235.97
Net return	1086.97	1223.24	1198.77	1228.65	1501.45	1469.25	1046.15	1076.41	1084.14
Benefit cost ratio	2.7	2.7	2.6	3.0	3.1	2.9	2.2	2.0	1.9

a) Maize =0.26 USD/kg b) Labor = 3.22 USD/day c) I taka = 0.012883 USD

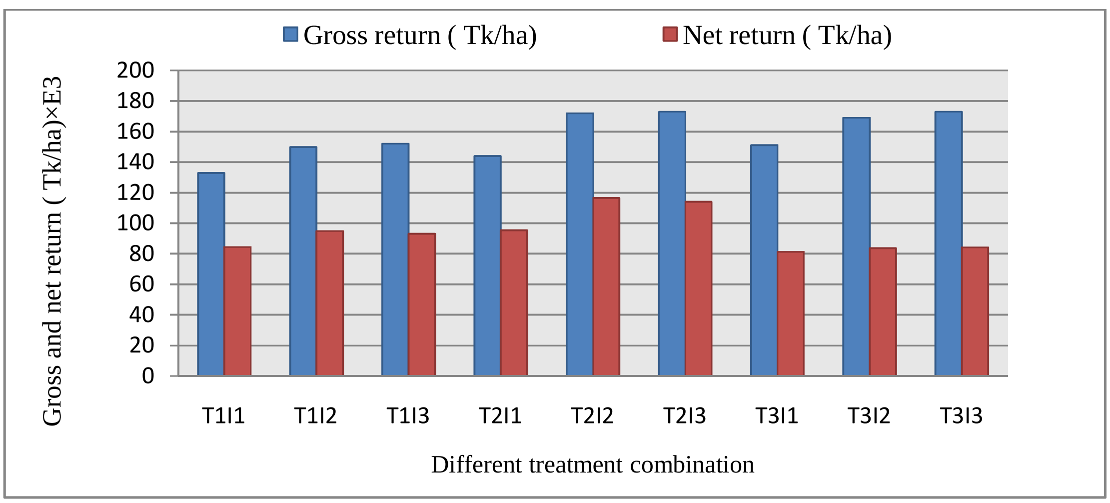


Fig. 5. Gross and net return of maize cultivation with different treatment combination

4. CONCLUSION

Irrigation has a significant effect on maize plant height, plant population, cob per plant, grain per cob, 100-grain weight and yields. Statistically same effect was found on maize yields in two irrigations (I_2) and three irrigations (I_3). Maximum yields was found in I_3 irrigation treatment but the lowest BCR and minimum net return were found in this treatment. Maximum water was required in I_3 irrigation treatment but yields were not increased as per increase of water. Therefore, I_3 irrigation treatment is not a rational treatment for maize cultivation. One irrigation treatment (I_1) has the lowest yields of maize in comparison to I_2 and I_3 irrigation treatments so; I_1 irrigation treatment is not optimum for maize cultivation. I_2 irrigation treatment has higher yields, higher BCR, higher net returns and higher gross returns. Among three type of irrigation treatment, (I_1, I_2 and I_3) two-time irrigation (I_2) treatment is scientifically, statistically, and economically appropriate for maize cultivation. In this study it was found that tillage has no significant effect on maize yields and maize yield contributing characters. Minimum amount of irrigation water was required in Zero (T_1) tillage treatment. The BCR values increased at a certain level with the increase of both irrigation and tillage treatment. The highest value was in the practice of I_2 irrigation with T_2 tillage practices. Therefore, T_2I_2 treatment combination is the best suitable for maize cultivation in considering yields, water saving method, scientifically, economically and statistically significances for this crop production.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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