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Water productivity and yield performances of wheat under different irrigation and tillage treatments

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Considering the ever increasing competition among different water users, improving water use efficiency in agriculture is now a grave concern. Contemplating this, the study was carried out to evaluate the interaction effects of different tillage and irrigation treatments on water productivity as well as yield and yield contributing characters of wheat. The field experiment was laid out in two factors using strip plots arrangement and replicated thrice. Treatment combination comprised of 3 levels of irrigation during wheat growth stages: I_1 (17-21 Days after sowing (DAS)), I_2 (17-21 DAS + 50-55 DAS) and I_3 (17-21 DAS + 50-55 DAS + 75-80 DAS). The tillage treatments were: T_1 (bed planting), T_2 (power tiller operated seeder), T_3 (strip tillage) and T_4 (zero/no tillage). The actual water requirement was calculated as the depth of water needed to bring the crop rooting zone to field capacity. Among yield contributing characters of wheat only grains spike^{-1} and spikes m^{-2} showed significant change in respect of irrigation and tillage treatments. Regardless of irrigation effects, the highest spikelets were observed in bed planting and the lowest in strip tillage condition. Interaction effects of irrigation and tillage on grain yield of wheat were statistically significant amounting maximum (4.37 t ha^{-1}) in T_1I_3 and the minimum (2.52 t ha^{-1}) in T_4I_1. Biological yield parameters were insignificantly influenced by interaction effects of irrigation and tillage. Maximum water productivity of wheat was 2.93 kg m^{-3} in T_4I_1 and minimum was 1.47 kg m^{-3}inT_4I_3. Water productivity increased due to less seasonal water use and decreased with increased irrigation. Highest water productivity and less total water used were observed in zero tillage due to higher infiltration rate in reduced tillage system. Based on the grain yield and water productivity, best combinations of tillage and irrigation treatments were T_1I_3 and T_4I_1, respectively. Regardless of irrigation effect, bed planting can be a good tillage option for wheat cultivation. However, considering water productivity of wheat less tillage operation methods (zero tillage and strip tillage) can also be recommended for water scarce areas.

INTRODUCTION

Bangladesh is one of most densely populated countries in the world. The country's population has an increasing trend and will likely to increase up to 223 million by 2030 requiring 48.0 million tons of food grains (Karim et al.1990). To mitigate this challenge, measures should be taken to increase our total food production. This increased food production cannot be achieved by only focusing on rice production where horizontal expansion of agriculture due to limited arable land is also a major concern (FAO 2000). To solve this problem, more attention should be given to produce supplementary cereals like wheat, maize and other cereals along with cultivating rice. In addition, with respect to water use efficiency, four times more water is required to get same yield from boro rice in comparison to wheat. It has been reported that total water required to produce 1 kg boro rice is 3000–4000 liters, with which four times more wheat can be grown (Satter 2004). In fact, wheat cultivation has already been popular in Bangladesh, it is now considered as the second important cereal crop next to

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rice (Razzaque and Hossain 1990). The area coverage of wheat is 0.56 million hectares with an annual production of 0.98 million tons and average production is 1.74 Metric tons per hectare (BBS 2005).

Though wheat is a very promising cereal crop in Bangladesh, it encounters a number of problems. The average yield of wheat is still low compared to that of the advanced countries of the world. In Holland, United Kingdom, France and Norway, the average yield of wheat is 7.1, 5.9, 5.6 and 4.1 t ha^{-1} respectively; whereas in Bangladesh, it is only 1.9 t ha^{-1} (FAO 1992). Ensuring optimum water availability to wheat plants during their growth is essential to reach its potential yield (Sarker et al. 2012). However, it has become a problem as wheat growing season is the driest period of the year (November-March) in respect of monthly distribution of rainfall. Therefore, about 50 percent of the total wheat growing area still remains without irrigation and is dependent on residual soil moisture (Alam 2012). Moreover, the soil moisture is depleted rapidly in the later part of crop season because of scanty of or no rainfall during the wheat growing period. This soil moisture stress has been reported to adversely affect the wheat yield (Ahmed and Claimants 1983).

In order to reduce soil moisture loss as well as to increase water use efficiency, various conservation tillage practices have been already adopted in agriculture sector (Alam 2012). Raised bed planting is one of them practiced in many parts of the world to reduce the cost of production and irrigation water (Abdelhadiet al. 2006). Raised bed was introduced to rice-wheat system of the Indo-Gangetic Plain (IGP) in the mid 1990s, initially for wheat (Humphreys and Roht 2006). Since then many advantages of growing wheat on raised beds have been reported as including increases yields, reduced water logging, opportunities for mechanical weeding and improved fertilizer, irrigation water savings, reduced seed rate and opportunities for intercropping. A number of studies have explored the effects of different tillage techniques (Sarker et al. 2009; Sarker et al. 2008) and the effects of irrigation treatments (Akhtear 2006; Kabir 2006; Ashok and Sharma 1997; Naser 1996; Jana and Mitra 1995) with their main focus on wheat yield. Very few studies have focused on water productivity of wheat. Edalat and Naderi (2016) and Sarker et al (2012) conducted their studies to find the effects of different irrigation and tillage treatments on yield and water productivity of wheat. They considered individual effect of different reduced tillage and irrigation practices without properly focusing on the interaction effects of both the treatments. However, there is still enough scope to explore the interaction effects of tillage and irrigation for wheat cultivation. In addition, considering future challenges of irrigation water availability, it is noteworthy to focus how irrigation water application can be reduced without hampering wheat yield. Contemplating all these issues, this study aims to explore how different tillage and deficit irrigation practices affect water productivity and yield characteristics of wheat.

Specific objectives of this study are:

- To assess the interaction effects of tillage and irrigation treatments on yield and water productivity of wheat.
- To find out the best combination of tillage and irrigation for higher yield and water productivity of wheat.

MATERIALS AND METHODS

Experimental Site

The experimental site is located in the agro-ecological zone (AEZ) 28 that lied at 23°59'13.53"N Latitude and 90°24'53.35"E Longitude. The elevation of the experimental site is 15 m above mean sea level. The soil of the experimental field belonged to the Madhupur Tract (BARC 2005) and it is silt loam underlain by sandy loam. The organic matter content of the experimental soil is 0.85 %. The climate of the experimental site falls under the sub-tropical, which is characterized by high temperature, high humidity, and average rainfall of 2376 mm with occasional gusty winds in kharif season (April–September). Whereas, less rainfall associated with moderately low temperature exists during the rabi season (October–March).

Experimental Treatments

The experimental plots were laid out with split plot design (SPD) having three irrigation treatments and four tillage treatments. There were three replications of combinations of both the treatments. According to the split plot design, tillage treatment was assigned in the main plot and the irrigation in the sub plots. All of these events were randomly chosen to avoid any biasness towards the selection. Irrigation treatments were:I_1: 17-21 DAS (Day after sowing)**,** I_2: 17-21 DAS + 50-55 DAS, I_3: 17-21 DAS +50-55 DAS + 75-80 DAS**;** and tillage treatments were: T1 (bed planting), T_2 (Power tiller operated seeder), T_3 (strip tillage) and T_4 (zero/no tillage).These methods are briefly explained below-

Bed Planting (T_1): Power tiller operated bed planter was used to make raised beds of 12–13 cm height where row (in between two beds) to row spacing was 55–56 cm. Seeding was done in two rows on each raised bed.

Power Tiller Operated Seeder (PTOS) (T_2): The main function of PTOS is to form broad beds and simultaneously undertake sowing in rows on the bed. Broad beds were separated by furrows at a spacing of 160 cm.

Strip tillage (T_3): It is a minimum tillage technique where seedbed is divided into seedling zone. The seedling zone (5–8 cm wide) was mechanically tilled to optimize the soil and microclimate environment for germination and seedling establishment.

Zero tillage (T_4): It is a way of growing crops without disturbing the soil. Seeding was done in rows by opening soil with the help of power tiller mounted zero tillage planter.

Sowing of seeds and application of fertilizer

Bangladesh Agricultural Research Institute (BARI) developed wheat variety- *Prodip* (BARI GAM-24) was sown in the experimental plots having different tillage conditions at the rate of 120 kg ha^{-1}. Seeds were sown in rows at 2–3 cm depth with 20 cm row to row spacing in all tillage treatments except bed planting. Two rows of seeds on each raised bed were maintained in case of bed planting where bed to bed spacing was 55–56 cm. Fertilizers were applied at the rate of 100 kg N, 26 kg P, 40 kg K, 20 kg S, and 1 kg B ha^{-1}. Urea, TSP, MoP, gypsum, and boric acid were used as sources for N, P, K, S, and B, respectively. Two-thirds of N and total amount of other fertilizers were applied at the time of sowing and the remaining N was top dressed after first irrigation.

Determination of crop water requirement (WR)

The water requirement for wheat was computed by the following equation having three components: total irrigation required (IR), effective rainfall (ER), and soil moisture contribution which comprises the last part of the equation (Michael 1985):

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

Where,
WR = seasonal water requirement, cm
IR = total irrigation water applied, cm
ER = seasonal effective rainfall, cm
M_{si} = moisture content at sowing in the i^{th} layer of the soil, %
M_{hi} = moisture content at harvesting in the i^{th} layer of the soil, %
AS_i = Apparent specific gravity of the i^{th} layer of the soil
D_i = depth of the i^{th} layer of the soil within the root zone, cm
n = number of soil layers in the root zone; the study considered three layers
: 0-15, 15-30, 30-45 cm.

The irrigation water applied (IR) to bring the soil moisture at field capacity was determined using the following equation:

$$IR = \frac{Fc - Mci}{100} \times AS \times D ....(ii)$$

where,
IR = Depth of irrigation, mm
F_c = Field capacity of the soil, %
Mc_i = Moisture content of the soil at the time of irrigation, %
D = Root zone depth, mm

Effective rainfall is the rainfall that is available in the plant rooting zone, allows the plant to germinate or maintain its growth. Effective rainfall (ER) was estimated using the USDA Soil Conservation Method (Schwab 1993) as given below:

$ER = R_{total}(125 – 0.2\ R_{total})/125$; if $R_{total} < 250$ mm
$ER = (125 + 0.1\ R_{total})$; if $R_{total} > 250$ mm
Where,
R_{total}= total rainfall, mm

Determination of Water Productivity

The water productivity (WP) is expressed as the ratio of crop yield (Y) to the total amount of water used during entire growing period of crop (Michael 1985). Thus, it is calculated as

$$WP = \frac{Y}{WR} ....(iii)$$

Where,
WP = Water Productivity, kg m^{-3}
Y= Crop yield (kg m^{-2})
WR= Total amount of water used by the crop, m

Determination of Harvest Index

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

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

Experimental Data Collection

Data on different yield contributing characteristics (spike, plant height, spike length, spike lets/spike, grains/spike, thousand grain weight, etc.) were recorded after harvesting of 5 sample plants from each plot. For calculation of grain yield, plants from 2x 1 m^2sample areaof each plot for zero tillage, PTOS, strip tillage, and 2x 1.1 m^2area for bed planting were harvested.Grains obtained from sample areas of the respective plot were dried in the sun and weighed at 12% moisture content to determine the grain yield per plot and was expressed in t ha^{-1}. Soil samples were collected from 0 – 15, 15 – 30, and 30 –45 cm depth of the experimental plots and average soil moisture content was calculated by gravimetric method.

Statistical analysis of data

An analysis of variance (ANOVA) was done for the data to sort out significant difference among treatments and DMRT was used to compare treatment means by using MSTAT-C program. Necessary graphs were made by using XLSTAT 2016 software.

RESULTS AND DISSCUSSION

Yield contributing characters

The significant or non-significant effects of irrigation and tillage treatments on different yield attributing characters of wheat were observed. The statistical analysis presented in Table 1 showed that the tallest plant height was found in the treatment T_3I_3 (948 mm) and the smallest plant height was obtained in T_3I_1 (810 mm). Even though the effect is not significant, increasing water supply had a significant effect on the plant height during vegetative stage. Spike length showed significant change in respect of irrigation as it increased with increasing water supply. Spikelets per spike were significantly influenced by different levels of irrigation. Maximum spikelets per spike of 20.8 were observed in T_1I_2 whereas minimum (19.2) was in T_3I_2. Regardless of irrigation effects, the change was due to variation in tillage practices as highest spikelets were observed in bed planting and lowest in strip tillage condition. The attribute, thousand grain weight (1000 grain weight), was affected non-significantly by the combined effects of irrigation and tillage even if the maximum and minimum values were 61.43 g and 48.77 g in the treatments of T_4I_1 and T_3I_2, respectively.

Grain yield

Interaction effects of irrigation and tillage treatments significantly affected grain yield of wheat. The maximum yield was 4.37 t ha^{-1} found in T_1I_3 treatment and the minimum was obtained as 2.52 t ha^{-1} in T_4I_1 (Table 1). It slightly differs from the findings of Sarker et al. (2012) who reported that the interaction effects of tillage and irrigation treatments on grain yield had no significant difference, however, the effect of only tillage was found significant. These results indicate that bed planting (T_1) and three levels of irrigation (I_3) are the best combination to improve the wheat yield. The results support the findings of increasing grain yield due to uniform ploughing and good seed germination in PTOS and bed planting methods (Sarker et al. 2012; Edalat and Naderi 2016), even though they found highest yield in case of PTOS instead of bed planting in this study.

Biological yield

The data of straw yield, biological yield (sum of grain yield and straw yield) and harvest index (ratio of grain yield to biological yield) for different treatments are presented in Table.2. Irrigation and tillage combination has a significant effect on different yield parameters. The highest straw yield was found as 5.20 t ha^{-1} for the treatment T_1I_1 and the lowest yield was 3.75 t ha^{-1} for the treatment T_2I_3. In case of biological yield, maximum value was 8.76 t ha^{-1} in T_3I_1 and minimum was 6.23 t ha^{-1} in T_2I_3. Maximum and minimum harvest index were 49.90% and 32.90% for combinations of T_3I_1 and T_1I_1, respectively. Biological yield is non-significantly influenced by different combinations of irrigation and tillage treatments, which are in agreement with the results of Karim et al. (2014).

Table 1. Yield and yield contributing parameters of wheat as affected by different tillage methods and levels of irrigation

Treatment	Plant population	Plant height (mm)	Spikes m^{-2}	Spike length (mm)	Grains $spike^{-1}$	Spikelets $spike^{-1}$	1000 grain weight (g)	Yield (t ha^{-1})
T_1I_1	238bc	846	130c	136	50.7c	19.8	53.39	2.55c
T_1I_2	297ab	853	170c	135	52.7abc	20.8	52.23	3.30bc
T_1I_3	301ab	846	191bc	142	53.3abc	20.7	56.48	4.37a
T_2I_1	163d	860	151c	131	56.1abc	19.6	52.35	3.19bc
T_2I_2	267ab	856	248b	130	54.8abc	20.3	49.45	3.69ab
T_2I_3	232cd	843	245b	136	54.6abc	20.3	54.78	3.75ab
T_3I_1	263ab	810	244b	97	58.9a	20.3	49.43	2.97bc
T_3I_2	309ab	854	284ab	138	51.8bc	19.2	48.77	3.50ab
T_3I_3	336a	948	312a	140	57.5ab	20.7	54.18	3.89ab
T_4I_1	151d	825	129c	127	50.1c	19.9	61.43	2.52c
T_4I_2	173cd	859	162c	127	51.9bc	19.6	55.09	3.01bc
T_4I_3	230cd	879	171c	130	50.6c	19.6	55.37	3.27bc
LSD (5%)	79.99	NS	62.53	NS	6.47	NS	NS	0.94
CV (%)	14.22	2.82	13.51	16.26	5.20	3.31	10.89	12.29

NS = Not significant, CV = Coefficient of variance, LSD = Least significance difference
In a column, numbers with same letter do not differ significantly, while those with dissimilar letters differ significantly at 5% level of significance (as per DMRT).

Table 2. Straw yield, biological yield and harvest index for different treatments

Treatment	Straw Yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
T_1I_1	5.20	7.75	32.90
T_2I_1	4.12	7.42	44.47
T_3I_1	4.39	8.76	49.90
T_4I_1	4.81	8.01	39.93
T_1I_2	5.05	8.74	42.22
T_2I_2	4.22	7.97	47.03
T_3I_2	4.43	7.40	40.16
T_4I_2	4.84	8.34	41.97
T_1I_3	4.1	8.00	48.73
T_2I_3	3.75	6.23	40.58
T_3I_3	3.91	6.92	43.52
T_4I_3	4.03	7.30	44.77

Water productivity

The total water used by the crop includes soil moisture contribution, effective rainfall and irrigation applied. Total water use (as shown in Figure 1), for the same irrigation treatment (I3), maximum amount of water was required for T4 (zero tillage) and minimum was for T1 (bed planting). Water productivity of wheat under different combinations of irrigation and tillage treatments showed that maximum water productivity of wheat was 2.93 kg/m^3 in T_4I_1 and minimum was 1.47 kg/m^3 inT_4I_3. Highest water productivity and less total water used were observed in zero tillage, the findings are also in agreement with that of Edalat and Naderi (2016), and Karim et al. (2014) where they found that highest water productivity and the lowest used water amount were obtained from reduced tillage. This is because, in reduced tillage system, irrigation water moves faster to the crop root zone through undisturbed soil pores, whereas irrigation water takes longer time to move due to puddle formation in the subsurface layer in case of conventional tillage. No significant effects were observed in case of soil moisture contribution under combination of treatments (as shown in Figure 2). However the maximum soil moisture contribution and minimum irrigation applied were 67 and 58 mm, respectively for T_1I_1. It can be said that regardless of irrigation treatment bed planting contributed to highest soil moisture contribution.

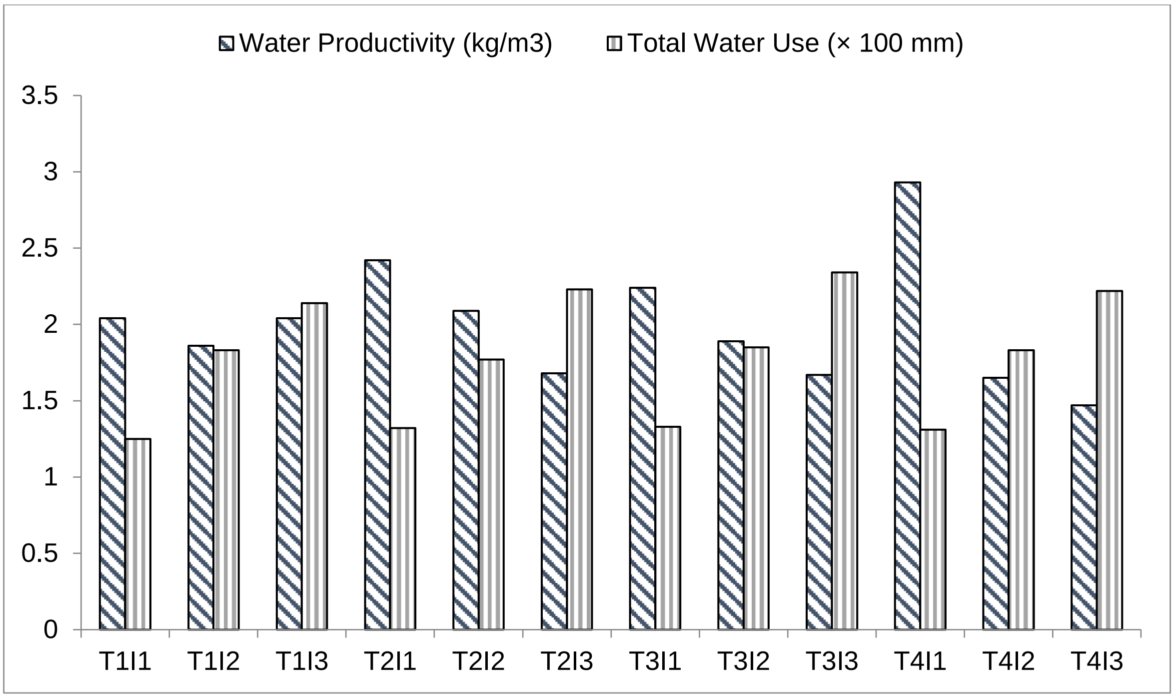

Figure 1. Water productivity and total water use pattern under different tillage and irrigation treatments

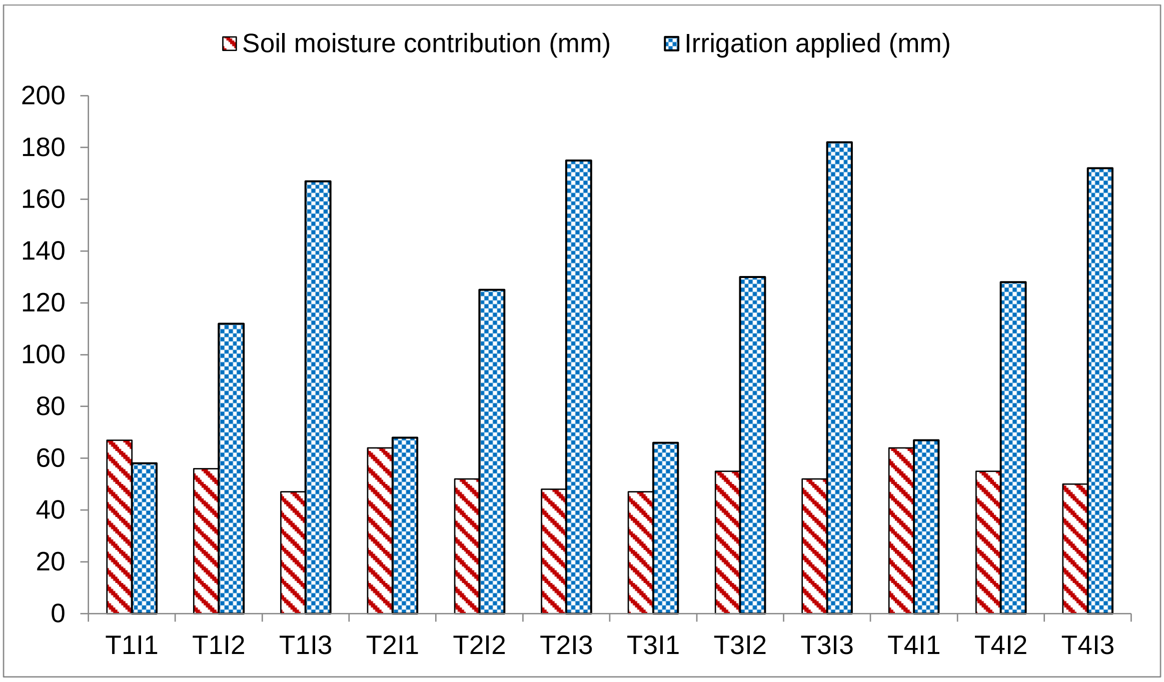

Figure 2. Water use pattern under different tillage and irrigation treatments

CONCLUSIONS

Based on the grain yield, bed planting (T_1) and three levels of irrigation (I_3) was found as the best combination for wheat cultivation. However, considering water productivity, the best combination was T_4I_1 (zero tillage and one irrigation). Regardless of irrigation effect bed planting can be a good tillage option for wheat cultivation. In addition, less tillage operation methods (zero tillage and strip tillage) may be recommended for wheat cultivation in water scarce areas even if it needs some sacrifices in yield. Further research may consider doing experiments in farmers' field at different places of Bangladesh under different agro-climatic conditions to confirm the findings of the present investigation.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

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