

WATER STRESS EFFECT ON WHEAT AT DIFFERENT MECHANICAL SEEDING SYSTEMS

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ABSTRACT. Judicial water use, as well as improving water use efficiency in agriculture is new challenge. Conservation tillage, as well as mechanical seeding system, offers various benefits over intensive tillage system. Considering this, the study was conducted to find out the water requirements and appropriate deficit irrigation schedule of wheat on different seeding system. This study consisted of following irrigation treatments, like I_1 = Irrigation at CRI stage, I_2 = Irrigation at CRI and vegetative stages, I_3 = Irrigation at CRI and grain filling stages and I_4 = Irrigation at CRI, vegetative and grain filling stages on four mechanical seeding methods, like T_1 = Bed planting, T_2 = PTOS, T_3 = Strip tillage, and T_4 = Zero tillage and laid out in a split plot design with three replications. From the result based on the grain yield and water productivity, bed planting (T_1) and three levels of irrigation (I_4) was found as the best combination for wheat cultivation. Besides, at water scarcity area bed planting (T_1), with two irrigation I_2 (CRI and vegetative) was the suitable reduce irrigation scheduling for wheat cultivation. In different seeding

methods, bed planting was increased yield about 10.58%, followed by PTOS and yield was identical in PTOS and ST. Comparatively, lowest yield was observed in zero. In irrigation treatment, three irrigations (I_4) was observed, the best scheduling for wheat on all seeding system and yield was increased 11.98% in I_4 , followed by I_2 and lowest yield was found in I_1 . The result also revealed that the soil moisture contribution was decreased with increased applied water, as well as number of irrigation.

Keywords: conservation agriculture; conservation tillage; bed planting; water productivity.

INTRODUCTION

Wheat is grown under a wide range of climatic and soil conditions. In Bangladesh, wheat is the second most important grain crop after rice and it is a crop of Rabi season, requires dry weather and bright sunlight. Well distributed rainfall between 40 and 110 cm is congenial for its growth. In Bangladesh, winter

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rainfall (November to March) is very limited. So, to get profitable yield must be applied irrigation water for rabi crops. It is however, wheat grows well in clayey loam soils. Wide-ranging practice, in wheat cultivation soil tilts 3 to 4 times in Bangladesh. Wheat Research Centre (WRC) of Bangladesh Agricultural Research Institute (BARI) recommended irrigation schedule for wheat, where irrigation water was applied 3 to 4 times. This irrigation scheduling suggested when soil tilts 3 to 4 times. Farmers in Bangladesh grow wheat fitting the crop in their intensive rice-based cropping systems. About 80% of wheat area is planted in a three-crop rotation and wheat-mungbean-T. aman cropping pattern is very popular to wheat growing farmers. It is important to seeding wheat in mid-November, but sometimes there were delays due to adverse environment and shortage of agricultural labor in three-crop rotation. In order to overcome this situation, farmers started use to mechanical seeding system instead to conventional tillage practice (3 to 4 times tilts soil) day by day. In rice based cropping systems, wheat were sown after 10 to 15 days of T. aman harvest. In mechanical seeding systems PTOS, bed planting, strip tillage and zero tillage are very popular for wheat. These seeding systems are components of conservation tillage, as well as conservation agriculture. This is a win approach that reduces operational costs, including machinery, labour,

fuel, while increasing yields and better utilize natural resources (Roy *et al.*, 2009). Yield and water use efficiency (WUE) in dry land areas depend strongly on soil-available water. Tillage practice showed a great role to reserve soil moisture. No-tillage (NT) and sub soiling tillage (ST) practices, as well as NT combined with ST, show promise in increasing soil water storage, improving WUE and increasing crop yield. In mechanical seeding based tillage technologies over conventional methods, the cost saving by minimum tillage, strip tillage, zero tillage and bed planting system were 65%, 67.5%, 69% and 40%, respectively than that of conventional methods of planting. Beside, mechanical seeding system also saved 94 l/ha/yr. of diesel fuel and 44% less emission of CO₂ into the atmosphere (Hossain *et al.*, 2015). As a result, time to say which irrigation schedule is appropriate for wheat on different mechanical seeding practices. Thus, we take the experiment to fulfil the mentioned objectives under wheat-mungbean-T. aman cropping patterns.

MATERIAL AND METHODS

The experiment was conducted at Regional Agricultural Research Station, BARI, Ishurdi, Pabna, in north western part of Bangladesh, during Rabi season 2017-2018 and 2018-2019. The experimental site was a silty clay loam having field capacity of 29%, permanent wilting point at 13% and bulk density of 1.45 g cm⁻³. Four irrigation treatments were assigned, like I₁ = Irrigation at CRI

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stage, I_2 = Irrigation at CRI and vegetative stages, I_3 = Irrigation at CRI and grain filling stages and I_4 = Irrigation at CRI, vegetative and grain filling stages on four mechanical seeding methods, like T_1 = Bed planting, T_2 = PTOS, T_3 = Strip tillage, and T_4 = Zero tillage in a split plot design with three replications. Seed of BARI Gom-30 was sown in unit plots of size was 7×7.5 m. In bed planting seeding method, seeds and fertilizer, like diammonium phosphate (DAP), were directly seeding by two wheeler operated bed planter where bed width 30 cm and bed to bed distance were 20 cm and 20 cm distance between two lines on single bed. Height of the bed 11 cm was maintained from base of the furrow to the crown level of the bed. Bed planter contained 24 tines for prepared bed.

In PTOS seeding system, seeds and DAP fertilizer were sown by PTOS planter with 3 to 6 cm tillage depth and maintained 20 cm row to row distance, used to 48 tines. PTOS performs tillage operation, seeding in line and seed covering simultaneously.

In strip tillage system seeds and DAP fertilizer were sown maintained 20 cm distance between two rows by using the BARI developed two wheeler operated strip tillage seeding machine. In strip till system, rotating blades were reduced to 24 numbers, where four blades in face to face configuration remain in the gang at front position of seed furrow opener for tilling and seed, fertilizer placement in strip 5 cm to 7 cm; strip width 4 cm to 5 cm and creating tilt soil just in front of furrow openers and between the two furrow openers the soil remained untilled. The J type blades of the seeder were rotating at the speed of 450 rpm. For strip-tillage, generally four blades are used on the rotor shaft per line furrow making by the strip till equipment

for minimizing the torque requirement and torque variation on the rotor shaft (Lee *et al.*, 2003).

Strip tillage system crop residue on the soil surface helps to preserve moisture and resist growing weeds, especially in rain fed moisture stress environment. In zero tillage seeding system, seeds and DAP fertilizer were sown by direct drilling instead of tilling. BARI developed two wheeler operated zero tillage machine was also used for zero tillage treatment and maintained 20 cm row to row distance. Bed planting, PTOS, strip and zero tillage seeding system, which employs tilling the soil just in front of furrow opener and place seed and fertilizer in line or bed at maintain right depth in a single operation, just after T. aman rice harvest to utilize the residual soil moisture. T. aman rice residue was also used and maintain height 15-20 cm. At the sowing condition, soil moisture was recorded 25-26%. Seeds were sown on 22 November in both years, harvested on 15 March 2018 and 16 March 2019.

Post sowing irrigation was applied up to field capacity to ensure germination. All the agronomic practices were carried out uniformly. The crops were harvested from the central 5 m×5 m area of each plot and the yields were converted to t/ha. Data was analyzed by using R software. SMD was determined by estimating soil moisture content. For this purpose, soil samples were taken from the effective root-zone of the wheat plant, which is 0-90 cm. The root-zone was divided into three sections, viz. 0-15, 15-30 and 30-45 cm. Soil samples were collected from these three sections with the help of an Augur. The fresh weight of the soil sampled was recorded immediately with the help of a portable weighing balance. After weighed, the samples were stored in soil sampling core, which were then

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placed in an electric oven for 24 h at 100°C. The dry weight of the samples was recorded after oven dry. Soil moisture

contents were then calculated using the following formula.

$$\text{Soil moisture content (\%)} = \frac{\text{Fresh weight of the sample}}{\text{Dry weight of the sample}} \times 100$$

The following irrigations were applied according to the specified treatments and irrigation water was applied up to field capacity at each irrigation and calculated amount of water by using flow meter. The amount of water applied to each treatment was calculated on the basis of the soil moisture contents at the time of irrigation by using the following expression: $d = M.C. \times B.D. \times D$,

where, d = depth of water to be applied; M.C. = moisture content (%); B.D. = bulk density of the soil; D = depth of root-zone to be irrigated.

The depth of rooting was considered 45 cm. It is reported that 70% of total moisture is extracted from the 50% effective root zone depth (Michael, 1997). The seasonal crop water use was calculated by the following relationship:

$$SWU = NIR + Rf + \sum_{i=1}^n \frac{(M_{bi} - M_{ei})}{100} \times AS_i \times D_i$$

where, SWU = seasonal water use, mm; NIR = total irrigation water depth, mm; Rf = seasonal rainfall, mm; M_{bi} = moisture percentage at the beginning of the season in the i th layer of the soil; M_{ei} = moisture percentage at the end of the season in the i th layer of the soil; n = no. of soil layers in the root zone, D_i

root zone, mm; AS_i = apparent specific gravity of i th layer of soil.

All other agronomic practices were carried out uniformly. The grain yield was recorded after harvest. Water use efficiency was used in evaluating the yield performance and water management practices. The water utilized by the crop was calculated by the following relationship:

This was considered of three of layers, 0-15, 15-30, and 30-45 cm. D_i = depth of the i th layer of soil within the

$$\text{Water productivity (WP)} = \frac{\text{Crop yield (kg/m}^2\text{)}}{\text{Seasonal crop water use (m)}} \times 100$$

In addition, meteorological data on parameters like temperature and rainfall were also recorded

RESULTS AND DISCUSSION

Climatic parameter

Maximum-minimum temperature and rainfall were presented in Fig. 1 (a, b). In first year, wheat received rainfall during CRI stages, which lead to less amount of water at first irrigation and have no effect on

irrigation treatment because water was applied in all irrigation treatment at CRI stages. Beside in second year, tiny rainfall occurred in 15 DAS after that pre maturity stages faced again rainfall. Second year rainfall effect was negligible due to water application of pre maturity or maturity stages was not sensitive for crop growth and development.

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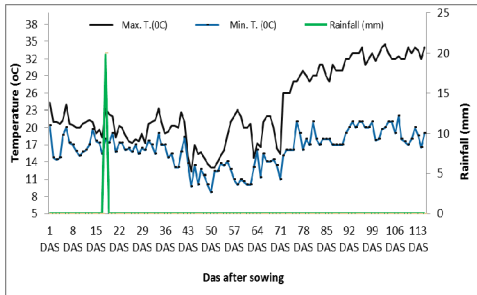


Figure 1a - Temperature and rainfall at 1st year

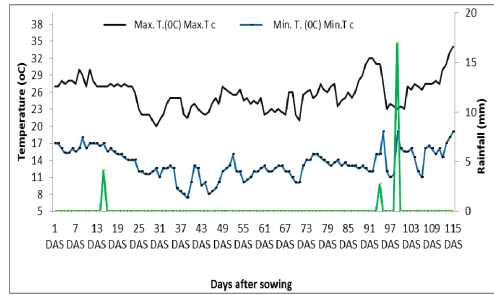


Figure 1b - Temperature and rainfall at 2nd year

Soil moisture profile

PTOS seeding method showed in lower soil moisture than others that indicated reduce tillage and bed planting having more soil moisture (Fig. 2). This result supported to the finding of Hossain *et al.* (2014), who reported that the maximum soil moisture content were observed in strip tillage, followed by PTOS than conventional tillage. Reason of this result, 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 deep tillage or conventional tillage. In irrigation treatment, soil moisture curve showed more available water for crop growth and development, where irrigation was applied three times. On the other hands, moisture curve showed decreasing trend and reached to near about permanent wilting point in water stress treatment. These finding agree with Ohiri *et al.* (1990), who observed higher soil

moisture content under conservation tillage (minimum tillage) than conventional system.

Amount of irrigation water at different stages on diverse seeding systems

Amount of water per irrigation was presented in Fig. 3 (a, b). Bed planting seeding system showed lowest water requirement at same irrigation treatment compare to others. The same result was reported by Mollah *et al.* (2009) that bed planting of wheat saved 41-48% irrigation water over flat land. These advantages come from the bed planting system, since irrigation water advances faster between two beds and water moves horizontally from the furrows into the beds and is pulled upwards in the bed towards the soil surface by capillarity, evaporation and transpiration, and downwards largely by gravity. Besides, bed planting system displayed less percolation loss due to untilled furrow and compacted furrow bottom, as well as furrow side causes

two wheeler passing at sowing time. PTOS seeding system disclosed highest amount of water due to more tillage, as well as flatbed. These results agree with Hasan *et al.* (2017), who reported that PTOS used highest water compare to bed and zero tillage. Though in strip tillage and zero tillage

seeding system contained more soil moisture due to less tilled, compared to bed and PTOS, but movement of water was slower than bed that led to more water. Faster water movement force is one of the reasons of less water in bed planting.

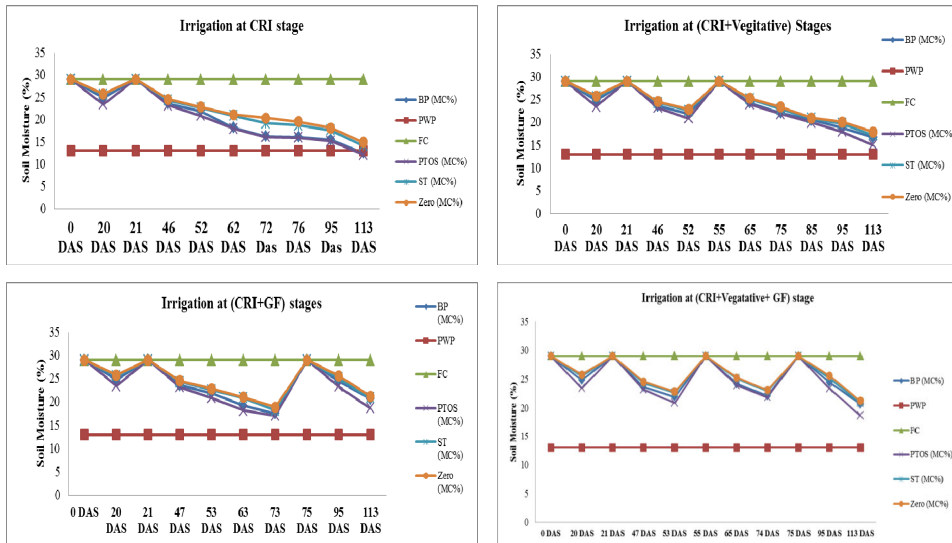


Figure 2 - Moisture profile of different irrigation treatment on different seeding method

Soil moisture contribution

Soil moisture contribution at same irrigation treatment was observed maximum in zero and minimum in PTOS *Fig. 4*. ST, zero tillage and bed planter take more moisture from the soil than PTOS. Soil moisture contribution was increased with reduce tillage. Besides, soil moisture contribution was decreased with increased applied water, as well as number of irrigation. Even water stress at vegetative stages showed more than water stress at grain filling stress.

Water productivity

Water productivity and total water used by the crop includes applied water by irrigation, effective rainfall, soil moisture contribution were displayed in *Fig. 5*. Total water use for the same irrigation treatment maximum amount of water was required in PTOS and minimum in bed planter. Trend of total water used by wheat was observed in PTOS>ST>Zero>BP, due to more advantages of bed than flat bed. Total water used by the wheat on different combinations of irrigation and seeding

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treatments revealed that maximum (248 mm) was in T₂I₄ and minimum 168 mm in T₁I₁. From the result, water productivity of same irrigation treatment highest in bed planting due to attained maximum yield and less water used. The same result was reported Waraich *et al.* (2010) that WUE was maximum under the treatment where crop was sown on bed with 68 cm bed width having six rows, as compared to conventional flat sowing. Besides, WP was found lowest in zero due to comparatively lower yield than that of others seeding method. Trend of WP was observed in

BP>ST>PTOS>Zero. Maximum water productivity was found about 2.44 kg m⁻³ in T₁I₄ and lowest about 1.45 kg m⁻³ in T₂I₃. Water stress at grain filling stages showed more WP (2.00-2.38 kg m⁻³), compared to water stress at vegetative (1.48-1.96 kg m⁻³) and water stress at CRI and vegetative that designated wheat is more water sensitive at vegetative stages than grain filling stages. ST gave more WP than PTOS and zero due to less water used, compared to PTOS and more yield achieved than zero, though zero used less water, compared to ST.

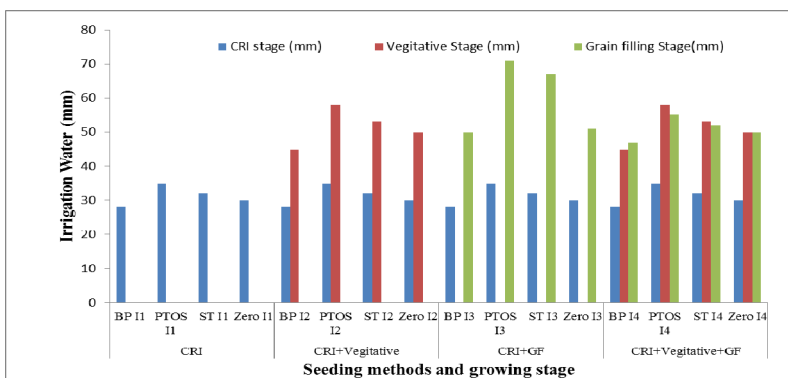


Figure 3a - Irrigation water at 1st year

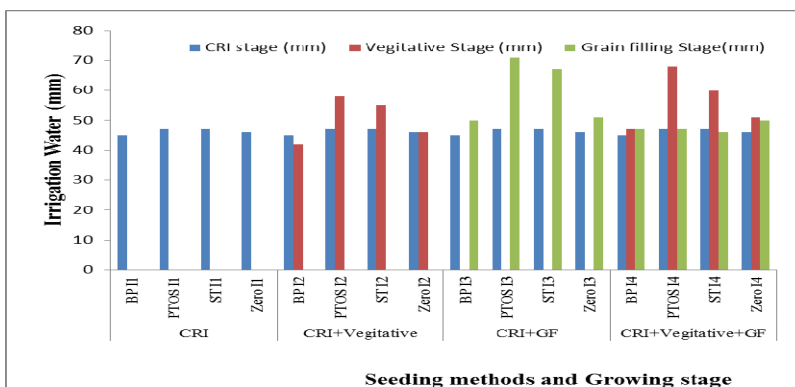


Figure 3b - Irrigation water at 2nd year

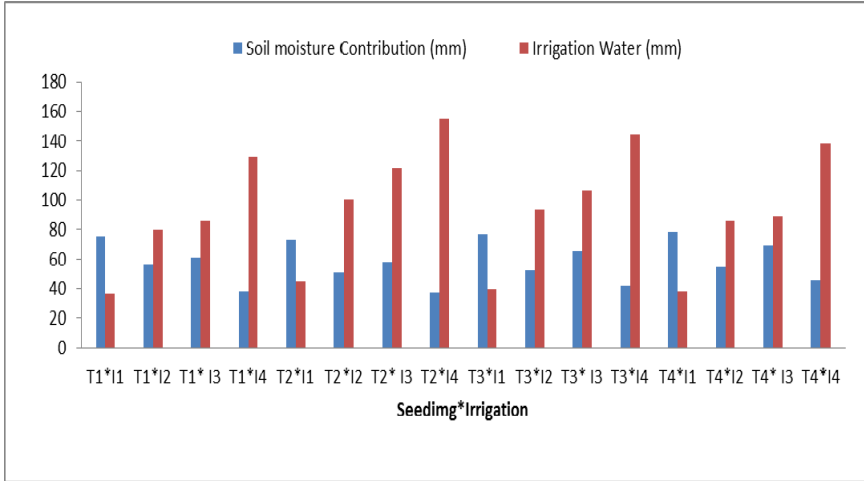


Figure 4 - Soil moisture contribution and irrigation water on different seeding and irrigation treatments

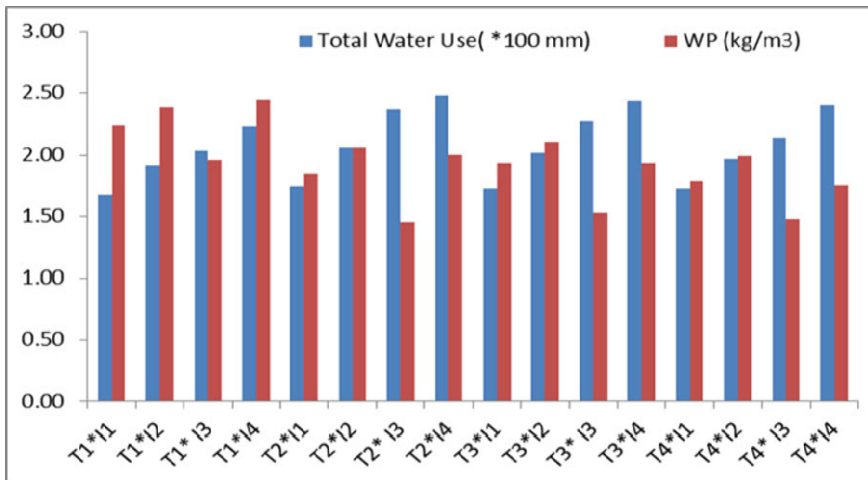


Figure 5 - Water productivity and seasonal water use pattern of altered seeding and irrigation treatments

Effect of seeding system on wheat

The significant increase in plant height, spikes m⁻², spike length, grains per spike, 1000-grain weight and grain yield were noted in raised bed planting system, compared to all other seeding methods (Table 1). These

results agree with Mollah *et al.* (2009), who mentioned that bed planting increased the number of spikes m⁻², number of grains spike m⁻¹ and 1000-grain weight of wheat. Plant height was statically identical in bed planting, PTOS and strip tillage

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seeding system. Spikes m⁻² was also identical in all treatment, except bed planting. There was no significant difference between PTOS and ST in spike length and observed lowest in zero. Bed planting seeding method increased yield 10.58%, followed by PTOS. Yield was identical in PTOS and ST and comparatively lowest yield was observed in zero. Highest yield was observed in bed planting causes achieved highest yield contributing parameters. These results agree with Aggarwal *et al.* (2003), who showed that yield and water use efficiency increased by 0.22 t/ha, under treatment with three rows of wheat per bed, compared to conventional planting.

Hossain *et al.* (2004) and Mollah *et al.* (2009) also found that planting of wheat on bed increased grain yield up to 21% over flat planting. Majeed

et al. (2015) showed that wheat planting on bed and nitrogen application at 120 kg ha⁻¹ produced 15.06% higher grain yield than flat planting at the same nitrogen rate. Hameed *et al.* (1993) suggested that wheat planted on bed and furrow irrigation showed higher yield and water use efficiency than flat-planted wheat.

These advantages come from the combined effect of having large number of effective spike, positive border effect that ensure enough light intensity, efficiently fertilizer placement and more efficiently application of irrigation water. Besides, raised beds make it easier to apply pesticides and herbicides because the beds allow the person spraying to follow the line. They also make possible mechanical weeding and easier rouging or hand weeding.

Table 1 - Effect of seeding system on wheat

Treatment	Plant height (cm)	Spike/m ² (No.)	Spike length (cm)	Grain/spike (No.)	TGW (g)	Yield (t/ha)
BD	93.67 a	265.12 a	10.45 a	45.66 a	25.04 a	4.44 a
PTOS	92.35 a	243.70 b	10.19 b	43.35 b	24.49 a	3.97 b
ST	92.79 a	244.70 b	10.07 b	42.60 b	23.39 b	3.95 b
Zero	90.41 b	236.33 b	9.64 c	41.42 b	23.01 b	3.59 c
CV (%)	2.86	6.69	3.84	7.56	3.86	6.77
LSD (0.05)	1.67	10.41	0.24	2.05	0.58	0.17

Effect of irrigation on wheat

Irrigation water was applied three times (CRI + Vegetative + Grain filling) and was observed higher yield and yield contributing parameter than that of other irrigation treatment entire

seeding system (*Table 2*). Yield increased 11.98% in I₄, followed by I₂ and lowest yield was found in I₁. Treatment I₂ exhibited higher yield, compared to I₃ that indicated vegetative stages is more water sensitive than grain filling stages for

wheat. These results suggested avoiding irrigation at grain filling stages with scarifying minimum yield loss at water scarcity area in all seeding methods.

Interaction effects of seeding and irrigation

Interaction effects of seeding and irrigation treatments significantly influenced grain yield of wheat (Table 3). Maximum yield was observed in T₁I₄ and minimum yield was found in T₄I₁. These results supported to Hasan *et al.* (2017), who reported that bed planting with three irrigation (CRI + Vegetative + Grain filling) gave maximum yield, compared to three irrigation on PTOS, ST and zero tillage, and zero tillage with one time irrigation (CRI stages) exhibited lowest yield.

These results indicate that bed planting (T₁) with three irrigation (I₄) are the best combination to improve the wheat yield. These advantages

come from the uniform ploughing and good seed germination in bed planting and efficient use of irrigation water.

On the other hand, this result slightly differs with Sarker *et al.* (2012), who reported that the interaction effects of tillage and irrigation on grain yield of wheat had no significant difference, but significant effects were found only tillage system. PTOS gave highest wheat grain yield instead to bed planter (Sarker *et al.*, 2012; Edalat and Naderi, 2016).

The treatment T₃I₄ and T₁I₂ both are third position based on grain yield and statically identical. These indicated that T₁I₂ was the best deficit irrigation scheduling among the different deficit and no water stress irrigation treatment on different seeding methods, except T₁I₄. The treatment T₁I₂ decreased yield of about 8.04%, compared to T₂I₄.

Table 2 - Effect of irrigation on wheat

Treatment	Plant height (cm)	Spike/m ² (No.)	Spike length (cm)	Grain/spike (No.)	TGW (g)	Yield (t/ha)
Irrigation at CRI	87.84 d	220.58 b	9.65 c	38.50 c	22.48 d	3.36 d
Irrigation at (CRI+ Vegetative)	95.30b	268.16 a	10.12 b	45.87 a	24.49 b	4.26 b
Irrigation at (CRI+ Grain filling)	89.18 c	225.75 b	10.02 b	41.53 b	23.28 c	3.52 c
Irrigation at (CRI+ Vegetative + Grain filling)	96.91 a	275.37 a	10.57 a	47.13 a	25.68 a	4.84 a
CV (%)	2.02	5.59	3.53	7.59	3.11	5.31
LSD(0.05)	1.08	8.04	0.2	1.9	0.43	0.12

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Table 3 - Interaction effects of seeding and irrigation

Treatment	Plant height (cm)	Spike/m² (No.)	Spike length (cm)	Grain/spike (No.)	TGW (g)	Yield (t/ha)
T1*I1	87.65 gh	236.33 f	10.01 def	40.16 fgh	23.53 _{ef}	3.76 f
T1*I2	98.01 ab	285 ab	10.63 ab	48.91 ab	25.54 _b	4.57 c
T1* I3	89.93 ef	242.5 ef	10.16 cde	42.84 def	24.21 _{de}	3.98 ef
T1*I4	99.1 a	296.66 a	10.98 a	50.75 a	26.88 _a	5.46 a
T2*I1	88.35 fgh	213.66 g	9.66 f	38.96 gh	23.07 _{fg}	3.23 hij
T2*I2	95.53 cd	268.5 cd	10.28 bcd	44.65 cde	25.21 _{bc}	4.27 d
T2* I3	88.28 fgh	217.83 g	10.2 cd	41.88 efg	23.83 _{def}	3.43 gh
T2*I4	97.26 abc	274.83 _{bc}	10.61 ab	47.9 abc	25.83 _b	4.97 b
T3*I1	88.26 fgh	218.66 g	9.76 ef	38.43 gh	21.71 _h	3.34 _{ghi}
T3*I2	95.93 bcd	263.16 _{cd}	9.95 def	44.75 cde	23.89 _{def}	4.26 d
T3* I3	89.7 efg	226.83 fg	10.10 cde	41.5 efg	22.62 _g	3.48 g
T3*I4	97.29 abc	270.16 _{bcd}	10.48 bc	45.75 bcd	25.33 _{bc}	4.71 c
T4*I1	87.1 h	213.66 g	9.16 g	36.46 h	21.60 _h	3.09 j
T4*I2	91.73 e	256 de	9.61 f	45.2 bcde	23.31 _{fg}	3.92 f
T4* I3	88.83 fgh	215.83 g	9.65 f	39.91 fgh	22.47 _{gh}	3.17 ij
T4*I4	94.00 d	259.83 cd	10.16 cde	44.13 cde	24.66 _{cd}	4.20 _{de}
CV (%)	2.02	5.59	3.53	7.59	3.11	5.31
LSD(0.05)	2.17	16.08	0.41	3.81	0.87	0.24

CONCLUSIONS

The results supports the following clarifications: based on the grain yield and water productivity, bed planting (T₁) and three levels of

irrigation (I₄) was found as the best combination for wheat cultivation. Besides, at water scarcity area bed, planting (T₁) with two irrigation I₂ (CRI and Vegetative) was the best deficit irrigation scheduling for wheat

cultivation where scarifying 8.04% grain yield, compared to T_2I_4 . Highest yield was observed in bed planting and yield increased about 10.58%, followed by PTOS and yield was identical in PTOS and ST. Comparatively, lowest yield was observed in zero. In case of irrigation, three times irrigations (I_4) was observed the best scheduling for wheat on all seeding system and yield was increased 11.98% in I_4 , followed by I_2 and lowest yield was found in I_1 .

Vegetative stages are more water sensitive than grain filling stages for wheat. The PTOS seeding method showed in lower soil moisture. Bed planting seeding system showed lowest water requirement and PTOS seeding system disclosed highest amount of water. Trend of total water used by wheat was observed in $PTOS > ST > Zero > BP$. Maximum water used (248 mm) was in T_2I_4 and minimum (168 mm) in T_1I_1 . Water productivity of same irrigation treatments was found highest in bed planting and trend of WP was observed in $BP > ST > PTOS > Zero$. Soil moisture contribution was decreased with increased applied water, as well as number of irrigation.

REFERENCES

- Aggarwal, P. & Goswami, B. (2003). Bed planting system for increasing water-use efficiency of wheat (*Triticum aestivum*) grown on inceptisol (Typic Ustochrept). *Indian J. Agric. Sci.*, 73(8): 422-425.
- Edalat, M. & Naderi, R. (2016). Interaction effect of tillage and irrigation methods on phenology, yield and water productivity of three wheat cultivars. *Biological Forum - An International Journal*, 8(2): 93-102.
- Hameed, A., Solangi, A.K. & Khoso, A.A. (1993). Water management strategies for areas with poor drainage or shallow water table conditions (second phase). Proceedings of Irrigation System Management Research Symposium, Lahore, Pakistan (April 11-13, 1993).
- Hasan, M.M., Mahmud, K., Islam, M.N., Sarkar, P.K. & Shariot-Ullah, M. (2017). Water productivity and yield performances of wheat under different irrigation and tillage treatment. *Fundam. Appl. Agric.*, 2(1): 196-201.
- Hossain, M.I., Meisner, C., Duxbury, J.M., Lauren, J.G., Rahman, M.M., Meer, M.M. & Rashid, M.H. (2004). Use of raised beds for increasing wheat production in rice-wheat cropping systems. In: New directions for a diverse planet: *Proc. of the 4th Int. Crop Science Congress*, Brisbane, Australia.
- Hossain, M.I., Gathala, M.K., Tiwari, TP. & Hossain M.S., (2014). Strip tillage seeding technique: a better option for utilizing residual soil moisture in rainfed moisture stress environments of north-west Bangladesh. *IJRDET*, 2(4).
- Hossain, M.I., Sarker, M.J.U. & Arshadul Haque, M. (2015) Status of conservation agriculture based tillage technology for crop production in Bangladesh. *Bangladesh J. Agric. Res.*, 40(2): 235-248, DOI: 10.3329/bjar.v40i2.24561
- Lee, K.S., S.H. Park, W.Y. Park & C.S. Lee (2003). Strip tillage characteristics of rotary tiller blades for use in a dry land direct rice seeder. *Soil Till. Res.*, 71(1): 25-32, DOI: 10.1016/S0167-1987(02)00159-9
- Majeed, A., Muhmood, A., Niaz, A., Javid, S., Ahmad, Z.A., Shah,

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- S.S.H. & Shah, A.H. (2015).** Bed planting of wheat (*Triticum aestivum* L.) improves nitrogen use efficiency and grain yield compared to flat planting. *Crop J.*, 3(2): 118-124, DOI: 10.1016/j.cj.2015.01.003
- Michael, A.M. (1997).** Irrigation: Theory and practice. *Vikas Publishing House Private Limited*, New Delhi, p. 539.
- Mollah, M.I.U., Bhuiya, M.S.U. & Kabir, M.H. (2009).** Bed planting: a new crop establishment method for wheat in rice-wheat cropping system. *J.Agric. Rural Dev.*, 7(1&2): 23-31, DOI: 10.3329/jard.v7i1.4418
- Ohiri, A.C. & Ezumah, H.C. (1990).** Tillage effects on cassava (*Manihot esculenta*) production and some soil properties. *Soil Till. Res.*, 17(3-4): 221-229, DOI: 10.1016/0167-1987(90)90037-E
- Roy, K.C, Haque, M.E., Justice, S.E., Hossain, I. & Meisner, C.A. (2009).** Development of tillage machinery for conservation agriculture in Bangladesh. *AMA*, 40 (2): 58-64
- Sarker, K.K., Sarker, P.K., Sarker, A.Z., Islam, A.M.F.T. & Xiaoyan, W. (2012).** Optimum water use in conservation tillage for wheat cultivation. *Bangladesh J.Agric.Res.*, 37(1): 27-37, DOI: 10.3329/bjar.v37i1.11172
- Waraich, E.A., Ahmad, R., Saifullah, & Ahmad, S. (2010).** Raised bed planting - a new technique for enhancing water use efficiency in wheat (*Triticum aestivum* L.) in semi-arid zone. *Iran.J. Plant Physiol.*, 1(2): 73-84.