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Research Paper

Influence of irrigation and tillage management on growth, yield and water-use efficiency of wheat (*Triticum aestivum*) in Gangetic plains in West Bengal

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ABSTRACT

A field experiment was carried out during the winter seasons of 2016–17 and 2017–18 at Gayeshpur, Nadia (West Bengal) in the Gangetic alluvial soil, to assess the impact of irrigation and tillage-management practices on growth attributes, yield components, yield and water-use efficiency of wheat (*Triticum aestivum* L.) cv. 'UP 262' Results revealed that increase in irrigation frequency from irrigation water : cumulative pan evaporation (IW : CPE) 0.4 to 1.0 significantly promoted growth parameters, and 6 irrigations at 16–17 days interval (IW : CPE ratio of 1.0) was found to be superior. Growth parameters were significantly higher under conventional tillage over minimum tillage. The plants receiving 6 irrigations (IW : CPE 1.0) recorded the highest consumptive use (CU), while the highest consumptive-use efficiency (CUE) was obtained with the plants receiving 5 irrigations. The maximum number of spikes/m^2, spike length and number of filled grains/spike were found in plants irrigated 6 times (IW : CPE 1.0) at an interval of 16–17 days. Maximum wheat grain and straw yield were obtained with 6 irrigations, closely followed by those obtained with 5 irrigations (IW : CPE 0.8). Tillage practices showed significant variation in the number of spikes/m^2 and it was maximum with crops grown under conventional tillage. Both grain and straw yields were significantly higher for plants grown under conventional tillage than those obtained under the minimum tillage. The gross returns, net returns and benefit: cost ratio were maximum when the crop received 6 irrigations under conventional tillage management. Hence, 6 irrigations under conventional tillage could be more effective in augmenting wheat yield, CUE and economics in the Gangetic plains of West Bengal.

Key words: Consumptive-use efficiency, Economics, Irrigation, Tillage, Wheat, Yield

Wheat is one of the most important cereal crops grown in India across the exceptionally diverse range of environments. India is the second largest producer of wheat, accounting 12% of the global production (Saha *et al.,* 2006). During 2016–17, wheat production reached 97.44 million tonnes with an average national productivity of 3,172 kg/ha (Director's Report 2016–17, IIWBR, Karnal). But for West Bengal, wheat contributes only 5.15% to the total foodgrain production and 3.1% to national production (Rana *et al.,* 2017). Hence, there is an urgent need to increase wheat productivity to meet the food requirements of this region, realizing rapid population growth and dietary preference of Bengal people (Banerjee *et al.,* 2019).

Irrigation water is essential and dwindling input which influences the growth and yield of dwarf wheat. Therefore, the productivity can be increased by providing plentiful water at the right time. In India, about 90% of the wheat area is under irrigation. However, the availability and application of irrigation water differs considerably from one region to another. Even soil texture very often determines the frequency of irrigation, as sandy soils require more irrigations than heavy soils. In general, yield and water-use efficiency (WUE) of wheat is found to be affected by deficit irrigation (Galavi and Moghaddam, 2012).

Moreover, the scheduling of irrigation is a key to water management. Water needs of crop are of paramount importance in determining the time of irrigation during the crop-growing season. Several direct and indirect methods are there to determine the water needs of the crop, namely consumptive use of water measurement, soil moisture depletion studies, tanks and lysimeter method, field experimental plot, inflow-outflow method, pan evaporation, Blaney-Criddle and Penmen methods (Khan *et al.,* 2007). Out of these, pan evaporation method is considered as the simplest one, and under this method evaporation is determined by the change in the level of water surface.

Tillage plays an important role for wheat production.

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Conventional tillage, popular in West Bengal till today, is mainly characterized by intensive tillage operation by mould board plough with or without straw burning, and excessive use of agro-chemicals (fertilizers, herbicides etc.). In contrary, minimum tillage aims at minimum soil manipulation (without turning over the soil) necessary for a successful crop production. It helps to control obnoxious weeds (Erenstein and Laxmi, 2008), shorten field time during tillage operations (Juergens *et al*., 2004), creates better soil structure, texture and aggregate stability (Ghuman and Sur, 2001), and finally improves soil water availability (Mitra *et al.,* 2019).

We hypothesized that irrigation and tillage operation could interactively affect wheat yield owing to improved water-use efficiency (WUE), particularly under water-stress condition. Hence, the objective of our study was to assess the sole and combined effect of irrigation and tillage management on growth, yield attributes, yield and consumptive use efficiency of wheat in Gangetic alluvial soils of West Bengal.

MATERIALS AND METHODS

The experiment was conducted during the winter seasons of 2016–17 and 2017–18 at Central Research Farm of the Bidhan Chandra Krishi Viswavidyalaya, Gayeshpur (22°87'N, 88°20' E, 9.75m above mean sea-level) Nadia, West Bengal in medium land situation under tropical climate. The soil at the experimental site (0–15 cm depth) was loamy, containing 52.57% sand, 26.3% silt and 21.12% clay with 6.58 *p*H and 0.54% organic carbon (OC). Available N, P_2O_5 and K_2O contents were 194.2, 47.5 and 198.1 kg/ha respectively. Meteorological data pertaining to the cropping seasons revealed that maximum and minimum temperature fluctuated between 30.9 and 18.1°C in winter 2016–17, and 32.5 and 19.1°C in winter 2017–18. Relative humidity prevailed between 86.3 and 51.3% in winter 2016–17, and 88.1 and 50.5% in winter 2017–18. The rainfall during the experimental period (November to March) was 43.3 mm (5 rainy days) and 41.5 mm (4 rainy days) in winter 2016–17 and 2017–18 respectively.

The experiment was laid down in a split-plot design with 4 replications, comprising 5 irrigation treatments in main plots [I_1, irrigation at irrigation water : cumulative pan evaporation (IW : CPE) of 0.4, i.e. 2 irrigations were applied at 40–42 days interval; I_2, irrigation at IW : CPE of 0.6, i.e. 4 irrigations at 25–27 days interval; I_3, irrigation at IW : CPE of 0.8, i.e. 5 irrigations were received at 20–22 days interval; I_4, irrigation at IW : CPE of 1.0 i.e. 6 irrigations were received at 16–17 days interval; and I_5, irrigation at physiological growth stages only, i.e. 4 irrigations received during crown root initiation (CRI) stage at 20–21 DAS (days after sowing), maximum tillering stage at 42–45 DAS, late jointing or heading stage at 65–66 DAS and flowering/milk stages at 82–85 DAS], and 2 tillage operations (T_1, minimum tillage and T_2, conventional tillage) in subplots. The seeds of wheat variety 'UP 262' were sown 25 cm apart from one row to another row while maintaining 5–7 cm plant-to-plant distance in the plots of 5.0 m × 4.0 m area. Dropping of seeds was done manually at a depth of 2-3 cm below the soil surface with the help of hand tynes and covered properly with soils. Irrigations were provided according to the treatment details. The crop was harvested at physiological maturity with 20% grain moisture content.

Growth parameters, viz. plant height, dry-matter accumulation (DMA), crop-growth rate (CGR), and leaf-area index (LAI) were recorded periodically at 30, 60, 90 DAS and at harvesting (120 DAS). Yield components, viz. number of spikes/m^2, length of spike, number of filled grains/spike, test weight (1,000-seed weight), grain yield and straw yield were recorded at harvest. To study the consumptive use and moisture-extraction pattern, soil samples at different depths (0–15, 15–30, 30–45 and 45–60 cm) were collected separately from each plot. For irrigation treatments, soil samples were taken before and 48 hours after each irrigation event from all plots and moisture (%) from different layers was determined on oven-dry weight basis at 105°C for 24 hours. Consumptive-use efficiency (CUE) was determined by taking into account seasonal consumptive values under different treatments and yield with the treatments.

Common cost of wheat cultivation in addition to variable irrigation and tillage practices (treatment cost) was estimated based on input used as per treatment details. The gross returns from the crop were calculated based on minimum procurement price of wheat grain by the Government of West Bengal.

The data were analyzed following the method described by Gomez and Gomez (1984). Significant difference of sources of variation was tested at the probability level of 0.05. The standard error of the mean (SEm±) and the CD value were indicated in the tables to compare the difference between the mean values. Bi-plot analysis was done using XLSTAT software to assess the relationship between two sets of variables.

RESULTS AND DISCUSSION

Growth attributes

Plant height and dry-matter accumulation (DMA) increased as the age of the crop progressed towards maturity, irrespective of irrigation and tillage-management practices (Table 1). Both these attributes recorded at different interval was significantly influenced by the levels of irrigation and the increase in irrigation frequency (IW : CPE 0.4 to

1.0) resulted in a significant increase in plant height and DMA. At maturity (120 DAS), the highest plant height and DMA were recorded with 6 irrigations at 16–17 days interval (IW : CPE ratio of 1.0). However, 5 irrigations (IW : CPE 0.8) caused the non-significant reduction of plant height. Higher plant height with more frequent irrigation to wheat crop was the indication of better internode elongation and good vegetative growth throughout the crop cycle. At the time of harvest, the highest DMA with heavily irrigated crops was attributed to ample supply of water with higher frequency at the right time, ultimately helping the plants to thrive and produce higher amount of green matter or dry matter. Leaf-area index (LAI) increased with the increase of aerial growth of wheat crop over the time up to 60 DAS, and then declined at maturity, irrespective of irrigation level (Table 1). The maximum LAI was obtained at 60 DAS with the application of 6 irrigations (IW : CPE 1.0 received 16–17 days interval). This might be owing to the overall improvement in crop growth at an increased level of irrigation. Further decrease in irrigation frequency (5 irrigations at IW : CPE 0.8) resulted in non-significant variation in LAI of wheat cultivar. In general, irrigation significantly altered the LAI, because water supply has a systematic and significant effect on leaf growth. It has been reported that, the increase in leaf area of plants and canopies is brought about by a substantial effect of water supply on the expansion of individual leaf (Pal *et al.,* 2000). In the present study, the rate of growth for wheat (cv. UP-262), as measured by computing CGR, reached at peak level during 60–90 DAS, beyond that it showed a declining trend towards maturity. The CGR of tested wheat cultivar was significantly influenced by the frequency of irrigation (Table 1) and the highest CGR during 60–90 DAS was recorded with 6 irrigations. In contrary, poorly irrigated crop (2 nos. only at IW : CPE 0.4) exhibited less height, DMA, LAI and CGR.

Tillage-management practice also had a significant effect on plant height, LAI, DMA and CGR (Table 1). The maximum plant height (at 120 DAS), LAI (at 60 DAS), DMA (at 120 DAS) and CGR (60–90 DAS) were recorded for plants grown under conventional tillage, accounting 11, 26, 16 and 6 more than minimum tillage respectively. Owing to conventional tillage, the soil was ploughed thoroughly and soil structure became more friable which created a favourable environment for crop growth and root establishment as well as proliferation of the plants resulting in better scope to extract moisture from soil (Islam *et al.,* 2011).

Yield components

Increase in irrigation frequency resulted in a significant increase in all yield components (Table 2). Maximum number of spikes/m^2 was found with 6 irrigations (based on IW : CPE ratio of 1.0) at an interval of 16–17 days. This might be owing to the fact that frequent application of the proper amount of irrigation at critical growth stages resulted in the highest number of productive tillers per unit area (Rana *et al.,* 2017). The highest irrigation level (6 nos.) also resulted

Table 1. Effect of levels of irrigation and tillage-management practices on growth-attributing characters of wheat grown during winter (pooled data of 2 years)

Treatment	Plant height (cm)				Leaf-area index				Dry-matter accumulation (g/m^2)				Crop-growth rate (g/m^2/day)		
	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS	30–60 DAS	60–90 DAS	90–120 DAS
Levels of irrigation															
I_1	23.8	45.3	62.5	62.8	0.18	2.19	2.37	2.04	39.9	202.6	495.5	548.9	5.42	8.57	1.78
I_2	26.3	55.5	80.2	81.4	0.19	2.65	2.71	2.54	44.0	233.4	636.6	711.6	6.31	13.44	2.50
I_3	27.6	66.9	88.1	89.5	0.24	3.10	3.02	2.87	47.1	244.5	692.1	778.4	6.58	14.92	2.88
I_4	29.1	71.0	92.8	93.4	0.26	3.25	3.24	3.05	54.1	254.2	712.2	830.5	6.67	15.27	3.94
I_5	26.4	59.0	81.2	83.7	0.20	2.82	2.85	2.80	46.4	238.1	658.1	749.1	6.39	14.00	3.03
SEm±	0.85	1.36	2.18	2.01	0.004	0.035	0.075	0.032	1.07	4.92	5.83	6.06	0.17	0.26	0.21
CD (P=0.05)	2.61	4.18	6.71	6.20	0.012	0.108	0.230	0.096	3.28	15.15	17.96	18.66	0.51	0.80	0.64
Tillage management practices															
T_1	25.7	56.6	76.7	77.8	0.20	2.48	2.64	2.51	43.2	223.6	609.8	658.8	6.01	12.87	2.54
T_2	27.5	62.5	85.3	86.5	0.22	3.12	3.04	2.90	49.4	245.5	653.7	761.6	6.54	13.61	3.60
SEm±	0.72	1.15	1.68	1.84	0.002	0.043	0.040	0.046	0.89	3.85	8.69	8.43	0.14	0.35	0.31
CD (P=0.05)	NS	3.47	5.08	5.55	0.006	0.129	0.121	0.139	2.69	11.61	26.18	25.42	0.41	NS	0.95

DAS, Days after sowing; NS, non-significant

I_1, IW : CPE 0.4; I_2, IW : CPE 0.6; I_3, IW : CPE 0.8; I_4, IW : CPE 1.0; I_5, physiological growth stages; T_1, minimum tillage; T_2, conventional tillage in long spikes, more filled grains/panicle and higher test weight. However, the crops receiving 5 and 6 irrigations exhibited non-significant variations between them regarding spike length only.

Tillage practices caused significant variation in all measured yield components, but the variation was non-significant only in number of filled grains/spike. Significantly highest number of spikes/m^2, spike length and test weight were observed in plants grown under conventional tillage, accounting 13, 4 and 7% more than minimum tillage respectively (Table 2).

Yield

Irrigation exerted a significant positive influence on wheat yield and it increased with increasing frequency of irrigation from 2 to 6 (Table 2). The maximum grain yield and straw yield were obtained with 6 irrigations. The superiority of this treatment might be owing to better availability of water and nutrient, improved vegetative growth (Rajanna *et al.,* 2019), and a greater synthesis of carbohydrates and their translocation (Khakwani *et al*., 2012). However, under limited irrigation, the extent of yield reduction due to restricted water availability depends on the degree, duration and timing of the imposed soil-moisture deficit (Dar *et al.,* 2019). Harvest index remained highest with 5 irrigations; however, it was statistically at par with the harvest index obtained with 6 irrigations at an interval of 16-17 days (IW : CPE 1.0). Our results confirm the report of Galavi and Moghaddam (2012).

Tillage-management practices caused significant variation in both grain and straw yields. Both grain yield (2.67 t/ha) and straw yield (4.56 t/ha) were significantly higher for plants grown under conventional tillage, accounting 23% and 21% more than minimum tillage respectively. The results support those of Sarker *et al.* (2012) and Edalat and Naderi (2016). In addition, harvest index did not show significant variation due to tillage-management practices (Table 2).

Interaction assessment through bi-plot analysis

In the present study, bi-plot analysis (Fig. 1) indicated the greater influence of irrigation frequency of 5 (IW : CPE 0.8) and 6 (IW : CPE 1.0) on harvest index (HI), grain yield (G_Y) in t/ha, straw yield (S_Y) in t/ha, 1,000-grain weight (TW) in g, grains/panicle (GP), spike/square m (SPQ), length of the spike (LS); weight of spike (WS) in g, no. of filled grains/spike (FG), and total dry matter (DMA1–4) in g/m^2 at 30, 60, 90, 120 DAS of wheat (var. ‘UP 262’), while conventional tillage practice exhibited greater influence on harvest index, grain yield, straw yield, 1,000-grain weight, grain per panicle, spike per square m, length of the spike, weight of spike, no. of filled grains/spike and total dry matter at different growth stages. All other measured growth attributes and yield components were neither affected by irrigation frequency nor by tillage practices. In this analysis, 92.36% of cumulative percentage variance (independent-dependent set relation) was obtained, that means 93.1% of the canonical dependent variable is predictable from the independent canonical variable.

Table 2. Effect of levels of irrigation and tillage-management practices on yield components, yield, harvest index, consumptive-use efficiency of wheat grown during winter (pooled data of 2 years)

Treatment	No. of spikes/m^2	Length of spike (cm)	No. of filled grains/spike	Test weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Consumptive use (mm)	Consumptive-use efficiency (kg/ha-mm)
Levels of irrigation									
I_1	260.0	14.55	27.00	23.07	0.89	2.28	28.04	79.9	11.15
I_2	317.4	15.55	37.88	38.46	2.30	4.29	34.75	179.5	12.81
I_3	341.1	16.50	44.00	39.34	3.04	4.56	39.99	236.2	12.85
I_4	369.5	16.80	46.50	41.41	3.45	5.39	39.03	278.5	12.36
I_5	320.2	15.95	38.50	38.64	2.43	4.35	35.74	187.6	12.95
SEm±	7.20	0.16	0.78	0.54	0.14	0.08	1.47	11.28	0.39
CD (P=0.05)	22.18	0.50	2.42	1.67	0.45	0.27	4.95	34.66	1.22
Tillage management practices									
T_1	302.0	15.56	37.75	35.35	2.17	3.78	36.62	-	-
T_2	341.4	16.18	39.80	37.01	2.67	4.56	36.92	-	-
SEm±	5.19	0.20	0.82	0.49	0.07	0.09	0.88	-	-
CD (P=0.05)	15.65	0.60	NS	2.51	0.23	0.29	NS	-	-

NS, Non-significant

I_1, IW : CPE 0.4; I_2, IW : CPE 0.6; I_3, IW : CPE 0.8; I_4, IW : CPE 1.0; I_5, physiological growth stages; T_1, minimum tillage; T_2, conventional tillage

Table 3. Production economics of wheat as influenced by levels of irrigation and tillage-management practices during winter (mean data of 2 years)

Treatment combination	Production cost (× 10³ ₹/ha)	Gross returns (× 10³ ₹/ha)	Net returns (× 10³ ₹/ha)	Benefit: cost ratio
$I_1 \times T_1$	10.6	17.5	6.8	1.64
$I_1 \times T_2$	11.8	19.1	7.2	1.61
$I_2 \times T_1$	17.5	40.3	22.8	2.30
$I_2 \times T_2$	21.4	51.1	29.6	2.39
$I_3 \times T_1$	20.8	53.8	32.9	2.59
$I_3 \times T_2$	23.9	63.3	39.4	2.65
$I_4 \times T_1$	23.2	59.2	35.9	2.56
$I_4 \times T_2$	27.9	75.3	47.3	2.70
$I_5 \times T_1$	17.7	43.1	25.4	2.39
$I_5 \times T_2$	21.6	54.0	32.4	2.51

Price of wheat grain: ₹18,000/t and straw: ₹1,000/t

I_1, IW : CPE 0.4; I_2, IW : CPE 0.6; I_3, IW : CPE 0.8; I_4, IW : CPE 1.0; I_5, physiological growth stages; T_1, minimum tillage; T_2, conventional tillage

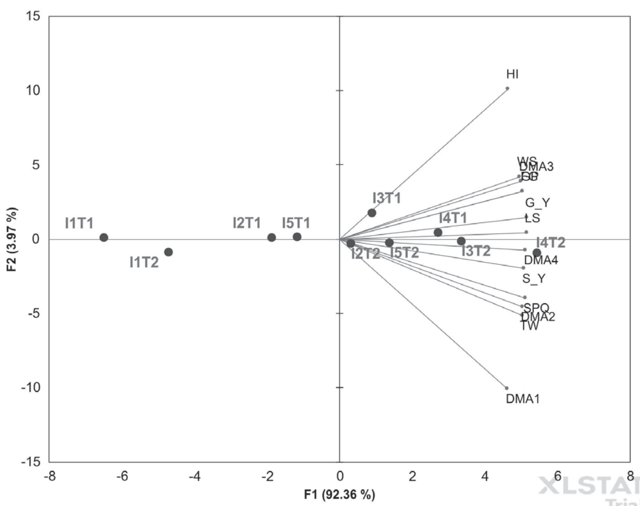

Fig. 1. Bi-plot showing proximity of observed parameters as influenced by main effects of irrigation and tillage (where HI, Harvest Index; G.Y., Grain yield in t/ha; S_Y, Straw yield in t/ha; TW, 1,000-grain weight in g; GP, Grains/panicle; SPQ; Spike/square m; LS, Length of spike; WS, Weight of spike; FG, No. of filled grains/spike; DMA1–4, Total dry matter at different growth stages in g/m² (30, 60, 90, 120 DAS) [I_1, IW : CPE 0.4; I_2, IW : CPE 0.6; I_3, IW : CPE 0.8; I_4, IW : CPE 1.0; I_5, physiological growth stages; T_1, minimum tillage; T_2, conventional tillage]

Consumptive use and consumptive-use efficiency

Irrigations at different frequency brought about moderate changes in consumptive use (CU) and consumptive-use efficiency (CUE) (Table 2). The CU progressively decreased with a reduction in frequency of irrigation. The plants receiving 6 irrigations (based on IW : CPE ratio of 1.0) showed the highest CU. Superiority of this irrigation treatment might be owing to greater availability of moisture in the soil resulting in more ET loss. Besides, the highest CUE was obtained with the crop receiving 5 irrigations (Table 2). However, the decrease in CUE associated with poor irrigation might be due to the relatively higher expense of water by evapotranspiration than the corresponding increase in grain yield.

Production economics

Gross return (₹75.3 × 10³/ha), net return (₹47.3 × 10³/ha) and benefit: cost (B:C) ratio (2.70) were higher when the crop received 6 irrigations under conventional tillage management (Table 3). This was owing to higher grain and straw yields realized under this treatment combination. The next best economic benefit was obtained when the crop irrigated 5 times under conventional tillage practice.

Thus, it could be concluded that wheat cultivar 'UP 262' with 6 irrigations (IW : CPE 1.0) could achieve higher productivity, consumptive-use efficiency (CUE) and economic benefit. Conventional tillage would be beneficial for higher yield attributes and yields of wheat than minimum tillage. Therefore, 6 irrigations under conventional tillage could be more effective in augmenting yield and CUE of wheat in the Gangetic plains of West Bengal.

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