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Research Paper

Growth, yield and economics of drip-irrigated wheat (*Triticum aestivum* L.) as influenced by timing and depth of irrigation water application

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ABSTRACT

An experiment was conducted during 2014–15 and 2015–16 at Ludhiana, Punjab, to study the effect of time and depth of irrigation water on growth, yield and economics of drip-irrigated wheat (*Triticum aestivum* L.). The experiment was conducted in a split-plot design comprising 3 irrigation timings [3 irrigations at crown-root initiation, booting and milking (CBM); 4 irrigations at crown-root initiation, tillering, booting and milking (CTBM) and 5 irrigations at crown-root initiation, tillering, booting, milking and dough (CTBMD)] in main plots and 4 irrigation depth [50 mm at each stage in 2 splits (2 SP); 75 mm at each stage in 3 splits (3SP); 100 mm at each stage in 4 splits (4SP); 75 mm at each stage conventionally (CP)] in subplots, replicated 4 times. Five irrigations at CTBMD resulted in significantly higher growth and yield attributes as well as grain yield than 3 irrigations at CBM; however, it was at par with 4 irrigations at CTBMD. The grain yield reduced by 12.9% and 13.6% in CBM than CTBMD during 2014–15 and 2015–16, respectively. Four splits of 100 mm irrigation depth resulted in significantly higher growth and yield attributes as well as grain yield than 2 splits and CP. Grain yield reduced by 10.7 and 10.2% in CP than 4 SP during 2014–15 and 2015–16, respectively. Though grain yield in 2 SP and CP was similar, there was water saving of 33.3% in 2 SP as compared to CP. The highest net returns (35.8 × 10³ ₹/ha) and benefit: cost ratio (1.90) were recorded with application of 5 irrigations at CTBMD. Similarly, the highest net returns (34.7 × 10³ ₹/ha) were recorded with water application in 4 irrigation splits (4SP), but benefit: cost ratio (1.89) was the highest with 3 irrigation splits (3 SP).

Key words: Drip irrigation, Economics, Growth, Irrigation depth, Irrigation timing, Yield

Limited irrigation is a practice in which the soil-water deficit is controlled at certain stages of crop growth, it has become more important in recent years in places where water resources are limited. The impact of soil-moisture deficit on crop yield depends on the particular phenological stage of the crop, and the most sensitive stage can show region-by-region variations (Singh *et al.,* 1991). Under limited irrigation, reduction in grain yield due to restricted water availability depends on the degree, duration and timing of the imposed soil-moisture deficit. Because these differences relate to regional variability in environment and agronomic practices, information specific to the region is needed for developing and refining limited irrigation schemes (Kang *et al*., 2002).

The wheat crop is conventionally irrigated at 4–5 growth stages with 7.5 cm of irrigation water, resulting in water stress in some stages while wastage of water other stages. In future, availability of freshwater will be reduced severely, jeopardizing the future food security of the country (Pradhan *et al*., 2014). Hence, there is an urgent need to increase crop water productivity of wheat. Due to rising costs of irrigation pumping, inadequate irrigation system capacities and limited irrigation supplies, deliberate application of less water to wheat is becoming a common practice (Panda *et al*., 2003).

The climate of Punjab is semi-arid, with average annual rainfall of 700 mm. Rainfall distribution is uneven, with more than 70% concentrated during July–September. The average rainfall of wheat-growing season is 115 mm. The distribution of rainfall is poor with respect to crop water need, compelling the farmers to pump groundwater to al-

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leviate the evapotranspiration (ET) deficit. The indiscriminate pumping of groundwater has led to fast depletion of aquifers in 80% area of Punjab at an alarming rate of 0.4 m/year (Brar *et al*., 2012). This has led to an urgent need for more efficient irrigation saving strategies and improving water-use efficiency for sustainable agriculture in this area. This can be possible only by efficient water-management practices by adopting advanced technology of irrigation like drip irrigation. Adoption of micro-irrigation might help in raising the irrigated area, productivity of crops and water-use efficiency (Kumar *et al*., 2015). A number of previous studies have shown considerable advantages of drip irrigation compared with other irrigation methods (Singh *et al*., 2003). Although its benefits are numerous, drip irrigation in India has been applied mainly to fruit trees, flowers and vegetables. At present, with the increasing shortage of water resources, drip irrigation is also slowly being applied on sparse row crops, such as cotton and sugarcane. However, application on dense field row crops such as wheat is not common in India due to high installation cost (Malve *et al*., 2017).

When the available water supply is limited, water deficits become unavoidable during some periods of crop growth. Scheduling of irrigation timings then becomes more complex, because irrigation decisions have to be based not only on the relationships between grain yield, crop-growing phase and crop water use, but also on the water availability. This requires evaluation of alternative irrigation schedules to select the one that maximizes crop yield and water use efficiency for a given level of water supply. Several studies have been conducted in Punjab to investigate the irrigation water requirements based on ET (Timsina *et al*., 2008), irrigation water/pan evaporation (Arora *et al*., 2007), soil-water deficit and critical growth stage (Timsina *et al*., 2008). Timsina *et al*. (2008) reported the highest grain yield with irrigation at 4 growth stages, i.e. crown-root initiation (CRI), booting, flowering and grain filling, whereas the lowest grain yield with 1 irrigation at grain filling. All these studies were carried under flood irrigated conditions; however adequate information is lacking with respect to timing and depth of irrigation water application under drip-irrigation conditions. Therefore, an experiment was conducted to study the effect of limited irrigation on growth and yield of drip-irrigated wheat.

MATERIALS AND METHODS

A field experiment was conducted at the Punjab Agricultural University (PAU), Ludhiana (30' 54A'' N, 75' 48A'' E, 247 m above mean sea level) during 2 wheat-growing seasons (2014–15 and 2015–16). The climate of the area is semi-arid, with average annual rainfall of 755 mm (75–80% of which is received in July–September). The weather data were obtained from meteorological observatory of PAU, Ludhiana, located 200 m from the experimental site. The mean maximum and minimum temperature and relative humidity during 2014–15 growing season were 22.1°C, 10.3°C and 77%, respectively and during 2015–16, these were 24.0°C, 10.7°C and 68%. The total sunshine hours and reference ET were higher in 2015–16 (947 h and 367 mm) than 2014–15 (917 h and 350 mm respectively). Profound variability in rainfall amount and distribution was observed for the 2 growing seasons (193.8 mm during 2014–15 and 70.6 mm during 2015–16). The pan evaporation and reference evaporation were higher by 15% and 5%, respectively, during 2015–16 as compared to 2014–15, owing to higher temperature during the second year.

The soil of the experimental field was alluvial sandy loam (Typic Ustochrept). The soil samples were taken from 0 to 1 m after every 10-cm interval in 2014 and the field capacity and bulk density were determined. The mean field capacity was 25% (V/V) and the bulk density was 1.6 Mg/m^3 in the 0–1 m soil profile. The detailed information on Materials and Methods is discussed by Dar *et al.* (2017).

The experiment was conducted in a split-plot design, keeping 3 irrigation timings [3 irrigations at crown-root initiation, booting and milking (CBM); 4 irrigations at crown-root initiation, tillering, booting and milking (CTBM) and 5 irrigations at crown-root initiation, tillering, booting, milking and dough (CTBMD)] in main plots, and 4 irrigation depth [50 mm at each stage in 2 splits (2 SP); 75 mm at each stage in 3 splits (3 SP); 100 mm at each stage in 4 splits (4 SP); 75 mm at each stage conventionally (CP)] in subplots, replicated 4 times. The first 3 irrigation treatments were applied using drip irrigation and the fourth irrigation treatment was flood irrigated. The amount of irrigation per split was 25 and 75 mm in drip and flood irrigated treatments, respectively. The details of treatments adopted and irrigation amount applied is given in Table 1. The date of application of irrigation in different treatments for both the years is given in Table 2. A buffer area of 1 m was maintained between the plots to prevent the inter-plot flow of water. Application of fertilizer was same for all the treatments i.e. 125 kg N/ha applied in 2 splits, 60 kg P_2O_5/ha and 30 kg K_2O/ha, applied basal as urea, diammonium phosphate and muriate of potash, respectively. Other crop-management practices were as per the local package of practices of the PAU (Package of Practices for Crops of Punjab, 2014–15)

A surface drip irrigation system was installed within 5–8 days of sowing; and managed to ensure uniform application. Polyvinyl chloride (PVC) pipeline was installed adjacent to the plots with an outlet (plot inlet) at the centre of each plot. Each plot inlet had a water-tight butterfly valve to ensure that only 1 plot in each replication is irrigated at a time. The pressure-compensating drippers with a flow rate of 2 L/hr were spaced 0.2 m apart on the laterals. Each lateral was placed between the 2 crop rows, spaced 0.2 m apart. For each treatment, irrigation water was added until the requisite amount is delivered. The irrigation water to be added was calculated as:

$$\text{Irrigation water (L/plot)} = \frac{\text{Irrigation to be applied (mm)}}{100} \times \text{Soil depth (cm)} \times \text{Plot area (m}^2)$$

Cost of cultivation, net monetary returns and benefit: cost ratios were calculated on the basis of prevailing market price of inputs and outputs.

Statistical Analysis

Analysis of variance was carried out using Proc GLM procedure of SAS version 9.4 (SAS Institute, Inc., Cary, NC, USA) and significant mean differences were compared using Fisher's protected least significant difference (LSD) test at P=0.05.

RESULTS AND DISCUSSION

Growth attributes

Plant height: The pooled data revealed that, plant height at 80, 110 days after sowing (DAS) and at harvesting was significantly influenced by timing of irrigation application and the amount of irrigation water applied (Table 3). However, non-significant difference was found at 50 DAS. Plant height was significantly higher with 5 irrigations applied at crown-root initiation, tillering booting, milking and dough stage (CTBMD) than 3 irrigations applied at crown root initiation, booting and milking stage (CBM), but at par with the plant height recorded with 4 irrigations applied at crown-root initiation, tillering, booting and milking stage (CTBM). The percentage reduction in plant height from CTBMD to CBM was 2.9, 11.3, 8.4 and 8.6% at 50, 80, 110 DAS and at harvesting.

Plant height was significantly influenced by the amount of irrigation applied. The plant height was significantly higher with 4 SP and as compared to 2 SP and CP at 80, 110 DAS and at harvesting. The percentage reduction in plant height from 4 SP to 2 SP was 4.4, 6.3, 5.3 and 4.5% at 50, 80, 110 DAS and at harvesting. The reduction in plant height may be due to reduction in photosynthetic rate and cell-division in response to water stress. Similar findings were reported by Shirazi *et al*. (2014) and Pawar and Dingre (2014).

Dry-matter accumulation: Dry matter accumulation (DMA) at 80, 110 DAS and at harvesting was significantly influenced by timing of irrigation application and the amount of irrigation water applied (Table 3). However, non-significant difference was found at 50 DAS. The DMA was significantly higher with 5 irrigations applied at CTBMD as compared to 3 irrigations applied at CBM, but at par with DMA recorded with 4 irrigations applied at CTBM at all stages except at harvesting stage. The percentage reduction in DMA from CTBMD to CBM was 3.8, 23.9, 12.3 and 10.5% at 50, 80, 110 DAS and at harvest.

The DMA was significantly higher with 4 SP and 3 SP than 2 SP and CP at 80, 110 DAS and at harvesting. The reduction in DMA from 4 SP to 2 SP was 5.1, 13.4, 7.1 and 6.5% at 50, 80, 110 DAS and at harvesting. The higher DMA in frequent irrigation regimes may be due to higher plant height (Table 3), leaf-area index (LAI) (Table 4) and tiller density (Table 4). Further, it is well known that reduction in soil moisture limits the cellular expansion and elongation, causes stomatal closure and raises the leaf temperature and reduces the net assimilation rate of photosynthates. Mehta *et al*. (2010) and Ihsan *et al*. (2016) also re-

Table 1. Detail of treatments applied during wheat crop-growing season of 2014–15 and 2015–16

Growth stages	Irrigation splits	No. of irrigations	Amount per application (mm)	Abbreviation
CBM (CRI, booting and milking)	2	6	25	CBM 2 SP
	3	9	25	CBM 3 SP
	4	12	25	CBM 4 SP
	0	3	75	CBMCP
CTBM (CRI, tillering, booting and milking)	2	8	25	CTBM 2 SP
	3	12	25	CTBM 3 SP
	4	16	25	CTBM 4 SP
	0	4	75	CTBMCP
CTBMD (CRI, tillering, booting, milking and dough)	2	10	25	CTBMD 2 SP
	3	15	25	CTBMD 3 SP
	4	20	25	CTBMD 4 SP
	0	5	75	CTBMDCP

ported decrease in DMA with increase in moisture deficit

Leaf-area index: The LAI at 65, 80, 95 and 110 DAS was significantly influenced by timing of irrigation application and the amount of irrigation water applied. However, non-significant difference was found at 50 DAS for timing of irrigation application (Table 4). The LAI was significantly higher with 5 irrigations applied at CTBMD than all the other treatments.

The leaf-area index was significantly influenced by the amount of irrigation applied. The LAI was significantly higher with 4 SP than 2 SP and CP at 65, 80, 95 and 110 DAS. The higher LAI in frequent irrigation regimes may be due to higher plant height (Table 3) and number of tillers/m^2 (Table 4). Further, it is well known that reduction in soil moisture limits the cellular expansion and elongation and causes decline in leaf elongation. Asif *et al*. (2010) and Ihsan *et al*. (2016) also reported decrease in LAI with increase in moisture deficit.

Number of tillers: The number of tillers at 80 and 110 DAS was significantly influenced by timing of irrigation application and the amount of irrigation water applied (Table 4). The number of tillers increased up to 80 DAS and decreased towards maturity, mainly due to competition for limited resources. The number of tillers was significantly higher with 5 irrigations applied at CTBMD than 3 irrigations applied at CBM, but at par with number of tillers recorded with 4 irrigations applied at CTBM.

The number of tillers was significantly higher with 4 SP than 2 SP and CP at 80 and 110 DAS. However, 3 SP and 4 SP were statistically at par. The maximum number of tillers was in 4 SP and the minimum in 2 SP or CP during both the years. The number of tillers increased up to 80 DAS and decreased thereafter towards harvesting of the crop. The reduction in number of tillers with increase in moisture deficit may be attributed to less availability of moisture for tiller development. Asif *et al*. (2010) and Mehta *et al*. (2010) also reported decrease in number of tillers with increase in moisture deficit.

Table 2. Details of irrigation applied during wheat crop-growing season of 2014–15 and 2015–16

Treatment	Dates of irrigation
2014–15	
CBM 2 SP	30 Nov, 03 Dec, 28 Jan, 01 Feb, 11 Mar and 14 Mar
CBM 3 SP	30 Nov, 03 Dec, 06 Dec, 28 Jan, 01 Feb, 04 Feb, 11 Mar, 14 Mar and 17 Mar
CBM 4 SP	30 Nov, 03 Dec, 06 Dec, 09 Dec, 28 Jan, 01 Feb, 04 Feb, 7 Feb, 11 Mar, 14 Mar, 17 Mar and 20 Mar
CBMCP	04 Dec, 03 Feb and 12 Mar
CTBM 2 SP	30 Nov, 03 Dec, 01 Jan, 04 Jan, 28 Jan, 01 Feb, 11 Mar and 14 Mar
CTBM 3 SP	30 Nov, 03 Dec, 06 Dec, 01 Jan, 04 Jan , 07 Jan, 28 Jan, 01 Feb, 04 Feb, 11 Mar, 14 Mar and 17 Mar
CTBM 4 SP	30 Nov, 03 Dec, 06 Dec, 09 Dec, 01 Jan, 04 Jan , 07 Jan, 10 Jan, 28 Jan, 01 Feb, 04 Feb, 7 Feb, 11 Mar, 14 Mar, 17 Mar and 20 Mar
CTBMCP	04 Dec, 03 Jan, 03 Feb and 12 Mar
CTBMD 2 SP	30 Nov, 03 Dec, 01 Jan, 04 Jan, 28 Jan, 01 Feb, 11 Mar, 14 Mar, 29 Mar and 01 Apr
CTBMD 3 SP	30 Nov, 03 Dec, 06 Dec, 01 Jan, 04 Jan , 07 Jan, 28 Jan, 01 Feb, 04 Feb, 11 Mar, 14 Mar, 17 Mar, 29 Mar, 01 Apr and 04 Apr
CTBMD 4 SP	30 Nov, 03 Dec, 06 Dec, 09 Dec, 01 Jan, 04 Jan , 7 Jan, 10 Jan, 28 Jan, 01 Feb, 04 Feb, 7 Feb, 11 Mar, 14 Mar, 17 Mar, 20 Mar, 29 Mar, 01 Apr, 04 Apr and 07 Apr
CTBMDCP	04 Dec, 03 Jan, 03 Feb, 12 Mar and 31 Mar
2015–16	
CBM 2 SP	29 Nov, 02 Dec, 26 Jan, 29 Jan, 05 Mar and 08 Mar
CBM 3 SP	29 Nov, 02 Dec, 05 Dec, 26 Jan, 29 Jan, 01 Feb, 05 Mar, 08 Mar and 11 Mar
CBM 4 SP	29 Nov, 02 Dec, 05 Dec, 08 Dec, 26 Jan, 29 Jan, 01 Feb, 04 Feb, 05 Mar, 08 Mar, 11 Mar and 14 Mar
CBMCP	03 Dec, 30 Jan and 06 Mar
CTBM 2 SP	29 Nov, 02 Dec, 30 Dec, 02 Jan, 26 Jan, 29 Jan, 05 Mar and 08 Mar
CTBM 3 SP	29 Nov, 02 Dec, 05 Dec, 30 Dec, 02 Jan, 05 Jan, 26 Jan, 29 Jan, 01 Feb, 05 Mar, 08 Mar and 11 Mar
CTBM 4 SP	29 Nov, 02 Dec, 05 Dec, 08 Dec, 30 Dec, 02 Jan, 05 Jan, 08 Jan, 26 Jan, 29 Jan, 01 Feb, 04 Feb, 05 Mar, 08 Mar, 11 Mar and 14 Mar
CTBMCP	03 Dec, 03 Jan, 30 Jan and 06 Mar
CTBMD 2 SP	29 Nov, 02 Dec, 30 Dec, 02 Jan, 26 Jan, 29 Jan, 05 Mar, 08 Mar, 27 Mar and 29 Mar
CTBMD 3 SP	29 Nov, 02 Dec, 05 Dec, 30 Dec, 02 Jan, 05 Jan, 26 Jan, 29 Jan, 01 Feb, 05 Mar, 08 Mar, 11 Mar, 27 Mar, 29 Mar and 01 Apr
CTBMD 4 SP	29 Nov, 02 Dec, 05 Dec, 08 Dec, 30 Dec, 02 Jan, 05 Jan, 08 Jan, 26 Jan, 29 Jan, 01 Feb, 04 Feb, 05 Mar, 08 Mar, 11 Mar, 14 Mar, 27 Mar, 29 Mar, 01 Apr and 04 Apr
CTBMDCP	03 Dec, 03 Jan, 30 Jan, 06 Mar and 30 Mar

Yield attributes and yield

Effective tillers: The number of effective tillers has a direct relation with yield. Higher the number of effective tillers more will be the yield of crop. Number of effective tillers was significantly influenced by timing of irrigation application and the amount of irrigation water applied (Table 5). Significantly higher number of effective tillers/m^2 was recorded in CTBMD than CBM and CTBM. The percentage reduction in number of effective tillers from CTBMD to CBM was 11.4.

Number of effective tillers was significantly influenced by the amount of irrigation applied. The number of effective tillers was significantly higher with 4 SP than 2 SP and CP, but at par with 3 SP. The reduction in number of effective tillers from 4 SP to CP was 7.9%. The effective tillers were higher with frequent irrigation treatments may be owing to better moisture availability throughout the season and higher number of total tillers (Table 4). Khan *et al.* (2007) and Asif *et al.* (2010) also reported reduction in effective tillers with increase in water deficit.

Ear length and grains/ear: Ear length and grains/ear were significantly influenced by timing of irrigation application and the amount of irrigation water applied (Table 5). The ear length recorded in CTBMD was significantly higher than that recorded with CBM and CTBM. The reduction in ear length was in turn responsible for reduced number of grains/ear. Corresponding to ear length, significantly higher number of grains/ear were recorded in CTBMD than CBM and CTBM. The percentage decrease in ear length from CTBMD to CBM was 14.2. While percentage decrease in grains/ear from CTBMD to CBM was 13.8%.

Table 3. Effect of growth stage-based irrigation schedule on plant height and dry-matter accumulation of wheat (pooled data of 2 years)

Treatment	Plant height (cm)				Dry-matter accumulation (g/m^2)			
	50 DAS	80 DAS	110 DAS	Harvesting	50 DAS	80 DAS	110 DAS	Harvesting
Growth stage								
CBM	37.2	66.5	91.8	93.3	108.5	318.4	627.1	946.9
CTBM	37.9	73.1	97.4	99.8	111.2	411.4	706.7	1026.3
CTBMD	38.3	75.0	100.2	102.1	112.8	418.2	714.9	1058.5
SEm±	0.41	0.66	0.71	0.83	1.57	5.47	7.93	5.51
CD (P=0.05)	NS	2.01	2.22	2.52	NS	16.80	24.31	16.81
Irrigation schedule								
2 SP	37.0	69.4	94.5	96.4	108.4	356.5	659.5	978.0
3 SP	38.2	73.4	97.8	99.7	112.4	400.5	700.4	1036.2
4 SP	38.7	74.1	99.8	101.0	114.2	411.6	709.8	1045.9
CP	37.4	69.2	93.8	96.1	108.5	362.1	661.8	982.2
SEm±	0.63	0.69	0.74	0.71	1.99	6.37	7.85	5.57
CD (P=0.05)	NS	1.96	2.10	2.01	NS	18.10	22.24	15.80

Details of growth stage and irrigation schedule are given under Materials and Methods; DAS, days after sowing

Table 4. Effect of growth stage based irrigation schedule on leaf area index and number of tillers of wheat (pooled data of 2 years)

Treatment	Leaf-area index				Number of tillers/m^2			
	50 DAS	65 DAS	80 DAS	95 DAS	110 DAS	50 DAS	80 DAS	110 DAS
Growth stage								
CBM	1.45	2.01	2.85	3.65	3.40	365.9	408.3	356.6
CTBM	1.47	2.73	3.75	4.34	4.11	368.1	439.8	378.2
CTBMD	1.52	2.89	3.91	4.61	4.35	369.8	444.2	385.2
SEm±	0.02	0.03	0.04	0.05	0.05	5.4	6.4	2.7
CD (P=0.05)	NS	0.11	0.12	0.16	0.16	NS	20.6	10.8
Irrigation schedule								
2 SP	1.42	2.38	3.21	3.87	3.55	364.9	418.5	360.8
3 SP	1.51	2.67	3.69	4.44	4.17	369.0	440.1	383.1
4 SP	1.56	2.76	3.83	4.70	4.50	371.7	444.2	388.3
CP	1.44	2.36	3.32	3.79	3.61	366.2	420.4	361.2
SEm±	0.05	0.04	0.05	0.06	0.05	4.3	2.5	2.6
CD (P=0.05)	NS	0.12	0.15	0.16	0.16	NS	10.7	10.9

Details of growth stage and irrigation schedule are given under Materials and Methods; DAS, days after sowing

The ear length and grains/ear decreased significantly with the decrease in the amount of irrigation water applied. Significantly higher ear length was recorded in 3 SP and 4 SP than 2 SP and CP. The decrease in ear length was responsible for reduction in number of grains/ear. Significantly higher number of grains/ear were recorded in 3 SP and 4 SP than 2 SP and CP. Corresponding to the percentage decrease in ear length by 8.6% from 4 SP to CP, the percentage decrease in grains/ear was also 8.6. Similar results were reported Khan *et al*. (2007) and Asif *et al*. (2010).

1,000-grain weight: The 1,000-grain weight was significantly influenced by timing of irrigation application and the amount of irrigation water applied (Table 5). The 1,000-grain weight in CTBMD was significantly higher than CBM and CTBM. The percentage reduction in 1,000-grain weight between CTBMD and CBM was 10.9.

The 1,000-grain weight decreased significantly with the decrease in the amount of irrigation water applied. The maximum 1,000-grain weight was in 4 SP, being significantly higher than 2 SP, 3 SP and CP. The reduction in 1,000-grain weight between 4 SP and CP was 5.9%. The 1,000-grain weight was reduced in deficit-irrigation treatments due to shrivelling of grains. Reduction in 1,000-grain weight with the increase in water deficit was noted by Pierre *et al*. (2007) and Jiang *et al*. (2013).

Biological yield: The biological yield was significantly influenced by timing of irrigation application and the amount of irrigation water applied (Table 5). The biological yield in CTBMD was significantly higher than CTBM and CBM. The reduction in biological yield between CTBMD and CBM was 13.2%.

The biological yield decreased significantly with the decrease in the amount of irrigation water applied. Significantly higher biological yield was recorded in 4 SP than 2 SP and CP. The reduction in biological yield between 4 SP and 2 SP was 7.6%. The biological yield was reduced under deficit-irrigation treatments due to reduction in plant height (Table 3), DMA (Table 3), LAI (Table 4) and tiller density (Table 4). Reduction in biological yield with the increase in water deficit was observed by Khan *et al*. (2007) and Jiang *et al*. (2013).

Harvest index: Harvest index was not influenced by timing of irrigation and the amount of irrigation water applied at each stage.

Grain yield: The wheat grain yield was significantly influenced by timing of irrigation application and the amount of irrigation water applied (Table 5). The pooled grain yield was significantly higher in CTBMD than CBM and CTBM. The grain yield decreased by 13.2%, with change in irrigation schedule from CTBMD to CBM and 6.2% with change in schedule from CTBMD to CTBM. The decline in grain yield with change in irrigation schedule was due to less number of irrigations applied in CBM (3) as compared to CTBM (4) and CTBMD (5), which imposed the drought conditions on the plant. The result was reduction in grain yield due to shortening of the duration of each developmental phase and forced maturity, reduction in the growth and yield attributes like plant height (Table 3), leaf-area index (Table 4), DMA (Table 3), effective tillers, grains/ear and 1,000-grain weight (Table 5). Ali *et al*. (2005) also reported the highest grain yield from fully irrigated treatments (5 irrigations) applied at crown root, booting, heading, anthesis and grain development and minimum with application of 2 irrigations at crown-root and booting stage.

Table 5. Effect of growth stage-based irrigation schedule on yield attributes and yields of wheat (pooled data of 2 years)

Treatment	Effective tillers (Nos./m^2)	Ear length (cm)	Grains/ear	1,000-grain weight (g)	Grain yield (t/ha)	Biological yield (t/ha)	Harvest index (%)
Growth stage							
CBM	284.0	9.1	38.2	38.5	4.61	10.71	43.1
CTBM	309.2	10.1	42.3	41.2	4.98	11.54	43.2
CTBMD	320.5	10.6	44.3	43.2	5.31	12.34	43.2
SEm±	3.5	0.2	0.6	0.3	0.07	0.08	0.7
CD (P=0.05)	10.2	0.4	1.7	1.2	0.23	0.29	NS
Irrigation schedule							
2 SP	292.9	9.6	40.2	40.1	4.77	11.12	43.0
3 SP	311.2	10.2	43.1	42.1	5.11	11.81	43.5
4 SP	318.1	10.5	44.0	42.6	5.27	12.04	43.9
CP	296.0	9.5	39.2	39.3	4.72	11.16	42.3
SEm±	3.7	0.12	0.87	0.39	0.03	0.06	0.5
CD (P=0.05)	10.7	0.36	0.90	1.30	0.11	0.25	NS

Details of growth stage and irrigation schedule are given under Materials and Methods; DAS, days after sowing

Table 6. Effect of growth stage based irrigation schedule on economics of wheat (pooled data of 2 years)

Treatment	Cost of cultivation (× 10³₹/ha)	Gross returns (× 10³ ₹/ha)	Net returns (×10³₹/ha)	Benefit: cost ratio
Growth stage				
CBM	37.0	65.6	28.6	1.77
CTBM	38.5	71.0	32.6	1.85
CTBMD	40.0	75.7	35.8	1.90
Irrigation schedule				
2 SP	36.5	67.9	31.4	1.86
3 SP	38.5	72.8	34.4	1.89
4 SP	40.5	75.2	34.7	1.86
CP	38.5	67.3	28.8	1.75

Details of growth stage and irrigation schedule are given under Materials and Methods; DAS, days after sowing

The grain yield varied with the irrigation treatment imposed. It was significantly higher in 4 SP than 3 SP, 2 SP and CP. However, 2 SP and CP were statistically at par with each other. The highest grain yield of 5.27 t/ha (Table 5) was obtained when 10 cm irrigation was applied in 4 splits (4 SP). The lowest grain yield of 4.72 t/ha was recorded in the conventional irrigation practice (CP). The grain yield decreased by 10.4%, with irrigation applied at CP as compared to 4 SP. The grain yield under deficit-irrigation treatments was lower due to shortening of the duration of each developmental phase and forced maturity, reduction in the growth and yield attributes like plant height, leaf-area index, DMA, effective tillers, grains/ear and 1,000-grain weight. Asch *et al*. (2005) and Farooq *et al*. (2009) reported that yield reduction under moisture stress may be due to physiological limitations like accelerated leaf senescence, damage to photosynthetic machinery, shortening of growth cycle, reduced carbon fixation and assimilate translocation or reduced grain set and development.

Net returns and benefit: cost ratio: The highest net income (35.8 × 10³₹/ha) and benefit: cost ratio (1.90) were recorded with application of 5 irrigations at CTBMD as compared to the other irrigation timings (Table 6). This may be attributed to higher yield in CTBMD. There was an increase in net income from 28.8 × 10³₹ /ha to 34.7 × 10³ ₹/ha and benefit: cost ratio from 1.75 to 1.86 with change in schedule from CP to 4 SP. The higher economic returns and benefit: cost ratio at higher irrigation splits were owing to higher yield in 4 SP than the other irrigation splits.

Thus, it can be concluded that 5 irrigations at CTBMD recorded significantly higher growth and yield attributes as well as grain yield than 3 irrigations at CBM. Grain yield reduced by 13.2% in CBM than CTBMD. Four splits of 100 mm irrigation resulted in significantly higher growth and yield attributes as well as grain yield than 2 splits and CP. Grain yield reduced by 10.2% in CP than 4 SP. Though grain yield in 2 SP and CP was similar, there was water saving of 33.3% in 2 SP as compared to CP. The highest net returns (35.8 × 10³ ₹/ha) and benefit: cost ratio (1.90) were recorded with application of 5 irrigations at CTBMD. Similarly, the highest net return (34.7 × 10³₹ /ha) was recorded with application of 4 irrigation splits (4 SP); however benefit: cost ratio (1.89) was the highest with 3 irrigation splits (3 SP).

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