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Research Paper

Influence of sowing dates and irrigation schedules on growth and yield of drip irrigated wheat (*Triticum aestivum*) under semi-arid conditions of Punjab

EAJAZ AHMAD DAR[1], AJMER SINGH BRAR[2], TODARMAL POONIA[3] AND MOHAMMAD AMIN BHAT[4]

Punjab Agricultural University, Ludhiana, Punjab 141 004

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ABSTRACT

A study was conducted during the winter (*rabi*) seasons of 2014–16 at Ludhiana, Punjab, to evaluate the influence of sowing time and drip-irrigation schedules on growth and yield of wheat (*Triticum aestivum* L.). The experiment was conducted in a split-plot design consisting of 4 sowing dates (D_1, 25 October; D_2, 10 November, D_3, 25 November and D_4, 10 December) in main plots and 5 irrigation treatments in subplots, replicated thrice. Four irrigation treatments based on soil water deficit from field capacity, were: 15% depletion (FC_{15}); 25% depletion (FC_{25}); 35% depletion (FC_{35}); and 45% depletion (FC_{45}) from field capacity (FC) and the fifth irrigation treatment was taken as conventional practice (CP). The results revealed that plant height, dry-matter accumulation, leaf-area index and number of tillers decreased significantly with delay in sowing from D_1 to D_4 at all stages of plant growth. The grain and biological yields were significantly higher in D_1 than the other sowing dates. The pooled grain and biological yields decreased by 9 and 8% from D_1 to D_2, 18 and 17% from D_1 to D_3 and 29 and 27% from D_1 to D_4 respectively. Significantly higher values of growth attributes and yield were recorded with application of irrigation at FC_{15} than the other irrigation schedules. The pooled grain yield in FC_{15} treatment was higher by 9, 25, 42 and 10% than FC_{25}, FC_{35}, FC_{45} and CP respectively. Thus, irrigating the crop at FC_{15} using drip irrigation saved 50% irrigation water as compared to the conventional practice of irrigating the crop at 4–5 week interval with 75 mm of water.

Key words: Drip irrigation, Irrigation schedule, Moisture regimes, Punjab sowing, Semi-arid, Wheat

Wheat is an important cereal crop for the food security of South Asia and is the 2nd major staple food crop after rice. It accounts for nearly 30% of global cereal production covering an area of 218.5 million ha with an average productivity of 3.26 tonnes/ha (FAO, 2014). At present, about 65% of the wheat production is used for food, 17% for feed, and 12% in industrial applications, including biofuels (FAO, 2014). In India, wheat production was recorded as 98.4 million tonnes (mt) from an area of 30.6 million ha in 2016–17 (GoI, 2017). Punjab, known as the bread basket of India, has 3.5 million ha under wheat cultivation with production and productivity of 16.4 mt and 4.70 t/ha respectively (GoI, 2017). The crop is sensitive to variation in environmental conditions for better emergence, development and anthesis and is highly vulnerable to high temperature that affects the partitioning of biomass from vegetative to reproductive organs (Mukherjee, 2012). The decision of appropriate sowing date is a vital management practice to enhance the grain yield of wheat. Numerous studies have revealed yield advantage with early sowing and yield reduction under delayed sowing after the ideal time (Mukherjee, 2012; Ram *et al*., 2012; Meena *et al.,* 2015).

In Punjab, average total rainfall is 115 mm during the wheat-growing season. The rainfall is poorly distributed relative to the crop water need resulting in heavy dependence on irrigation for optimal yield realization. For this reason, the farmers pump groundwater to irrigate wheat to alleviate 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). Therefore, it is need of the hour to check the decreasing rate of groundwater table by reducing the amount of irrigation water without facing any yield penalty. This implies the need for refining irrigation scheduling from plentiful to limited irrigation vis-a-vis evaluating novel precise irrigation methods.

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[1]**Corresponding author's Email:** darajaz9@gmail.com
[1,3]Ph.D. Scholar, [2]Senior Agronomist, Department of Agronomy; Punjab Agricultural University, Ludhiana, Punjab 141 004; [4]Ph.D. Scholar, Department of Soil Science, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana 125 004

Number of studies in Punjab has examined the irrigation water requirements based on ET and irrigation water: pan evaporation ratio, but very few are based on soil-moisture deficit (SWD) (Meena *et al.,* 2015). Irrigation scheduling at 25% maximum allowable deletion (MAD) of available soil moisture (ASM) results in significantly higher growth and yield as compared to 50 and 75% MAD of ASM (Meena *et al.* 2015). Panda *et al.* (2003) reported that, grain yield did not decrease until a depletion of 15–45% of available soil water (ASW) and severe reduction in grain yield occurs when irrigation is applied at 60–75% depletion of ASW. However, all these studies were carried out under flood-irrigated conditions but a meager literature is available on drip irrigation conditions. However, number of previous studies have shown considerable advantages of drip irrigation compared with other irrigation methods (Singh *et al*. 2003).

Keeping all these factors in view, an experiment was conducted to standardize the soil-moisture depletion based drip-irrigation schedule for wheat under different sowing dates.

MATERIALS AND METHODS

A field experiment was conducted during wheat-growing seasons of 2014–15 and 2015–16 at the Punjab Agricultural University, Ludhiana (30° 54" N, 75° 48" E, 247 m above sea-level). The climate of the area is semi-arid, with average annual rainfall of 700 mm (75–80% of which is received in July–September) and average wheat season rainfall of 115 mm, daily minimum temperature of 0–4 °C in January and daily maximum temperature of 40–45°C in May. The mean maximum and minimum temperature during 2014–15 growing season were 22.3°C and 10.4°C for 25 October sowing (D_1); 21.7°C and 10°C for 10 November sowing (D_2); 21.5°C and 10.3°C for 25 November sowing (D_3); and 21.5°C and 10.9°C for 10 December sowing (D_4) respectively. The mean relative humidity varied from 76 to 79% during 2014–15 and 66–68% during 2015–16. During 2015–16, the mean maximum and minimum temperatures were 24°C and 10.9°C for D_1; 23.9°C and 10.7°C for D_2; 24.1°C and 10.9°C for D_3; and 24.3°C and 11.1°C for D_4 respectively. The rainfall varied widely between the 2 growing seasons (196.3–219.4 mm during 2014–15 and 70.1–70.6 mm during 2015–16). The soil was alluvial sandy loam (Typic Ustochrept) with 55–59% sand, 23–26% silt and 17–19% clay in different soil layers. Soil samples were taken every 10 cm from 0 to 1 m in 2014 and the bulk density and field capacity were determined. The mean bulk density was 1.6 Mg/m^3 and mean field capacity was 25% (v/v) in the 0–1 m soil profile. The detailed information on Materials and Methods is discussed elsewhere by Dar *et al.* (2017).

The experiment on wheat variety 'HD 2967' was conducted in a split-plot design, consisting of 4 sowing dates (D_1, 25 October; D_2, 10 November; D_3, 25 November and D_4, 10 December) in main plots and 5 irrigation treatments in subplots, replicated 3 times. Four irrigation treatments, based on soil water deficit from field capacity, were: 15% depletion (FC_{15}); 25% depletion (FC_{25}); 35% depletion (FC_{35}); and 45% depletion (FC_{45}) from field capacity (FC) of the top 0–40 cm layer, and the fifth irrigation treatment was taken as conventional practice (conventional practice here refers to irrigating the crop with 75 mm water after every 4–5 weeks, irrespective of the crop-growth stage or soil-moisture depletion). The amount of irrigation per application was 15 mm, 25 mm, 35 mm, 45 mm and 75 mm, respectively, for the 5 irrigation treatments. The details of treatments adopted and irrigation amount applied is given in Table 1. The method of irrigation for the first 4 treatments was drip irrigation, while the fifth was flood irrigated. 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, 60 kg P_2O_5/ha and 30 kg K_2O/ha, applied as urea, diammonium phosphate and muriate of potash respectively. Whole dose of phosphorus and potassium, and half dose of N were applied at the time of sowing by broadcasting. The remaining half dose of N was top-dressed 22–28 days after sowing (DAS). Other crop-management practices were as per the local package of practices of the PAU (Package of practices for crops of Punjab, 2014–15). The harvesting of wheat was done manually on 10th (168 DAS), 13th (154 DAS), 16th (143 DAS) and 20th April (132 DAS) during 2015 for D_1, D_2, D_3 and D_4 respectively. During 2016, the harvesting was done, respectively, on 8th (167 DAS), 13th (156 DAS), 18th (146 DAS) and 19th April (133 DAS).

Surface drip-irrigation system was installed within 5–8 days after sowing; and managed to ensure uniform application. Polyvinyl chloride (PVC) pipeline (with diameter of 63 mm for main line and 12 mm for laterals) was installed adjacent to the plots with an outlet (plot inlet) at the centre of each plot of size 6 m × 2 m. Each plot inlet had a watertight butterfly valve to ensure that only one plot in each replication is irrigated at a time. The pressure compensating drippers with a flow rate of 2 L/h were spaced 0.2 m apart on the laterals. Each lateral was placed between the 2 crop rows. For each treatment, irrigation water was added at a pressure of 1–1.5 kg/cm^2 until the requisite deficit is fulfilled. The date of application of irrigation in different treatments for both the years is given in Table 2.

Analysis of variance was performed using Proc GLM procedure of SAS version 9.4 (SAS, 2017) and significant

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

Date of sowing	Treatment (Depletion from FC, %)	No. of irrigations	Amount per application (mm)	Abbreviation
		Year 2014–15		
D_1	15	11	15	D_1 FC_{15}
(25 October)	25	5	25	D_1 FC_{25}
	35	3	35	D_1 FC_{35}
	45	2	45	D_1 FC_{45}
	Conventional Practice (CP)	5	75	D_1 CP
D_2	15	9	15	D_2 FC_{15}
(10 November)	25	4	25	D_2 FC_{25}
	35	2	35	D_2FC_{35}
	45	1	45	D_2 FC_{45}
	Conventional Practice (CP)	5	75	D_2 CP
D_3	15	7	15	D_3 FC_{15}
(25 November)	25	4	25	D_3 FC_{25}
	35	2	35	D_3 FC_{35}
	45	1	45	D_3 FC_{45}
	Conventional Practice (CP)	4	75	D_3 CP
D_4	15	7	15	D_4 FC_{15}
(10 December)	25	3	25	D_4 FC_{25}
	35	2	35	D_4 FC_{35}
	45	1	45	D_4 FC_{45}
	Conventional Practice (CP)	4	75	D_4 CP
		2015–16		
D_1	15	16	15	D_1 FC_{15}
(25 October)	25	9	25	D_1 FC_{25}
	35	6	35	D_1 FC_{35}
	45	4	45	D_1 FC_{45}
	Conventional Practice (CP)	5	75	D_1 CP
D_2	15	15	15	D_2 FC_{15}
(10 November)	25	8	25	D_2 FC_{25}
	35	5	35	D_2FC_{35}
	45	3	45	D_2 FC_{45}
	Conventional Practice (CP)	5	75	D_2 CP
D_3	15	13	15	D_3 FC_{15}
(25 November)	25	7	25	D_3 FC_{25}
	35	4	35	D_3 FC_{35}
	45	3	45	D_3 FC_{45}
	Conventional Practice (CP)	4	75	D_3 CP
D_4	15	12	15	D_4 FC_{15}
(10 December)	25	6	25	D_4 FC_{25}
	35	3	35	D_4 FC_{35}
	45	2	45	D_4 FC_{45}
	Conventional Practice (CP)	4	75	D_4 CP

mean differences were tested using Fisher's protected least significant difference (LSD) test at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Growth attributes of wheat

Plant height: Plant height is a reliable index of plant growth and represents the infrastructure build up over a period of time. Plant height was significantly influenced by the date of sowing and irrigation schedule at 50, 80, 110 DAS and at harvesting (Table 3). It was significantly higher in D_1 than that in all the other sowing dates at 50, 80, 110 DAS. However, plant height was statistically at par with D_2 at harvesting. The percentage reduction in plant height from D_1 to D_4 was 40, 18, 11 and 12 at 50, 80, 110 DAS and at harvesting. Plant height decreased with deferral in sowing time due to of less favourable weather conditions and shorter crop-growing period. Several authors reported reduction in plant height with delay in sowing time from the optimum (Meena *et al.,* 2015).

Irrigation schedule also influenced the plant height significantly. Plant height was significantly higher in FC_{15} than all the other irrigation schedules at all stages of plant growth during both the years. The percentage reduction in plant height from FC_{15} to FC_{45} was 34, 20, 14 and 12 at 50, 80, 110 DAS and at harvesting. The difference in plant height was more at earlier stages than at later stages of plant growth. The higher plant height in frequent irrigation regimes may be owing to higher tissue water content, net photosynthesis, cell-division and its multiplication. Pawar and Dingre (2014) also reported enhancement in plant height with increase in irrigation levels.

Dry-matter accumulation: The dry-matter decreased successively and significantly with delay in sowing from D_1 to D_4 at 50, 80, 110 DAS and at harvesting. DMA was significantly higher in D_1 than the other sowing dates at 50, 80, 110 DAS and at harvesting. The percentage reduction in DMA from D_1 to D_4 was 68, 39, 24 and 30 at 50, 80, 110 DAS and at harvesting. The dry-matter decreased with deferral in sowing time due to less favourable weather conditions and shorter crop-growing period, reduced plant height (Table 3) and LAI (Table 4). Kumar *et al.* (2013) also reported that, DMA was higher in early-sown crop because of favourable cool climate accessible for longer period as compared to late-sown crop.

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

Treatment	Dates of irrigation
	2014–15
D_1 FC_{15}	4 Nov, 14 Nov, 24 Nov, 03 Dec, 12 Dec, 31 Dec, 16 Jan, 01 Feb, 15 Feb, 28 Mar and 07 Apr
D_1 FC_{25}	08 Nov, 24 Nov, 11 Dec, 16 Jan and 28 Feb
D_1 FC_{35}	24 Nov, 31 Jan and 7 Mar
D_1 FC_{45}	12 Dec and 17 Feb
D_1 CP	16 Nov, 25 Dec, 27 Jan, 06 Mar and 01 Apr
D_2 FC_{15}	22 Nov, 04 Dec, 13 Dec, 01 Jan, 17 Jan, 01 Feb, 15 Feb, 29 Mar and 08 Apr
D_2 FC_{25}	27 Nov, 13 Dec, 12 Jan and 28 Feb
D_2 FC_{35}	21 Jan and 01 Mar
D_2 FC_{45}	31 Jan
D_2 CP	02 Dec, 06 Jan, 10 Feb, 07 Mar and 01 Apr
D_3 FC_{15}	08 Dec, 01 Jan, 19 Jan, 01 Feb, 15 Feb, 29 Mar and 08 Apr
D_3 FC_{25}	12 Dec, 12 Jan, 28 Feb and 13 Apr
D_3 FC_{35}	27 Jan and 12 Mar
D_3 FC_{45}	17 Feb
D_3 CP	25 Dec, 27 Jan, 05 Mar and 02 Apr
D_4 FC_{15}	01 Jan, 19 Jan, 01 Feb, 15 Feb, 25 Mar, 05 Apr and 15 Apr
D_4 FC_{25}	12 Jan, 28 Feb and 13 Apr
D_4 FC_{35}	02 Feb and 12 Mar
D_4 FC_{45}	17 Feb
D_4 CP	03 Jan, 06 Feb, 08 Mar and 06 Apr
	2015–16
D_1 FC_{15}	03 Nov, 14 Nov, 25 Nov, 06 Dec, 18 Dec, 28 Dec, 06 Jan, 27 Jan, 05 Feb, 13 Feb, 23 Feb, 03 Mar, 10 Mar, 23 Mar, 29 Mar and 05 Apr
D_1 FC_{25}	08 Nov, 25 Nov, 17 Dec, 03 Jan, 01 Feb, 13 Feb, 29 Feb, 24 Mar and 05 Apr
D_1 FC_{35}	16 Nov, 13 Dec, 07 Jan, 08 Feb, 03 Mar and 1 Apr
D_1 FC_{45}	26 Nov, 10 Jan, 25 Feb and 01 Apr
D_1 CP	16 Nov, 22 Dec, 24 Jan, 27 Feb and 28 Mar
D_2 FC_{15}	20 Nov, 04 Dec, 20 Dec, 31 Dec, 20 Jan, 02 Feb, 08 Feb, 14 Feb, 22 Feb, 01 Mar, 10 Mar, 22 Mar, 28 Mar, 04 Apr and 10 Apr
D_2 FC_{25}	27 Nov, 21 Dec, 09 Jan, 07 Feb, 18 Feb, 02 Mar, 26 Mar and 09 Apr
D_2 FC_{35}	08 Dec, 08 Jan, 11 Feb, 04 Mar and 04 Apr
D_2 FC_{45}	26 Dec, 14 Feb and 30 Mar
D_2 CP	01 Dec, 05 Jan, 08 Feb, 08 Mar and 03 Apr
D_3 FC_{15}	13 Dec, 29 Dec, 26 Jan, 07 Feb, 15 Feb, 24 Feb, 02 Mar, 10 Mar, 22 Mar, 28 Mar, 04 Apr, 10 Apr and 15 Apr
D_3 FC_{25}	20 Dec, 11 Jan, 07 Feb, 22 Feb, 04 Mar, 28 Mar and 10 Apr
D_3 FC_{35}	31 Dec, 15 Feb, 09 Mar and 09 Apr
D_3 FC_{45}	28 Jan, 04 Mar and 03 Apr
D_3 CP	17 Dec, 23 Jan, 28 Feb and 30 Mar
D_4 FC_{15}	27 Dec, 21 Jan, 08 Feb, 18 Feb, 27 Feb, 04 Mar, 10 Mar, 23 Mar, 29 Mar, 04 Apr, 10 Apr and 15 Apr
D_4 FC_{25}	03 Jan, 09 Feb, 25 Feb, 10 Mar, 28 Mar and 12 Apr
D_4 FC_{35}	07 Feb, 03 Mar and 08 Apr
D_4 FC_{45}	15 Feb and 03 Apr
D_4 CP	02 Jan, 06 Feb, 10 Mar and 08 Apr

The dry-matter was significantly higher under FC_{15} treatment as compared to all other irrigation schedules at all stages of plant growth during both the years. And it decreased successively and significantly with reduction in irrigation water application from FC_{15} to FC_{45}. The reduction in DMA from FC_{15} to FC_{45} was 52, 52, 43 and 40% at 50, 80, 110 DAS and at harvesting. The difference in DMA was more at earlier stages than at later stages of plant growth. The higher DMA in frequent irrigation regimes may due to better availability of soil moisture, higher plant height (Table 3) and leaf-area development (Table 4). Further, it is well known that reduction in soil moisture limits the cellular expansion and elongation, causes stomatal closure, raises the leaf temperature and reduces the net assimilation rate of photosynthates. Idnani and Kumar (2012) also reported decrease in DMA with increase in moisture deficit.

Leaf-area index: Leaf-area index (LAI) is an important factor influencing the interception of solar radiation, photosynthesis and ultimately the total biomass production. It is an indicator of source size and dictates the efficiency of photosynthetic surface. The LAI was significantly influenced by date of sowing and the irrigation schedule at 50, 65, 80, 95 and 110 DAS (Table 4) and increased successively with advancement in age of crop and maximum value attained at 95 DAS and thereafter LAI decreased due to senescence of leaves during both the years irrespective of treatment. The LAI was significantly higher under D_1 than all the other sowing dates at all growth stages. Reduction in LAI from D_1 to D_4 was 41, 30, 25, 21 and 20% at 50, 65, 80, 95 and 110 DAS. The LAI decreased with deferral in sowing time due to less favourable weather conditions and shorter crop-growing period that resulted in reduced crop growth, particularly plant height (Table 3) and number of tillers (Table 4) as compared to optimum sowing dates. Meena *et al.* (2015) reported that higher LAI in the timely sown crop in view of positive cool climate accessible for longer period than what was accessible to the late sown crop.

Irrigation schedule also influenced the LAI significantly. The pooled LAI was significantly higher in FC_{15} than that under all the other irrigation schedules. The reduction in LAI from FC_{15} to FC_{45} was 39, 27, 36, 36 and 35% at 50, 65, 80, 95 and 110 DAS respectively. The higher LAI in frequent irrigation regimes may be due to better availability of soil moisture for a longer time period, higher plant height (Table 3) and higher number of tillers (Table 4). Further, it is well known that reduction in soil moisture limits the cellular expansion and elongation and causes serious decline in leaf elongation. Meena *et al.,* (2015) also reported decrease in LAI with increase in moisture deficit.

Number of tillers: Sowing date had significant effect on number of tillers. Postponement of sowing date significantly reduced the number of tillers, being significantly higher under D_1 than D_3 and D_4 at all the growth stages. However, it was statistically at par with D_2. There was a progressive decrease in number of tillers as the sowing date was delayed from 25th October to 10th December. The number of tillers increased up to 80 DAS and decreased towards maturity, mainly due to competition for limited resources. The reduction in number of tillers with delay in

Table 3. Effect of date of sowing and irrigation schedule on plant height and dry matter accumulation of wheat (pooled data of 2 years)

Treatment	Plant height (cm)				Dry matter accumulation (g/m²)			
	50 DAS	80 DAS	110 DAS	Harvesting	50 DAS	80 DAS	110 DAS	Harvesting
Sowing date								
D_1	38.8	72.0	99.1	102.9	194.1	498.6	795.9	1053.9
D_2	33.8	68.4	96.1	100.6	142.9	407.1	723.5	981.2
D_3	29.6	63.8	92.3	95.6	92.7	359.1	662.5	838.3
D_4	23.2	59.1	87.9	90.2	61.9	308.5	608.6	739.1
SEm±	0.6	0.7	0.9	0.8	4.2	8.2	13.0	16.5
CD (P=0.05)	2.3	2.7	3.4	3.0	14.5	26.8	40.7	52.1
Irrigation schedule								
FC_{15}	37.1	72.3	100.1	103.2	164.3	522.6	856.0	1093.4
FC_{25}	33.5	67.8	95.3	99.0	135.6	437.4	767.5	991.3
FC_{35}	28.3	63.0	91.2	94.2	100.4	326.0	617.5	805.6
FC_{45}	24.5	58.0	86.5	90.9	80.1	255.2	492.0	652.4
CP	33.1	68.1	96.1	99.3	134.0	425.4	755.0	972.9
SEm±	0.4	0.5	0.7	0.8	3.4	7.3	9.5	10.6
CD (P=0.05)	1.9	2.2	2.4	2.6	11.6	23.8	30.2	33.5

D_1 (25 October), D_2 (10 November), D_3 (25 November), and D_4 (10 December), are the 4 sowing dates; FC_{15}, FC_{25}, FC_{35} and FC_{45} indicate 15, 25, 35 and 45% depletion from field capacity, CP represents the conventional irrigation practice; DAS, Days after sowing

sowing may be attributed to reduction in plant height (Table 3), LAI (Table 4) and DMA (Table 3). Meena *et al.* (2015) also reported similar results.

Irrigation schedule also influenced the number of tillers significantly during both the years. The maximum number of tillers was recorded in FC_{15} which was significantly higher than all other irrigation schedules during both the years at 50 and 80 DAS, while at 110 DAS difference in tillers among FC_{15}, FC_{25} and CP were statistically at par (Table 4). 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 can be attributed to less availability of moisture for tiller development. Meena *et al.* (2015) also reported decrease in number of tillers with increase in moisture deficit.

Ear length and ear weight: The ear length and ear weight are 2 important yield-determining attributes. Both of these were significantly influenced by the sowing date. The ear length and ear weight were significantly higher in D_1 than all other sowing dates. The percentage reduction in ear length and ear weight from D_1 to D_4 was 27 and 31% respectively. The reduction in number of ear length and ear weight with delay in sowing may be attributed to reduction in LAI (Table 4) and DMA (Table 3). Similar results were obtained by Meena *et al.* (2015).

The ear length and ear weight varied with the irrigation treatment imposed. The maximum ear length and ear weight was obtained when irrigation was applied at 15% depletion from FC (Table 5), which was significantly higher than all other irrigation schedules. The reduction in ear length and ear weight from FC_{15} to FC_{45} was 17 and 14% respectively. The reduction in these yield attributes with deficit in irrigation may be due to physiological limitations imposed by moisture deficit. Similar results were reported by Idnani and Kumar (2012) and Meena *et al.,* (2015).

Grain yield

Date of sowing and irrigation schedule had significant bearing on grain yield of wheat (Table 5). The grain yield was significantly higher in D_1 than all the other sowing dates. The grain yield decreased by 9% from D_1 to D_2, 18% from D_1 to D_3 and 29% from D_1 to $D_{4.}$ The decline in grain yield with delay in sowing may be due to shortening of the duration of each developmental phase and forced maturity of late-sown wheat, reduction in plant height (Table 3), DMA (Table 3), LAI (Table 4) and tiller density (Table 4), ear length and ear weight (Table 5). Our results confirm the findings of Gao *et al.,* (2014).

The highest grain yield was obtained when irrigation was applied at 15% depletion from FC (Table 5), which was significantly higher than all other irrigation schedules, and the lowest grain in the least irrigated treatment (FC_{45}). The grain yield decreased by 30% with irrigation applied at 45% depletion as compared to 15% depletion (Table 5). The grain yield in FC_{25} and CP was statistically at par. However, there was water saving of 57% (Table 2) in FC_{25} as compared to CP. The lower grain yield in water-deficit treatments may be due to depletion of soil moisture to the

Table 4. Effect of date of sowing and 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	50 DAS	80 DAS	110 DAS	Harvesting
Sowing date								
D_1	1.56	2.76	4.00	4.34	4.10	379.4	433.2	368.4
D_2	1.29	2.52	3.53	3.93	3.75	368.5	417.4	355.2
D_3	1.09	2.18	3.24	3.72	3.50	342.7	372.6	345.2
D_4	0.93	1.93	3.00	3.44	3.30	326.4	352.5	329.7
SEm±	0.05	0.03	0.04	0.06	0.09	4.4	5.9	4.2
CD (P=0.05)	0.23	0.12	0.14	0.22	0.35	14.5	18.9	13.5
Irrigation schedule								
FC_{15}	1.47	2.65	4.07	4.52	4.29	389.7	424.3	372.3
FC_{25}	1.34	2.52	3.83	4.27	4.10	368.9	410.5	360.7
FC_{35}	1.03	2.26	3.02	3.42	3.13	338.0	381.5	336.0
FC_{45}	0.91	1.93	2.61	2.89	2.78	319.9	356.4	321.1
CP	1.34	2.39	3.68	4.19	4.00	354.6	396.9	358.0
SEm±	0.03	0.03	0.05	0.04	0.06	3.1	4.0	4.8
CD (P=0.05)	0.12	0.13	0.18	0.13	0.19	10.7	13.2	15.6

D_1 (25 October), D_2 (10 November), D_3 (25 November), and D_4 (10 December) are the 4 sowing dates; FC_{15}, FC_{25}, FC_{35} and FC_{45} indicate 15, 25, 35 and 45% depletion from field capacity, CP represents the conventional irrigation practice

DAS, Days after sowing

Table 5. Effect of date of sowing and irrigation schedule on ear length, ear weight, grain yield, biological yield and harvest index of wheat (pooled data of 2 years)

Treatment	Ear length (cm)	Ear weight (g)	Grain yield (t/ha)	Biological yield (t/ha)	Harvest Index (%)
Sowing date					
D_1	12.4	6.4	5.40	12.49	43.3
D_2	11.4	5.9	4.94	11.47	43.0
D_3	9.7	5.0	4.41	10.39	42.4
D_4	9.0	4.4	3.83	9.10	42.0
SEm±	0.2	0.1	0.4	2.4	0.8
CD (P=0.05)	0.8	0.4	1.8	8.5	NS
Irrigation schedule					
FC_{15}	11.6	5.9	5.37	12.34	43.4
FC_{25}	10.9	5.4	4.91	11.42	43.0
FC_{35}	10.2	5.3	4.31	10.12	42.6
FC_{45}	9.6	5.1	3.77	9.08	41.5
CP	10.9	5.5	4.88	11.34	43.0
SEm±	0.1	0.1	0.3	1.5	0.6
CD (P=0.05)	0.6	0.3	1.3	5.7	NS

D_1 (25 October), D_2 (10 November), D_3 (25 November), and D_4 (10 December), are the four sowing dates; FC_{15}, FC_{25}, FC_{35} and FC_{45} indicate 15, 25, 35 and 45% depletion from field capacity, CP represents the conventional irrigation practice

extent that could limit water extraction by roots and imposing severe physiological limitations like accelerated leaf senescence, damage to photosynthetic machinery and shortening of growth cycle, reduced carbon fixation and assimilate translocation or reduced grain set and development (Asch *et al.,* 2005; Farooq *et al.,* 2009).

Biological yield

The biological yield was significantly influenced by the sowing date and the irrigation schedule. The biological yield decreased with delay in sowing time. The biological yield in D_1 was significantly higher than all other sowing dates. The reduction in biological yield was 8% from D_1 to D_2, 17% from D_1 to D_3 and 27% from D_1 to D_4 (Table 5). The biological yield was higher in earlier sowing owing to higher plant height (Table 3), DMA (Table 3), LAI (Table 4) and tiller density (Table 4). Meena *et al.* (2015) also reported that, earlier sowing of the crop resulted in higher biological yield than the crop sown late in the season.

The biological yield was significantly influenced by irrigation schedules. The maximum biological yield was recorded in FC_{15} which was significantly higher than all the other irrigation schedules. The percentage reduction in biological yield between FC_{15} and FC_{45} was 27%. The biological yield was reduced in deficit irrigation treatments due to reduction in plant height, tiller density, DMA and LAI. Meena *et al.* (2015) observed reduction in biological yield with increase in water deficit.

Harvest index

The harvest index was not significantly influenced either by the sowing date or by irrigation schedule.

It can be concluded that plant growth attributes and yield were significantly higher in D_1 as compared to all the other sowing dates. Significantly higher growth attributes and yield were recorded with application of irrigation at FC_{15} than the other irrigation schedules. The pooled grain yield in FC_{15} was higher by 9, 25, 42 and 10% than FC_{25}, FC_{35}, FC_{45} and CP respectively. It was found that irrigating at FC_{15} using drip method of irrigation saves 50% irrigation water as compared to the conventional practice of irrigating the crop at 4–5 weeks interval with 75 mm of water.

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