Indian Journal of Agronomy **60** (1): 92–98 (March 2015)

Research Paper

Influence of date of sowing and irrigation regimes on crop growth and yield of wheat (*Triticum aestivum*) and its relationship with temperature in semi-arid region

RAJESH KUMAR MEENA[1], S.S. PARIHAR[2], MAN SINGH[3] AND MANOJ KHANNA[4]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012

Received : August 2014; Revised accepted : January 2015

ABSTRACT

A field experiment was conducted during the winter (*rabi*) seasons of 2010–11 and 2011–12 on sandy-loam soil at New Delhi, to study the effect of sowing dates and irrigation regimes on growth parameters, yield attributes, yield and water-use efficiency (WUE) of wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.], and influence of prevailing temperature on grain yield. The experiment was laid out in split-plot design with 3 replications involving 4 sowing dates, viz. S_1, 1 November; S_2, 16 November; S_3, 1 December; S_4, 16 December in main-plots and 4 irrigation regimes, viz. I_1, 25% maximum allowable depletion (MAD) of available soil moisture (ASM); I_2, 50% MAD of ASM; I_3, 75% MAD of ASM; I_4, based on 4 critical growth stages, in subplots. Significantly highest grain yield was obtained in 1 November sowing (5.20 t/ha) and was at par with 16 November sowing (5.05 t/ha). Yield attributes were also the highest under 1 November sowing. Amongst the irrigation regimes, irrigation scheduling at 25% MAD of ASM resulted significantly more grain yield (4.93 t/ha), followed by I_2, I_4 and I_3 treatments. The I_1 treatment resulted in 27.4% more yield than I_4 treatment. Intermittent irrigation with small amount of water applied in I_1, resulted higher grain and straw yields. The grain yield reduction was 43.7% due to high seasonal mean temperature (+2.2°C) in 16 December sowing over 1 November sowing. The highest water-use efficiency (15.0 kg/ha/mm) and benefit: cost ratio (2.16) were recorded in 25% MAD of ASM and 50% MAD of ASM respectively.

***Key words* :** Available soil moisture, Irrigation regimes, Maximum allowable depletion, Sowing dates, Water-use efficiency

Bread wheat is one of the most important staple food crops of the world and emerged as the backbone of India's food security. In India, wheat production reached 95.8 million tonnes from 31.3 million ha area. In the past decade, a general slowdown in increase in productivity of wheat has been observed, particularly under environments relatively unfavourable for growth and development of wheat (Nagarajan, 2005). Recently, there has been a decline in wheat productivity from 3.13 (2011–12) to 3.05 t/ha (2013–14) (Economic Survey, 2014). In India, around 13.5 million ha of wheat is heat stressed (Joshi *et al*., 2007). The productivity of wheat is reduced considerably by combined stress of temperature and moisture than by either stress alone and has considerable effect on photosynthetic processes (Shah and Paulsen, 2003). Wheat productivity can be increased substantially by adjusting sowing date to optimum atmospheric temperature. In north-west India, better wheat growth reported when crop sown on 20 November than that sown on 1 November or 10 December. However, there was little grain yield difference between 2 dates of November (Kumar *et al*., 2000).

Since wheat is sensitive to moisture stress, it needs frequent irrigation for good growth and yield (Mishra *et al*., 1995; Alderfasi and Nielsen., 2001). But yield increase and water-use efficiency (WUE) decrease above 4 irrigations (Chen *et al*., 2014). The crop parameters and yield of wheat were significantly higher under high frequency irrigation, and grain yield reduced drastically with increase in maximum allowable depletion (MAD) of available soil water (ASW) from 40 to 75% (Mugabe and Nyakatawa, 2000; Panda *et al*., 2003; Gontia and Tiwari, 2008). Irrigation at 50% depletion of available soil moisture (ASM) resulted in the highest plant height, dry matter, biomass

Based on a part of Ph.D. Thesis of the first author submitted to Indian Agricultural Research Institute, New Delhi (unpublished)

[2]**Corresponding author Email:** ssp_wtc@iari.res.in
[1]Scientist, National Bureau of Soil Survey and Land Use Planning, Regional Centre, New Delhi 110 012; [2,4]Principal Scientist, [3]Professor and Principal Scientist, Water Technology Centre, Indian Agricultural Research Institute, New Delhi 110 012

and water-use efficiency for biomass of the wheat grown under semi arid region (Badel *et al*., 2013).

With growing water scarcity and competition for irrigation water availability, deficit irrigation would be better to reduce irrigation water use for moderate yield of wheat. At the same time, the need to meet increasing demand for food will require increased production per unit of water, which is becoming important cost and constraint for its production. In future, due to climate change and shrinking water availability, demand for irrigation might not meet fully. Therefore, irrigation scheduling (amount and timing) based on soil depletion can avoid excess water applied to the crop and thereby water-use efficiency could be improved for cropping as well as irrigation strategies in semi-arid region. In these conditions, shifting in sowing time and efficient water management are the important production practices to attain higher productivity of wheat in futuristic scenario. Most of the earlier studies have examined the effects of sowing dates and number of irrigation on crop growth and yield of wheat. However, little information is available on the combined effect of prevailing temperature under different sowing and moisture depletion on crop growth and yield. Therefore, present study was undertaken with the objective of comparing the response of crop growth, yield attributes, grain yield, straw yield and water-use efficiency under different sowing and irrigation regimes and temperature influence on grain yield of wheat under varying sowing dates.

MATERIALS AND METHODS

The field experiment was conducted during the winter (*rabi*) seasons of 2010–11 and 2011–12 at the experimental farm of Water Technology Centre, Indian Agricultural Research Institute, New Delhi (77°11' 37.6" E, 28°38' 56.22" N; 229 m above mean sea-level). The region is characterized by a semi-arid and sub-tropical with warm dry summer (March–June), wet monsoon season (late June–mid-September) and cold winter seasons (November–February) and falls under the agro-climatic zone of 'Trans-Gangetic plains'. The mean annual rainfall is 734 mm, about 80% of which falls during active south-west monsoon months, viz. July, August and September. The soil is sandy loam Typic Haplustept in texture with medium angular blocky structure, non-calcareous and slightly alkaline. Soil was low in organic carbon (0.39%) and available N (141 kg/ha) and medium in available P (22 kg/ha) and available K (165 kg/ha) content in 0–30 cm soil depth. The bulk density was 1.52 Mg/m^3 in 0–30 cm soil depth. Available soil moisture ranges from 17.2 (field capacity) to 7.5% (wilting point) from 0 to 0.90 m soil depth.

The experiment was laid out in split-plot design with sowing dates in main plots and irrigation regimes in sub-plots and replicated thrice. There were 16 treatments, consisting of four sowing dates viz. S_1, 1 November; S_2, 16 November; S_3, 1 December and S_4, 16 December and 4 irrigation regimes, viz. I_1, 25% maximum allowable depletion (MAD) of available soil moisture (ASM); I_2, 50% MAD of ASM; I_3, 75% MAD of ASM; I_4, based on 4 most critical growth stages (crown-root initiation, late tillering, flowering and milking).

Wheat cultivar 'DBW 17' seeds were sown manually as per treatment schedule. The seeds were sown at row spacing of 20 cm and row orientation was north–south to facilitate favourable micro-climate. The plots dimensions were 5 m × 4 m. The N applied @ 120 kg/ha with half dose of N (60 kg/ha) and full dose of P (60 kg/ha) and K (40 kg/ha) as basal and remaining N was applied in 2 equal doses, at first and at second irrigations. The N, P and K were applied through urea, diammonium phosphate (DAP) and murate of potash (MOP) respectively. The plots were kept weed free by weeding cum hoeing and also kept free from insect-pest by taking suitable control measures.

The irrigation scheduling was done on the basis of soil-moisture depletion in the root zone determined gravimetrically at weekly interval during cropping season.

The pre-defined level of MAD was calculated by the following equation (Martin *et al*., 1990):

$$\text{Depletion } (\%) = 100 \times \frac{1}{n} \sum_{1}^{n} \left(\frac{FCi - \theta i}{FCi - WP} \right)$$

where n is the number of sub-divisions of the effective rooting depth used in the soil moisture sampling; FC_i the soil moisture at ûeld capacity for ith layer; $è_i$ the soil moisture in ith layer; and WP, the soil moisture at permanent wilting point.

The amount of water applied after the attainment of pre-defined MAD (%) was calculated as:

$$Vd = \frac{MAD(FC - WP)\ Rz \ \times\ A}{100}$$

where V_d is the volume of irrigation water to be applied; R_Z is the effective rooting depth and A is the surface area of the plot.

Under treatment I_1, the irrigation events were scheduled at small intervals and quantities of water applied during irrigation were low. The irrigation interval and quantity of water applied during each irrigation events increased from 25% MAD of ASM to 75% MAD of ASM, whereas the treatment I_4 had applied irrigation at 4 critical stages. Other standard crop-management practices recommended for wheat crop under semi-arid irrigated condition were adopted. Crop-growth parameters were recorded as per the established procedure for each of the 3 replicates. The weather data were obtained from Meteorological Observatory, IARI, New Delhi, for the crop-growing period (46 to 15 standard meteorological weeks, SMWs) for the period spanning from 1981 to 2012. To study temperature effect on crop yield, the whole growth period (GPw)–vegetative growth stage and reproductive growth stage–were divided 6 growth period, i.e. VGS1 (sowing to crown-root initiation, CRI); VGS2 (CRI to tillering); VGS3 (tillering to heading); RGS1 (heading to anthesis); RGS2 (anthesis to milking) and RGS3 (milking to dough) and the temperature variations were analysed. The net plot was harvested manually at the physiological maturity by cutting plants near ground surface after leaving the border rows. The plants were dried and weighted for biomass as well as for grain yield and 20 plants from each plot were selected for yield attributes determination. The cost of cultivation, net returns and benefit: cost ratio were calculated by taking into account the prevailing cost of inputs and minimum support price (MSP) of grain and straw price as per the local market. The statistical analysis of the data (pooled data of 2 cropping season) was done as per procedure of analysis suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Weather parameters

The monthly mean temperatures were similar in both years except December, which was slightly cooler in 2010–11 and February and April relatively warmer in 2011–12 (Table 1). More specifically, there was a sudden increase in daily maximum temperature from the first week of March, which was above 27°C in both years and relatively higher daily minimum temperature was observed in February and March in 2010–11. Higher temperature noted during March and April coincided with the reproductive stage of crop growth. The higher atmospheric evaporative demand (> 4 mm/day) was observed during reproductive stage, but it was 2.9 mm/day during February 2011 due to high amount of rainfall. The overall atmospheric evaporative demand was the highest in 2011–12, ranging from 4.2 to 6.9 mm/day. The average daily bright sunshine during crop growth periods were 5.5 and 5.2 hr for 2010–11 and 2011–12 respectively. Rainfall during crop growing season 2010–11 (63.5 mm) was significantly higher than 2011–12 (40.8 mm). There was a good amount of rainfall in February (49.9 mm) in first year and January (14.8 mm) and March (19.2 mm) during second year. The average relative humidity was 64 and 60% in respective years and the sky was cloud free for most of the time during crop growth period.

Temperature (*T*max and *T*min) departure since 2001-02 to 2010-11 from long-term (30 years, 1981 to 2011) temperature (*T*max and *T*min) during crop growing season (46 to 15 SMWs) is shown in Fig 1. During the last decade, it was observed that *T*max was less than long-term *T*max in November, December and January, while it was observed above the long-term *T*max in February and March. During same period, *T*min was found above the long-term *T*min in all months except January, when it was less than the long-term *T*min temperature. As shown in Table 2, a rise in *T*max and *T*min temperatures was observed throughout the wheat-growing season, but the rate of rise of *T*max was the highest for November (0.24°C per annum), whereas *T*min rise was the highest in April (0.22°C per annum), followed by December and November during the 46 to 15 SMW of wheat-growing season in the last decade.

Table 1. Weather conditions during the period of study

Months	Mean Temperature (°C)	Rainfall (mm)	Pan evaporation (mm/day)	Mean relative humidity (%)	Sunshine hours (hr/day)
			2010–11		
November	21.1	10.6	3.4	70.5	3.3
December	13.6	0.7	3.2	67.3	3.0
January	11.7	0.0	2.8	67.0	3.8
February	16.3	49.9	2.9	70.0	5.4
March	21.1	2.3	4.4	62.1	9.6
April	24.9	0.0	6.0	47.8	7.9
			2011–12		
November	21.1	0.0	2.9	60.8	4.2
December	14.2	0.0	2.2	67.2	3.2
January	12.1	14.8	2.1	72.6	3.5
February	15.3	0.0	4.2	54.4	6.6
March	21.3	19.2	5.5	50.4	6.8
April	27.1	6.8	6.9	54.4	6.9

Table 2. Long term[a] temperature (*T*max and *T*min) during wheat growing period (46th to 15th SMW) at New Delhi

Months	*T*max	*T*min	Rate of change of temperatures during last decade[b] (*T*max and *T*min, °C/annum)	
			*T*max	*T*min
November	26.9	10.4	0.24	0.14
December	22.5	7.0	2E-05	0.16
January	19.8	6.4	0.030	0.008
February	23.5	9.1	0.002	3E-05
March	29.1	13.6	0.05	0.008
April	34.5	17.5	0.07	0.22

[a]Long-term means average of 30 years data, from 1980–81 to 2010–11; [b]included wheat growing period (46 to 15 SMW) from 2001–02 to 2010–11; SMW: Standard meteorological weeks

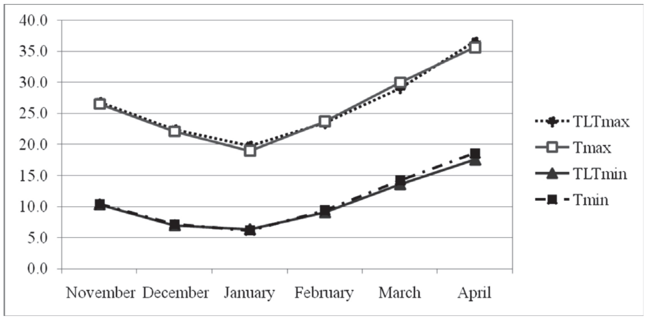

Fig. 1. Temperature (*T*max and *T*min) departure since 2001–02 to 2010–11 (46 to 15 SMW) from long-term (1981 to 2011) temperature (Tmax and Tmin) during crop-growth period

Temperature during vegetative and reproductive stages

Data on *T*max and *T*min temperatures experienced during vegetative (VGS1, VGS2, VGS3) and reproductive stages (RGS1, RGS2, RGS3) of wheat revealed that cropping season 2011–12 appeared relatively warmer during vegetative stage over 2010–11. Temperature (*T*max and *T*min) during reproductive stage followed same trend in both years except heading to anthesis growth stage (RGS1) in 1 November and 16 November sowing, when *T*max and *T*min were found higher in 2010–11. Sowing in 1 November experienced temperature ranges between 9.5–24.1°C and 6.9–20.9°C, while 16 December sown crop has temperature in between 6.3 and 20.3°C and 13.5 and 31.1°C during vegetative and reproductive stages of wheat respectively. Phenology of wheat was modified by prevailing temperature. Different sowing dates exposed vegetative and reproductive stages to various temperature regimes. During vegetative stage, 1 November sowing has mean temperatures 16.2 and 17.4°C, while it was 14.3 and 14.8°C in 16 November sowing in 2010–11 and 2011–12 respectively. These temperature ranges favour plant growth and results in increased plant height, leaf area and biomass production. December sowings have shown sub-optimal temperatures during vegetative stage of crop growth. Lower temperature led to enhanced crop vegetative growth period, while higher temperature accelerates crop growth. During reproductive stage, relatively lower temperature was noticed in November sowings and relatively higher temperature in December sowings, which adversely affected grain growth and development. High temperature stress (+2.4 and +1.9°C seasonal mean and +7.5 and +7.4°C during reproductive stage in 2010–11 and 2011–12) reduced grain yield and yield-attributing characters to varying extent among different sowing dates. The high temperature stress in delayed sowing causes supra-optimal thermal stress at reproductive stage, which forced the crop maturity. This high temperature stress at reproductive stage of wheat results in poor grain filling, reduced number of grains/spike, shrivelling of grains and thereby reducing grain yield. These results are in agreement of those reported by Godding *et al*. (2003) and Sharma *et al*. (2007). The grain yield reduction was 43.7% due to 2.2°C high temperature in 16 December sowing compared to 1 November sowing.

Growth parameters

Significant differences were observed due to date of sowing and irrigation regimes on crop-growth parameters (Table 4). The date of sowing significantly influenced the plant height and leaf-area index (LAI). The plant height and LAI at the 90 days were significantly higher in 1 November sowing than the other sowing dates. This can be ascribed to better establishment of plant owing to favourable atmospheric conditions, especially temperature prevailed during growing period. The results confirm the findings of Tahir *et al*., (2009). Decrease in plant height

Table 3. Average temperature (*T*max and *T*min) during vegetative growth stage (VGS) and reproductive growth stage (RGS) of wheat

Sowing dates	Vegetative growth stage											
	Sowing to CRI (VGS1)				CRI to tillering (VGS2)				Tillering to heading (VGS3)			
	2010–11		2011–12		2010–11		2011–12		2010–11		2011–12	
	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}
S_1	27.8	14.3	29.8	13.4	23.0	8.4	26.3	10.6	18.2	5.7	20.0	4.21
S_2	24.0	10.7	27.0	11.0	21.6	5.6	21.9	5.1	18.0	5.8	19.0	5.07
S_3	22.0	5.7	23.5	7.0	15.7	5.7	19.2	4.8	22.0	7.9	20.0	5.9
S_4	17.8	5.9	20.0	4.6	19.8	5.5	18.4	4.3	22.8	9.6	23.2	7.8
	Reproductive growth stage											
	Heading to anthesis (RGS1)				Anthesis to milking (RGS2)				Milking to dough (RGS3)			
S_1	20.8	6.0	17.8	5.3	21.6	6.5	21.0	6.8	23.0	10.2	23.8	9.0
S_2	23.7	9.1	20.8	5.9	22.5	10.2	22.8	8.7	24.7	10.7	27.0	9.7
S_3	22.8	9.5	25.5	9.0	24.7	11.2	28.2	10.3	31.3	13.2	25.5	13.7
S_4	26.5	11.8	28.0	9.9	31.8	14.0	29.3	13.1	32.8	16.1	32.5	15.8

and leaf-area index (LAI) in 1 December and 16 December sowings was due to reduction in duration of vegetative growth stage. This reduction might be due to lower temperature prevailed during earlier vegetative growth stage, which slows the cell expansion and their growth, and sudden increase in temperature at late vegetative stage forced the crop growth and development. This high temperature hastened the leaf senescence and crop maturity in late-sown crop. These results are in line with those reported by Ram *et al*. (2012).

Irrigation regimes showed significant differences for plant height and LAI. Growth parameters progressively increased with the decrease in depletion levels and increase in frequency of water applied. Plots irrigated at 25% MAD of ASM recorded the highest plant height and leaf-area index, and were significantly better than the other treatments. There was 13.8 and 24% increase in LAI in 25% MAD of ASM over critical stages and 75% MAD of ASM treatments. Reduction in plant height and LAI in 75% MAD of ASM was due to depletion of soil moisture affecting root-water extraction. These differences in growth parameters might be attributed to moisture regime during vegetative stage of crop.

Yield attributes

All yield attributes were significantly affected by the date of sowing and irrigation regimes (Table 4). Effective tillers/m^2, ear length, grains/ear, grains weight/ear and 1,000-grain weight were the highest in 1 November sowing and statistically at par with 16 November sowing. Delay in sowing beyond 16 November resulted in significantly less yield attributes compared to earlier sowing dates. This reduction might be due to very low temperature in late-sown conditions during vegetative growth stage, which slows the cell-division and cell-expansion. This reduced cell expansion also affect on meristematic development of yield attributes (Mukherjee, 2012). Grains/ear were 2.9 and 2.0% more in 1 November sowing than 16 November sowing. Less grains/ear in late sowing was due to less production of photosynthates due to shorter growing period. The maximum grain weight/ear was 3.7% more in 1 November sowing over 16 November sowing. Overall mean grain number and grains weight/ ear head were less in late-sown treatments. Date of sowing significantly affected the 1,000-grain weight. The reduction in 1,000-grain weight due to delay in sowing was mainly attributed to reduction in growth and shrivelled grains because of forced maturity which occurred due to sudden temperature rise and westerly wind prevailed during milking and grain filling stage. Our results confirm earlier studies those of Mukherjee, 2012.

Irrigation regimes showed significant variation in different yield attributes. Frequent irrigation with small quantities of water in 25% MAD of ASM resulted in higher LAI and vigorous growth, which ultimately converted into higher number of effective tillers, ear lengthcm), grains/ ear, grains weight/ear and 1,000-grain weight. Idnani and Kumar (2012) also reported similar beneficial effect of irrigation on yield attributes of wheat.

Grain and straw yields

Significant differences in grain yield, straw yield and harvest index were recorded with the different dates of sowing and irrigation regimes (Table 4). The grain yield, straw yield and harvest index of wheat varied significantly due to dates of sowing, as grain yield is function of vari-

Table 4. Effect of different sowing dates and irrigation regimes on growth, yield attributes and yield of wheat (pooled data of 2 years).

Treatment	Plant height (cm)	Leaf area index	Effective tillers/m^2	Ear length (cm)	Grains/ ear head	Grain weight/ spike	1,000-grain weight	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)
Sowing dates										
S_1	84.9	3.49	412.7	10.5	54.3	2.23	40.9	5.20	5.97	46.4
S_2	83.2	3.34	394.2	10.4	52.9	2.15	40.6	5.05	5.99	45.8
S_3	72.7	3.10	356.8	10.2	51.1	1.90	37.4	3.77	5.40	41.2
S4	65.1	2.66	315.9	9.6	47.5	1.72	36.3	2.93	4.71	38.7
SEm±	2.3	0.08	3.9	0.1	0.8	0.06	1.4	0.06	0.15	1.0
CD (P=0.05)	7.9	0.29	13.5	0.4	2.9	0.23	4.9	0.23	0.53	3.5
Irrigation regimes										
I_1	82.4	3.46	403.3	10.4	55.2	2.21	40.1	4.93	6.11	44.4
I_2	78.9	3.30	380.5	10.2	52.3	2.09	39.8	4.73	5.74	44.6
I_3	71.1	2.79	337.7	9.9	47.5	1.74	36.8	3.42	5.06	40.5
I_4	73.7	3.04	358.2	10.1	50.7	1.96	38.5	3.87	5.16	42.6
SEm±	2.1	0.07	4.8	0.1	0.8	0.06	1.3	0.06	0.11	1.2
CD (P=0.05)	7.8	0.28	18.1	0.4	3.0	0.23	4.8	0.25	0.42	4.4

ous yield-attributing characters. The maximum grain yield was obtained in 1 November sowing, which was statistically at par with 16 November sowing grain yield. The crop sown on 1 November registered 3% higher grain yield over than that sown on 16 November. The harvest index was the highest in 1 November sowing (46.4%) but at par with 16 November sowing (45.8%). High temperature in December sowings affected the partitioning of biomass from vegetative to reproductive organs. This decreases the initials tillers, which lead small reproductive organs and consequently yield reduction (Mukherjee, 2012). Yield variations amongst various sowing date explains the effect of temperature rise as sowing delayed and hence, offer opportunity for yield improvement by shifting sowing time of wheat crop in 1 week of November. Late-sown crop adversely affected by exceptional high temperature for March and April, which coincided with thermo-sensitive grain-filling stage of wheat and led to forced crop maturity. Similar observations were also made by Pradhan *et al*. (2014). Straw production showed significant variation with date of sowing and irrigation regimes. The maximum straw production was recorded with 16 November sowing, but at par with straw yield in 16 November sowing. This might be due to favourable conditions prevails during vegetative growth period. There was 11 and 27.2% more straw yield was obtained in 16 November sowing over 1 December and 16 December sowings. The increase in grain yield of wheat under 1 November sowing could be attributed to higher yield-attributing parameters, whereas increase in straw yield was due to higher plant height and leaf-area index. Hence, 1 November sowing offers relatively favourable weather conditions as in 16 November sowing during crop-growing period.

Among irrigation regimes, 25% MAD of ASM had significantly higher yield-attributing characters and in turn significantly more grain yield but at par with 50% MAD of ASM grain yield and produced 27.4% higher grain yield over the 4 irrigations at most sensitive critical stages, which is still practised by majority of wheat growers in India. The grain yield was lower for 75% MAD of ASM due to soil moisture was depleted sufficient enough to limit the extraction of water by roots and thereby affecting grain yield. The grain yield was higher under frequent irrigation scheduling and reduced drastically in low frequency irrigation due to reduction in moisture availability. With increase in MAD from 50% to 75%, the grain and straw yield reduced drastically due to significant reduction in available soil moisture. Similar results were obtained by Panda *et al*. (2003).

Water-use efficiency

The highest water use efficiency (WUE) was attained when irrigation scheduled at 25% MAD of ASM, followed by 50% MAD of ASM, critical stages and 75% MAD of ASM in November, 1 sowing and at par with 16 November sowing. In 16 December sowing, WUE reduced drastically and found to be almost similar in 25% MAD of ASM, 50% MAD of ASM and critical stages treatments and recorded the lowest in 75% MAD of ASM treatment. Irrigation scheduling with 25% and 50% MAD of ASM should be maintained to obtain high grain yield and WUE under 1 November and 16 November sowing. Frequent irrigation with small amount of water promotes faster plant growth, higher biomass, yield attributes, consequently resulting in higher grain yield and ultimately leading to enhanced WUE. These results are in line agreement with those reported by Jin *et al*. (2014).

Economics

The net returns and benefit: cost ratios were influenced by sowing dates and irrigation regimes (Table 5). However, highest benefit: cost ratio was obtained in 50% MAD of ASM in 1 November and 16 November sowing dates, whereas 25% MAD of ASM recorded highest benefit: cost ratio in later-sowing dates.

The study revealed that shift in sowing time from mid-November to 1st week of November could be effective against mitigation of terminal heat stress. The 1 November sowing recorded better crop growth, higher yield and yield attributes but at par with 16 November sowing, prevalent in north-west semi-arid region of India. Irrigation scheduling at 50% MAD of ASM found to be economical and efficient irrigation scheduling strategy for timely sown wheat in semi-arid region.

REFERENCES

Alderfasi, A.A. and Nielsen, D.C. 2001. Use of crop water stress index for monitoring water status and scheduling irrigation in wheat. *Agricultural Water Management* **47**(1): 69–75.

Badel, M., Sarobol, E. and Degewione, A. 2013. Impact of soil moisture depletion levels at different growth stages on growth, evapotranspiration and biomass yield of bread wheat grown under semi-arid condition. *Agricultural Science, Engineering and Technology Research* **1**(3): 26–34.

Chen, S., Sun, H., Shao, L. and Zhang, X. 2014. Performance of winter wheat under different irrigation regimes associated with weather conditions in the North China Plain. *Australian Journal of Crop Science* **8**(4): 550–57.

Economic Survey. 2014. *3rd Advance Estimates (3rd AE).* Economic Survey of India, Ministry of Finance, Government of India.

Gontia, N.K. and Tiwari, K.N. 2008. Development of crop water stress index of wheat crop for scheduling irrigation using infrared thermometry. *Agricultural Water Management* **95**(10): 1,144–52.

Gomez, K.A. and Gomez, A.A. 1984. *Statistical Procedures for Agricultural Research,* 2nd. An International Rice Research Institute Book. Wiley-InterScience Publication, John Wiley & Sons, New York.

Gooding, M.J., Ellis, R.H., Shewry, P.R. and Schofield, J.D. 2003. Effects of restricted water availabily and increased temperature on the grain filling, drying and quality of winter wheat. *Journal of Cereal Science* **37**(3): 295–09.

Idnani, L.K. and Kumar, A. 2012. Relative efficiency of different irrigation schedules for conventional, ridge and raised bed seeding of wheat (*Triticum aestivum*). *Indian Journal of Agronomy* **57**(2): 148–51.

Jin, X.L., Feng, H.K., Zhu, X.K., LI, Z.H., Song, S.N., Song, X.Y., Yang, G., Xu, X.G. and Guo, W.S. 2014. Assessment of the Aquacrop model for use in simulation of irrigated winter wheat canopy cover, biomass and grain yield in the north China plain. *Public Library of Science One* **9**(1): 1–11.

Joshi, A.K., Mishra, B., Chatrath, R., Ortiz Ferrara, G. and Singh, R.P. 2007. Wheat improvement in India: present status, emerging challenges and future prospects. *Euphytica* **157**(3): 431–46.

Kumar, S., Bangarwa, A.S. and Kadian, V.S. 2000. Response of wheat varieties to sowing dates and nitrogen levels. *Annals Agriculture and Biological Research* **5**(1): 99–03.

Martin, D.L., Stegman, E.C. and Freres, E. 1990. Irrigation scheduling principles. (In): *Management of Farm Irrigation Systems* pp. 155–372. Hoffman, G.L., Howell, T.A., Solomon, K.H. (Eds). ASAE Monograph.

Mishra, H.S., Rathore, T.R. and Tomar, V.S. 1995. Water use efficiency of irrigated wheat in the *Terai region* of India*. Irrigation Science* **16**(2): 75–80.

Mugabe, F.T. and Nyakatawa, E.Z. 2000. Effect of deficit irrigation on wheat and opportunities of growing wheat on residual soil moisture in southeast Zimbabwe. *Agricultural Water Management* **46**(2): 111–19.

Mukherjee, D. 2012. Effect of different sowing dates on growth and yield of wheat (*Triticum aestivum*) cultivars under mid-hill situation of West Bengal. *Indian Journal of Agronomy* **57**(2): 152–56.

Nagarajan, S. 2005. Can India produce enough wheat even by 2020? *Current Science* **89**(9): 1,467–71.

Panda, R.K., Behera, S.K. and Kashyap, P.S. 2003. Effective management of irrigation water for wheat under stressed conditions. *Agricultural Water Management* **63**(1): 37–56.

Pradhan, S., Sehgal, V.K., Sahoo, R.N., Bandyopadhyay, K.K. and Singh, R. 2014. Yield, water and nitrogen use efficiencies of wheat (*Triticum aestivum*) as influenced by nitrogen levels in a semi-arid environment. *Indian Journal of Agronomy* **59**(2): 267–75.

Ram, A., Pannu, R.K. and Prasad, D. 2012. Effect of management practices on growth, yield and quality of late sown wheat (*Triticum aestivum*). *Indian Journal of Agronomy* **57**(1): 92–95.

Shah, N.H. and Paulsen, G.M. 2003. Interaction of drought and high temperature on photosynthesis and grain filling of wheat. *Plant and Soil* **257**(1): 219–26.

Sharma, K.D., Pannu, R.K. and Behl, R.K. 2007. Effect of early and terminal heat stress on biomass partitioning, chlorophyll stability and yield of different genotypes. (In): *Proceedings of the International Conference on Sustainable Crop Production in Stress Management: Management and Genetic Options* pp.187–94. Singh, D.P., Tomar, V.S., Behl, R.K., Upadhyaya, S.D., Bhale, M.S. and Khare, D. (Eds) Agrobios, Jodhpur.

Tahir, M., Ali, A., Ather, N. M., Hussain, A. and Khalid, F. 2009. Effect of different sowing dates on growth and yield of wheat (*T. aestivum*) varieties in district Jhang, Pakistan. *Pakistan Journal of Life Sciences* **7**(1): 66–69.