

Growth response and water production functions of wheat (*Triticumaestivum* L.) under abiotic stresses in central and south-western Punjab

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सार – अजैविक दबावों के तहत गेहूं की वृद्धि, उपज और जल उपयोग दक्षता का अध्ययन करने के लिए पंजाब के दो कृषि जलवायु क्षेत्रों (अर्थात्, मध्य मैदानी क्षेत्र का प्रतिनिधित्व करने वाला लुधियाना और दक्षिण-पश्चिमी शुष्क क्षेत्र का प्रतिनिधित्व करने वाला बठिंडा) में एक क्षेत्र प्रयोग आयोजित किया गया था। गेहूं की किस्म HD-2967 का मूल्यांकन पांच थर्मल वातावरण (D1 - 20 अक्टूबर, D2 - 05 नवंबर, D3 - 20 नवंबर, D4 - 05 दिसंबर और D5 - 20 दिसंबर) के तहत किया गया था ताकि फसल को विभिन्न थर्मल वातावरण और दो नाइट्रोजन स्तरों के लिए उजागर किया जा सके। (एन 1- एन और एन 2 की अनुशंसित खुराक - अनुशंसित एन से 25 प्रतिशत कम) मुख्य भूखंडों और दो सिंचाई स्तरों (आई 1- इष्टतम (अनुशंसित) सिंचाई (सीआरआई, संयुक्त, फूल और नरम आटा चरण में सिंचाई) और आई 2- उप में सिंचाई - 2017-18 और 2018-19 के लगातार दो रबी मौसमों के दौरान उप-भूखंडों में इष्टतम सिंचाई (अनुशंसित से एक सिंचाई कम) (सीआरआई में सिंचाई, फलैग लीफ उभरना और नरम आटा चरण)। 45 डीएस पर; टिलर / एम 2 की संख्या, 20 अक्टूबर को बोई गई फसल की ऊंचाई, शुष्क पदार्थ संचय और पत्ती क्षेत्र सूचकांक दोनों वर्षों के दौरान दोनों स्टेशनों पर बुवाई की अन्य तिथियों की तुलना में काफी अधिक था, लेकिन कटाई के समय, 5 नवंबर के तहत फसल की संख्या और पौधे की ऊंचाई सबसे अधिक थी। बोई गई फसल, जबकि सूखी मटकी पर संचय और पत्ती क्षेत्र सूचकांक 20 अक्टूबर बोई गई फसल के तहत काफी उच्चतम था। 5 नवंबर के तहत उपज और उपज के गुण काफी अधिक थे और 20 दिसंबर की बोई गई फसल के तहत काफी कम थे। गेहूं की फसल में उच्चतम WUE w.r.t का प्रदर्शन किया गया। 5 नवंबर की बुवाई (डी2) में पुआल और अनाज की पैदावार जो 20 अक्टूबर की बुवाई के बराबर थी और 20 दिसंबर (डी5) के तहत दोनों फसलों के मौसम में दोनों स्थानों पर बोई गई फसल के तहत पानी के उपयोग की दक्षता काफी कम थी। नाइट्रोजन की अनुशंसित खुराक और इष्टतम सिंचाई ने भी दोनों वर्षों के दौरान दोनों स्थानों पर काफी अधिक WUE का उत्पादन किया। अध्ययन ने निष्कर्ष निकाला कि अनुशंसित नाइट्रोजन और इष्टतम सिंचाई के साथ गेहूं की पहले बुवाई से विकास और उपज विशेषताओं के साथ-साथ दोनों कृषि क्षेत्रों में जल उपयोग दक्षता में काफी सुधार हो सकता है।

ABSTRACT. A field experiment was conducted in two agroclimatic zones of the Punjab (*viz.*, Ludhiana representing central plain zone and Bathinda representing south-western arid zone) to study the growth, yield and water use efficiency of wheat under abiotic stresses. The wheat variety HD-2967 was evaluated under five thermal environments (D1 - 20th October, D2 - 05th November, D3 - 20th November, D4 - 5th December and D5 - 20th December) to expose the crop to different thermal environments and two nitrogen levels (N1- Recommended dose of N and N2 - 25 per cent less than recommended N) in main plots and two irrigation levels (I1-Optimal (recommended) irrigation (Irrigation at CRI, Jointing, Flowering and Soft dough stage) and I2-Sub-optimal irrigation (one irrigation less than recommended) (Irrigation at CRI, Flag leaf emergence and Soft dough stage) in sub-plots during two consecutive rabi seasons of 2017-18 and 2018-19. At 45 DAS; number of tillers/m², plant height, dry matter accumulation and leaf area index in 20th October sown crop was significantly higher than other dates of sowing at both the stations during both the years. But at the time of harvesting, tiller count and plant height was highest under 5th November sown crop, whereas dry matter accumulation and leaf area index was significantly highest under 20th October sown crop. Yield and yield attributes were significantly highest under 5th November and significantly lowest under 20th December sown crop. Wheat crop exhibited significantly highest WUE w.r.t. straw and grain yield in 5th November sowing (D2) which was at par with that under 20th

October sowing and significantly lowest water use efficiency was observed under 20th December (D5) sown crop at both the locations during both crop seasons. Recommended dose of nitrogen and optimal irrigation also produced significantly higher WUE at both the locations during both the years. The study concluded that earlier sowing of wheat along with recommended nitrogen and optimal irrigation can significantly improve growth and yield attributes as well as water use efficiency in both the agroclimatic regions.

Key words – Wheat, Water use efficiency, Nitrogen, Irrigation, Abiotic stresses.

1. Introduction

Wheat (*Triticumaestivum* L.) contributes to a great extent to the national food security as it provides more than 50 per cent of the calories to the people relying on it (Barkha *et al.*, 2017). Wheat was grown in India over an area of about 30.23 million hectares with a production of 97.44 million tonnes during 2018-19 (Anonymous, 2018a). Whereas, in Punjab, it was grown on 35.00 lakh hectares with a production of 176.13 lakh tonnes and productivity of 47.50 quintals per hectare during 2017-18 (Anonymous, 2018b). Photoperiodically wheat is a long day plant and it requires photoperiod of a critical length of 14 to 18 hours (Pandey and Sinha, 2006). To meet the increasing demand of food grains, it is desired to have a higher yield per unit area. A number of factors including land preparation, time of sowing, fertilizer application, irrigation scheduling and weed management etc. are responsible for the variation in grain yield of wheat, but all these factors are greatly influenced by preventing weather conditions, *viz.*, rainfall, temperature and humidity etc. (Malik *et al.*, 2009). Temperature, moisture and nutrient are the major abiotic factors which affect the growth, development and yield of crops. In addition to this, increased concentrations of greenhouse gases and warming will have serious consequences like increased evaporation, uncertainty in rainfall and occurrence of extreme weather events like floods, droughts and heat waves etc. All these events have great impact on crop yields due to increase in abiotic and biotic stresses (Reddy and Hodges, 2000; IPCC, 2013).

Water is one of the most important factors necessary for proper growth, balanced development and higher yield of all crops. Water deficiency affects plant growth and grain yield (Hussain *et al.*, 2004). Irrigation management is one of the important managerial activities and effects the effective utilization of water by crop. Maximum grain yield (2.27 t/ha) was obtained with application of 200 mm irrigation treatment (Shirazi *et al.*, 2014). Under scarcity of water, four irrigation schedules at crown root initiation, tillering, flowering and milking stages recorded higher grain yield resulting in saving two irrigation for wheat (Kumar *et al.*, 2015). Irrigation at jointing and anthesis improved grain yield by an average of 12.70 and 18.65% as compared with no irrigation in wheat (Zhang *et al.*, 2017). The steep fall in groundwater levels in Punjab owing to excessive removal for agricultural and other uses

with high costs of fuel and electrical energy used in drawing groundwater. However, a holistic strategy to evolve integrated solutions for multiple problems has been elusive (Singh *et al.*, 2016).

As water scarcity is increasingly serious, there is a need for adopting optimum irrigation scheduling. Irrigation scheduling has been described as a primary tool to improve water use efficiency, crop yield and availability of water resources for other uses. In view of this, the present investigation was carried out to evaluate the growth, yield and water use efficiency of wheat under abiotic stresses in central and south-western Punjab.

2. Materials and method

2.1. Study area

A field experiment was conducted at the research farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana and Regional Research Station, Bathinda during *rabi* seasons of 2017-18 and 2018-19. Ludhiana is situated in central plain agroclimatic zone, representing the upper Indo-Gangetic alluvial plain located at 30°54' N latitude, 75°54' E longitude and 247 meter altitude above the mean sea level, whereas, Bathinda is situated in south-western zone located at 30°36' N latitude, 74°28' E longitude and 211 meter altitude above mean sea level. These two locations are characterized by sub-tropical semi-arid type of climate with hot summers and severe cold winter. May is the hottest month and January is the coolest month at both the locations. During winter, the night time temperature can be as low as 0 °C, whereas during hot summer months, day time temperature can be as high as near 50 °C. The average annual rainfall is 755 and 400 mm for Ludhiana and Bathinda, respectively, approximately 75 per cent of which is received during south-west monsoon season (June to September). During winter months, the rainfall is received from western disturbances. The soil is loamy sand with alkaline reaction at Ludhiana and sandy loam at Bathinda.

2.2. Experimental details

The experiment was laid out in Split Plot Design with twenty treatments by keeping dates of sowing in

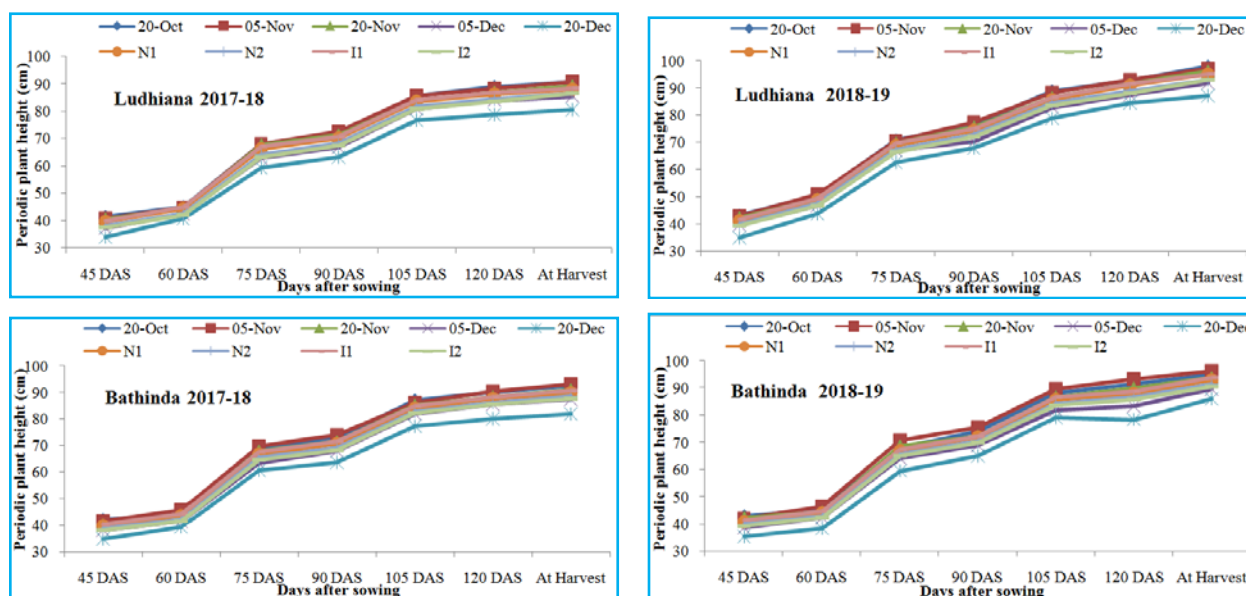


Fig. 1. Periodic plant height (cm) as influenced by different sowing dates, nitrogen and irrigation levels at Ludhiana and Bathinda during *rabi* 2017-18 and 2018-19

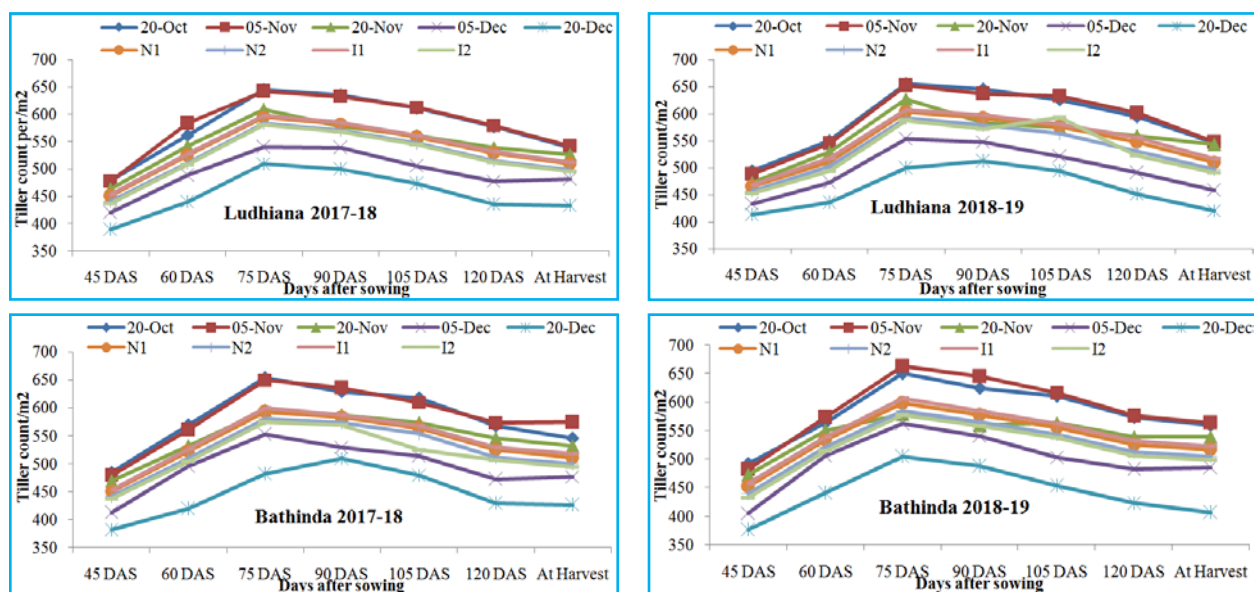


Fig. 2. Periodic tiller count (m^{-2}) as influenced by different sowing dates, nitrogen and irrigation levels at Ludhiana and Bathinda during *rabi* 2017-18 and 2018-19

main plots and nitrogen and irrigation levels (in combination) in sub-plots in three replications. The treatments included five sowing dates; 20th October (D₁), 05th November (D₂), 20th November (D₃), 5th December (D₄) and 20th December (D₅) in main plots; two nitrogen levels; N₁- Recommended dose of Nitrogen and N₂ - 25 per cent less than recommended dose of nitrogen and two irrigation levels in sub plots; I₁ - Optimal (recommended) irrigation (Irrigation at CRI, Jointing,

Flowering and Soft dough stage) and I₂ - Sub-optimal irrigation (Irrigation at CRI, Flag leaf emergence and Soft dough stage).

2.3. Observations recorded

The growth attributes, *viz.*, plant height (cm), number of tillers/m², leaf area index and dry matter accumulation were recorded at 45 days after sowing at

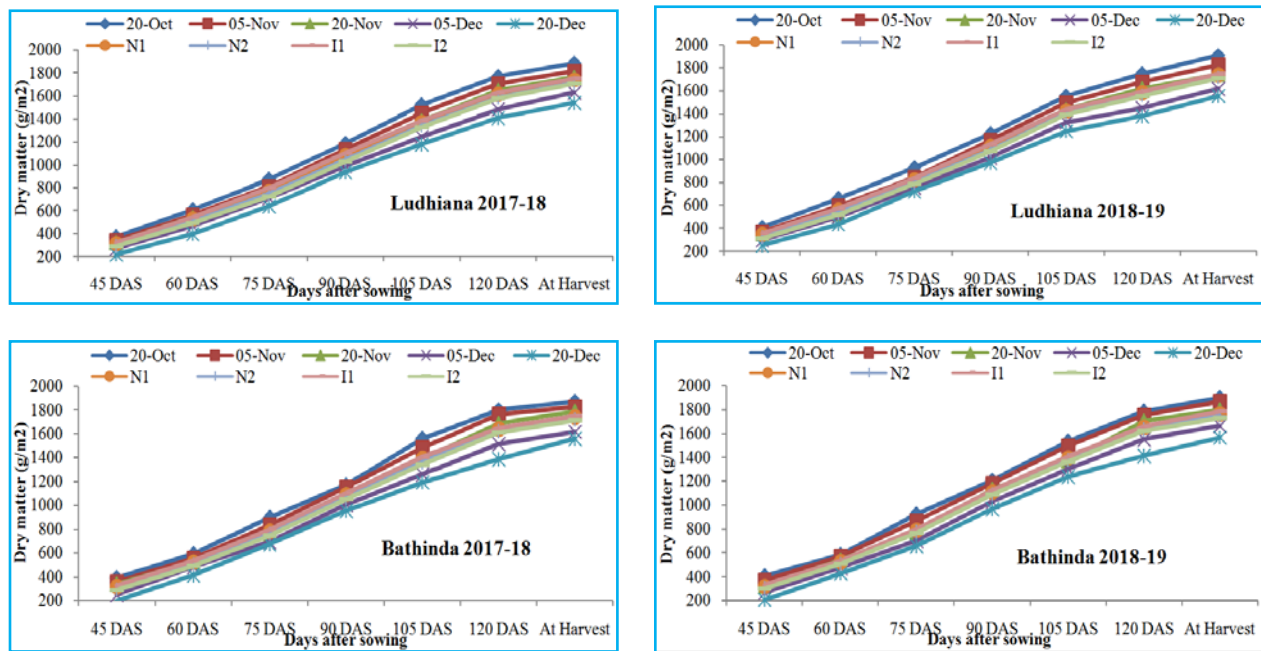


Fig. 3. Periodic dry matter accumulation (g/m²) as influenced by different sowing dates, nitrogen and irrigation levels at Ludhiana and Bathinda during *rabi* 2017-18 and 2018-19

15 days interval upto maturity. The yield attributes, viz., number of spikes, spike length, number of grains/spike and 1000-grain weight was recorded at harvest. Biological and grain yield were recorded from the net plot size. Straw yield was calculated by subtracting the grain yield from biological yield.

2.4. Computation of crop water use

Total water use during growth season of crop was obtained from summation of root zone soil water depletion at successive time intervals as given below:

The retention at each soil moisture sampling is given by:

$$\text{Root zone water retention} = \sum_{i=1}^n D$$

where,

i = Soil depth interval, e.g., 0-15 cm, 15-30cm.....90-120cm

D = Depth of water retained in the respective soil depth interval

n = Number of soil layers

In order to compute soil water depletion, the difference in water retention between the two successive samplings was taken as soil water use by the crop (Kingra and Mahey, 2009).

2.5. Water use efficiency

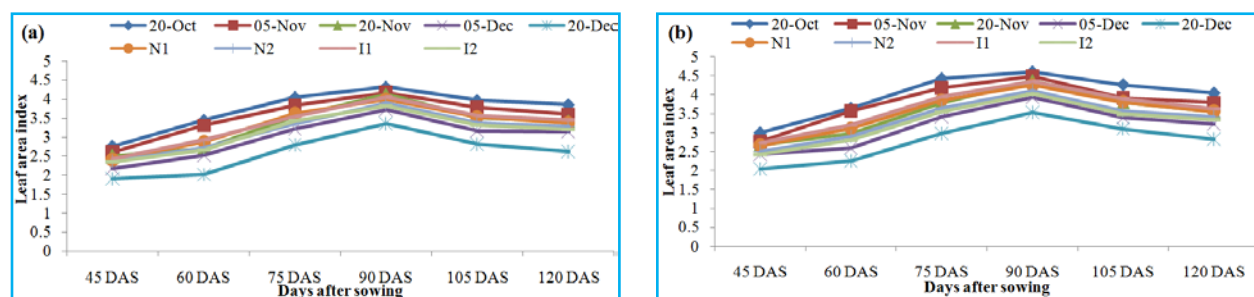
Water use efficiency was computed as following:

$$\text{Water use efficiency (WUE)(kg/ha/mm)} = \frac{\text{Grain yield(kg/ha)}}{\text{Water used by the crop(mm)}}$$

3. Results and discussion

3.1. Growth attributes

At 45 DAS, the number of tillers/m² (479.25, 493.50 and 484.50, 492.08 per m², respectively during 2017-18 and 2018-19 at Ludhiana and Bathinda), plant height (41.77, 43.08 and 42.08, 43.00 cm, respectively during 2017-18 and 2018-19 at both the stations), dry matter accumulation (371.89, 409.20 and 387.50, 404.00 g/m², respectively during 2017-18 and 2018-19 at both the stations) and leaf area index in 20th October sown crop was significantly highest (2.75 and 2.99 during 2017-18 and 2018-19 at Ludhiana) than other sowing dates at both the locations during both years. However, at the time of harvesting, tiller count (538.42, 546.25 and 574.50, 564.00 per m², respectively, during 2017-18 and 2018-19



Figs. 4(a&b). Periodic leaf area index as influenced by different sowing dates, nitrogen and irrigation levels at Ludhiana during *rabi* (a) 2017-18 and (b) 2018-19

at Ludhiana and Bathinda) and plant height (90.65, 97.25 and 93.08, 96.17, respectively, during 2017-18 and 2018-19 at both the stations) were highest under 5th November sown crop and dry matter accumulation (1882.84, 1908.98 and 1872.55, 1896.25 g/m², respectively, during 2017-18 and 2018-19 at Ludhiana and Bathinda) and leaf area index (3.85 and 4.04 during 2017-18 and 2018-19 at Ludhiana) were significantly highest under 20th October sown crop (Figs. 1-4). Earlier studies have also reported decrease in plant height (Gupta *et al.*, 2007 and Shirpurkar *et al.*, 2007), LAI (Mishra *et al.*, 2003 and Shivani *et al.*, 2003) and dry matter accumulation (Gupta *et al.*, 2010 and Mukherjee, 2012) with delay in sowing of wheat.

Tiller count, plant height, dry matter accumulation and leaf area index was significantly higher in case of recommended nitrogen application (N₁) as compared to 25% lower dose (N₂) treatment at all the growth stages of wheat crop. At harvesting, the tiller count (509.30, 509.43 and 511.83, 517.40 per m², respectively during 2017-18 and 2018-19 at both the stations), plant height (87.98, 95.07 and 89.90, 92.87 cm, respectively, during 2017-18 and 2018-19 at Ludhiana and Bathinda), dry matter accumulation (1740.10, 1739.70 and 1741.00, 1765.80 g/m², respectively during 2017-18 and 2018-19 at both stations) and leaf area index was significantly higher in N₁ (3.37 and 3.56 during 2017-18 and 2018-19 at Ludhiana) than N₂ during 2017-18 and 2018-19 at Ludhiana and Bathinda. Among irrigation treatments, the tiller count (513.03, 516.03 and 517.47, 522.47 per m², respectively during 2017-18 and 2018-19 at both the stations), plant height (88.18, 95.17 and 90.63, 93.67 cm, respectively, during 2017-18 and 2018-19 at Ludhiana and Bathinda), dry matter accumulation (1747.70, 1747.90 and 1750.00, 1783.20 g/m², respectively during 2017-18 and 2018-19 at both stations) and leaf area index were significantly higher in optimal irrigation (3.45 and 3.63 during 2017-18 and 2018-19 at Ludhiana) than sub-optimal irrigation at all the growth stages during both the years at both the locations. Kibe and Singh (2003) also reported positive effect of irrigation on tiller density of wheat. Pal *et al.* (2000) reported that with higher number of irrigations, an

increase in the number of productive tillers takes place. Pandey *et al.* (1997) also reported a marked increase in leaf area index with increasing amount of irrigation.

Increase in plant height at higher level of irrigation could be possible due to maintenance of constant water supply to the plants, which maintained various metabolic processes. The results are in agreement with the findings of Rahman *et al.* (2006) and Brahma *et al.* (2007). Adequate supply of nutrients favoured the nutrient uptake and nutrient utilization towards protein which favoured vertical and lateral growth of the plant and ultimately increase the area of leaves, the results are in agreement with the findings of Bondey *et al.* (2004) and Laghari (2010). The higher dry matter at higher fertility level might be due to proper nutrition availability which resulted in increased vegetative growth of plants. Similar results also reported by Laghari *et al.* (2010) and Kale *et al.* (2015).

3.2. Yield attributes

The yield attributing characters, *viz.*, no. of effective tillers/m², ear length (cm), no. of grains/ear and 1000-grain weight of wheat crop were significantly influenced by different sowing dates, nitrogen and irrigation levels (Table 1). At both the stations, during 2017-18 and 2018-19; number of effective tillers/m² (471.67, 492.50 and 486.00, 488.25 per m², respectively, during both years at Ludhiana and Bathinda), ear length (10.61, 11.81 and 11.22, 11.94 cm, respectively, during 2017-18 and 2018-19 at both the stations), no. of grains/ear (69.68, 73.87 and 68.33, 72.25 per ear, respectively, during both years at Ludhiana and Bathinda) and 1000-grain weight (43.42, 46.00 and 43.33, 45.42, respectively, during 2017-18 and 2018-19 at Ludhiana and Bathinda) were significantly highest under 5th November sown crop followed by 20th October, 20th November, 5th December and significantly lowest under 20th December sown crop. Shirpurkar *et al.* (2007) also reported that with delayed sowing, there was significant decrease in number of effective tillers. Gupta *et al.* (2010) also reported that

TABLE 1
Yield attributing characters of wheat under different dates of sowing, nitrogen and irrigation levels at Ludhiana and Bathinda during rabi 2017-18 and 2018-19

Treatment	Yield Attributing Characters															
	No. of Effective Tillers/m ²				Ear Length (cm)				No. of Grains/Ear				1000 Grain Weight			
	Ludhiana		Bathinda		Ludhiana		Bathinda		Ludhiana		Bathinda		Ludhiana		Bathinda	
	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
Sowing Time																
Oct 20	451.00	461.33	459.33	456.25	11.03	12.03	12.02	10.89	61.60	67.00	63.58	65.17	40.20	43.50	39.17	40.67
Nov 5	471.67	492.50	486.00	488.25	10.61	11.81	11.22	11.94	69.68	73.87	68.33	72.25	43.42	46.00	33.33	45.42
Nov 20	436.83	478.25	454.00	469.50	10.50	11.27	10.08	10.55	65.65	70.58	66.50	64.33	42.00	43.83	41.08	42.58
Dec 5	383.92	442.33	382.58	411.83	9.85	10.13	9.44	9.21	54.35	62.08	51.75	55.00	39.92	40.75	40.50	37.83
Dec 20	313.17	422.42	307.00	401.92	9.22	9.66	8.56	8.28	40.55	47.28	43.25	40.33	36.92	37.42	37.25	35.25
CD (p = 0.05)	19.40	10.29	18.53	7.65	0.23	0.69	0.56	0.54	1.58	3.43	2.01	3.51	1.30	2.63	1.07	2.53
Nitrogen levels																
Recommended (125 kg/ha)	418.67	465.10	426.07	449.97	10.37	11.12	10.53	10.36	59.41	65.21	59.43	60.20	41.15	43.30	40.90	40.90
25 % less than recommended	400.47	453.63	409.50	441.13	10.11	10.83	10.00	9.98	57.32	63.11	57.93	58.63	39.83	41.30	39.63	39.80
CD (p = 0.05)	12.10	10.95	13.43	6.15	0.16	0.24	0.26	0.25	0.99	2.02	0.90	1.04	0.59	1.39	0.81	0.84
Irrigation levels																
Optimal irrigation	424.57	471.30	439.07	454.80	10.37	11.17	10.74	10.51	59.79	65.55	60.10	60.90	37.50	44.63	41.53	41.57
Sub-optimal irrigation	394.07	447.43	396.50	436.30	10.11	10.78	9.79	9.83	56.95	62.78	57.27	57.93	36.33	39.97	39.00	39.13
CD (p = 0.05)	12.10	10.95	13.43	6.15	0.16	0.24	0.26	0.25	0.99	2.02	0.90	1.04	0.59	1.39	0.81	0.84

under normal sown wheat crop, there was higher thousand grain weight as compared to delayed sowing.

In case of nitrogen treatments, a significant difference in number of effective tillers/m², ear length, no. of grains/ear and 1000-grain weight was observed. Number of effective tillers/m² (418.67, 465.10 and 426.07, 449.97 per m², respectively, during both years at Ludhiana and Bathinda), ear length (10.37, 11.12 and 10.53, 10.36 cm, respectively, during 2017-18 and 2018-19 at both the stations), no. of grains/ear (59.41, 65.21 and 59.43, 60.20 per ear, respectively, during both years at Ludhiana and Bathinda) and 1000-grain weight (41.15, 43.30 and 40.90, 40.90, respectively, during 2017-18 and 2018-19 at Ludhiana and Bathinda) were significantly higher in case of N₁ level as compared to N₂ level. Among irrigation treatments, *i.e.*, optimal irrigation (I₁) and sub-optimal irrigation (I₂), number of effective tillers/m² (424.57, 471.30 and 439.07, 454.80 per m², respectively, during both years at Ludhiana and Bathinda), ear length (10.37,

11.17 and 10.74, 10.51 cm, respectively, during 2017-18 and 2018-19 at both the stations), no. of grains/ear (59.79, 65.55 and 60.10, 60.90 per ear, respectively, during both years at Ludhiana and Bathinda) and 1000-grain weight (37.50, 44.63 and 1.53, 41.57, respectively, during 2017-18 and 2018-19 at Ludhiana and Bathinda) was higher in case of optimal irrigation than sub-optimal irrigation. Pal *et al.* (2000) also reported increase in the number of productive tillers under more frequent irrigation application.

3.3. Grain and straw yield

Grain (q/ha) and straw yield (q/ha) were significantly influenced by different sowing dates, nitrogen and irrigation levels (Fig. 5). Among dates of sowing, significantly highest grain yield (50.87, 52.25 and 51.33, 52.92 q/ha, respectively during both the years and at both the stations) and straw yield (97.50, 100.27 and 95.68, 98.50 q/ha, respectively, during 2017-18 and

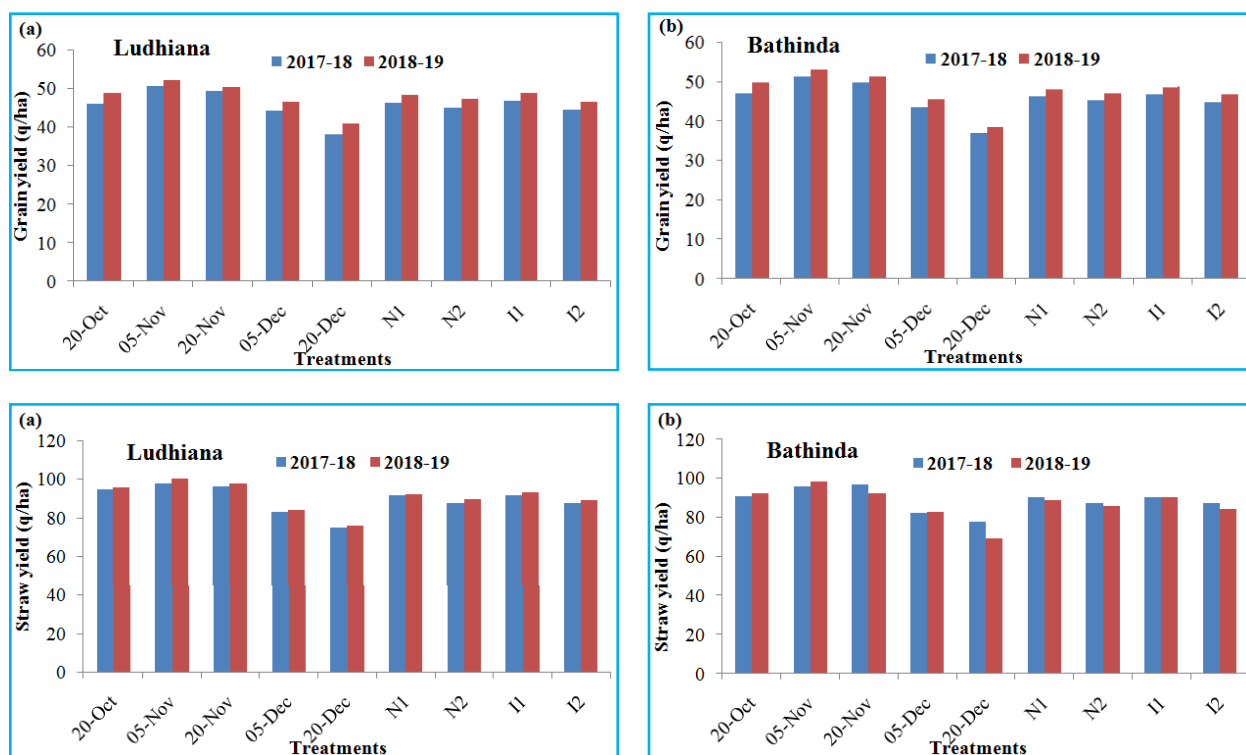


Fig. 5. Grain and straw yield (q/ha) of wheat as influenced by different sowing dates, nitrogen and irrigation levels at Ludhiana during *rabi* 2017-18 and 2018-19 at Ludhiana and Bathinda

2018-19 at both the stations) was obtained under 5th November sown crop and significantly lowest under 20th December sown crop at Ludhiana and Bathinda during 2017-18 and 2018-19. Sardana *et al.* (2002) also found that delay in sowing from 15th November to 15th December significantly decreased wheat grain yield (Fig. 5). Meena *et al.* (2015) reported that significantly higher grain yield was produced in 1st November sown crop and was statistically at par with the crop sown on 16th November. Shirpurkar *et al.* (2007) reported that under normal sowing of wheat higher grain yield was recorded than late sown wheat. Sardana *et al.* (2002) reported that sowing time significantly influenced the growth, yield attributes, grain and straw yields.

Among nitrogen and irrigations levels, recommended nitrogen and optimal irrigation level had significant effect on biological, grain and straw yield during both years and at both locations. With increase in levels of irrigation, an increase in biological yield was also observed by Akram (2011). Huang *et al.* (2005) also reported that with more irrigation levels, there is increase in biomass production.

3.4. Crop water use

Among different dates of sowing, wheat crop extracted significantly higher water (388.65 and

391.28 mm at Ludhiana and 393.63 and 389.83 mm at Bathinda) under 20th October and (388.25 and 389.46 mm at Ludhiana and 386.53 and 389.78 mm at Bathinda) under 5th November sowing and significantly lowest under 20th December (321.97 and 328.70 mm at Ludhiana and 334.43 and 334.23 mm at Bathinda) during 2017-18 and 2018-19 (Table 2). Among the nitrogen and irrigation levels, water use was observed to be significantly higher under recommended nitrogen dose (368.91 and 369.81 mm at Ludhiana and 371.30 and 372.02 mm at Bathinda) and optimal irrigation (374.72 and 376.40 mm at Ludhiana and 377.29 and 379.51 mm at Bathinda). Singh and Kingra (2015) also reported decrease in moisture extraction with delay in sowing of wheat and reduction in irrigation frequency in wheat.

3.5. Water use efficiency

During both the years at both the stations, the crop sown on 5th November (D_2) (26.15, 25.21 and 24.29, 24.20 kg/ha-mm for straw yield and 13.50, 13.92 and 13.58, 13.88 kg/ha-mm for grain yield at Ludhiana and Bathinda, respectively during 2017-18 and 2018-19) exhibited highest WUE w.r.t. straw and grain yield which was at par with that under 20th October (D_1) and significantly higher than other dates of sowing (Table 2). Significantly lowest water use efficiency was observed

TABLE 2

Water use and its utilisation efficiency w.r.t. grain and straw yield of wheat under different dates of sowing, nitrogen and irrigation levels during *rabi* 2017-18 and 2018-19 at Ludhiana and Bathinda

Treatment	Water use				Water use efficiency w.r.t. grain yield (kg/ha/mm)				Water use efficiency w.r.t. straw yield (kg/ha/mm)			
	Ludhiana		Bathinda		2017-18		2018-19		2017-18		2018-19	
Date of Sowing												
Oct 20	388.65	391.28	393.63	389.83	13.39	13.47	13.44	13.70	25.17	24.27	24.16	24.00
Nov 05	388.25	389.46	386.53	389.78	13.50	13.92	13.58	13.88	26.15	25.21	24.29	24.20
Nov 20	373.77	372.51	368.10	369.46	13.13	13.24	13.12	13.59	25.11	24.58	24.09	23.85
Dec 05	349.41	346.09	352.08	350.37	12.77	12.85	12.39	13.03	24.07	23.85	23.44	23.56
Dec 20	321.97	328.70	334.43	334.23	11.97	12.04	11.05	11.52	23.47	23.63	23.00	23.03
CD (p = 0.05)	13.50	14.35	7.92	4.04	0.20	0.17	0.27	0.13	0.40	0.30	0.51	0.25
Nitrogen levels												
Recommended (125 kg/ha)	368.91	369.81	371.30	372.02	12.63	13.34	12.45	12.94	24.82	24.58	24.15	24.11
25% less than recommended	359.91	361.41	362.61	363.04	12.59	13.25	12.46	12.94	24.33	23.72	23.24	23.23
CD (p = 0.05)	1.86	3.36	2.12	2.25	NS	NS	NS	NS	0.13	0.21	0.14	0.15
Irrigation levels												
Optimal irrigation	374.72	376.40	377.29	379.51	12.63	13.37	12.49	13.07	24.76	24.63	24.07	24.15
Sub-optimal irrigation	354.10	354.81	356.61	355.55	12.58	13.21	12.42	12.82	24.40	23.67	23.32	23.18
CD (p = 0.05)	1.86	3.36	2.12	2.25	NS	0.12	NS	0.08	0.13	0.21	0.14	0.15

TABLE 3

Relation of water use with growth, yield attributes and yield of wheat

Production function	Equation	R ²	Equation	R ²
	2017-18		2018-19	
Ludhiana				
Tiller count/m ²	Y= 16.26x-91.14	0.68	Y=14.26x-15.41	0.86
Plant height	Y=1.44x+32.75	0.81	Y=1.33x+41.24	0.82
Leaf area index	Y=0.14x-1.71	0.70	Y=0.15x-2.07	0.83
Dry matter	Y=39.32x+290.25	0.73	Y=41.71x+205.76	0.86
Effective tillers/m ²	Y=7.91x+170.07	0.51	Y=20.29x-330.02	0.84
Ear length	Y=0.22x+2.31	0.75	Y=0.305x-0.15	0.68
No. of grains/ear	Y=2.58x-30.28	0.57	Y=3.21x-58.68	0.77
1000-grain weight	Y= 1.10x+1.90	0.52	Y=0.71x+14.58	0.61
Grain yield	Y=1.21x+3.59	0.65	Y=1.42x-6.09	0.75
Biological yield	Y=4.05x-9.22	0.75	Y=4.39x-24.64	0.82
Straw yield	Y=2.83x-12.80	0.73	Y=2.96x-18.55	0.80
Bathinda				
Tiller count/m ²	Y=20.48x-252.19	0.76	Y= 17.69x-145.39	0.80
Plant height	Y=2.01x+12.30	0.74	Y=1.53x+30.62	0.77
Dry matter	Y=43.68x+122.07	0.79	Y=43.33x+142.19	0.80
Effective tillers/m ²	Y=10.38x+58.85	0.59	Y=25.35x-516.18	0.82
Ear length	Y=0.45x-6.76	0.73	Y=0.50x-8.03	0.80
No. of grains/ear	Y=3.26x-61.44	0.72	Y=3.61x-75.17	0.73
1000-grain weight	Y= 0.70x+14.62	0.41	Y= 1.12x-1.53	0.53
Grain yield	Y=1.79x-20.01	0.71	Y=1.76x-17.81	0.72
Biological yield	Y=4.19x-19.88	0.70	Y=5.52x-60.79	0.74
Straw yield	Y=2.41x+0.13	0.62	Y=3.51x-43.46	0.69

under 20th December (D₅) sown crop. Among nitrogen treatments, WUE was higher in N₁ (24.82, 24.58 and 24.15, 24.11 kg/ha-mm for straw yield and 12.63, 13.34 and 12.45, 12.94 kg/ha-mm for grain yield, respectively during 2017-18 and 2018-19 at Ludhiana and Bathinda) than N₂. For irrigation levels, WUE was more in optimal irrigation (I₁) (24.76, 24.63 and 24.07, 23.32 kg/ha-mm for straw yield and 12.63, 13.37 and 12.49, 13.07 kg/ha-mm for grain yield, respectively during 2017-18 and 2018-19 at Ludhiana and Bathinda) than sub-optimal (I₂) level. On an average, WUE was more in 2017-18 in comparison to 2018-19. Singh and Kingra (2015) also observed higher WUE in earlier sown wheat crop.

3.6. Crop water production functions

Water use explained 67.7, 81.5, 70.2 and 73.4 per cent variation in 2017-18 and 85.7, 82.2, 82.6 and 80.4 per cent variation in number of tillers/m², plant height (cm), leaf area index and dry matter accumulation (g/m²), respectively in 2018-19 at Ludhiana. At Bathinda, the regression relationship explained 75.3, 73.7, 72.6 and 50.8 per cent variation in 2017-18 and 80.4, 76.6, 85.7 and 83.9 per cent variation in number of tillers/m², plant height (cm), leaf area index and dry matter accumulation (g/m²), respectively in 2018-19 (Table 3). The regression relationship explained 50.8, 74.7, 57.3 and 52.4 per cent variation in 2017-18 and 83.9, 68.1, 76.7 and 61.3 per cent variation ineffective tillers/m², ear length (cm), number of grains/ear and 1000 grain weight, respectively in 2018-19 at Ludhiana. At Bathinda, the regression relationship explained 58.7, 73.4, 71.9 and 41.0 per cent variation in 2017-18 and 82.4, 80.4, 72.8 and 53.3 per cent variation ineffective tillers/m², ear length (cm), number of grains/ear and 1000 grain weight, respectively in 2018-19. The regression relationship explained 64.6, 75.1 and 73.0 per cent variation in 2017-18 and 75.1, 82.3 and 79.8 per cent variation in grain yield, biological yield and straw yield, respectively in 2018-19 at Ludhiana. At Bathinda, the regression relationship explained 71.3, 70.4 and 61.7 per cent variation in 2017-18 and 72.0, 73.4 and 69.1 per cent variation in grain yield, biological yield and straw yield, respectively in 2018-19.

4. Conclusions

Among growth attributes, at the time of harvesting, tiller count and plant height was significantly highest under 5th November sown crop and dry matter accumulation and leaf area index was significantly highest under 20th October sown crop. In general, earlier sowing along with recommended nitrogen and optimal irrigation application significantly improved growth and yield attributes, grain and straw yield of wheat. Water use by the crop significantly decreased with delay in sowing and

lower nitrogen and sub-optimal irrigation application. However, water use efficiency was found to be higher under earlier sown crop with recommended nitrogen application. The study concluded that sowing of wheat during 20th October to 5th November along with recommended nitrogen and optimal irrigation are crucial to improve its water utilization efficiency.

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References

- Akram, M., 2011, "Growth and yield components of wheat under water stress of different growth stages", Bangladesh, *J. Agril. Res.*, **36**, 455-468.
- Anonymous, 2018a, Website: <http://www.indiastat.com>.
- Anonymous, 2018b, Package of practices for rabi crops of Punjab. Punjab Agricultural University, Ludhiana, Punjab.
- Barkha, Bhanvadia, A. S. and Dholiya, S. N., 2017, "Yield, water use efficiency and economics of wheat (*Triticumaestivum* L.) as influenced by drip irrigation scheduling and nitrogen levels", *J. of Pharmacogn. Phytochem.*, **6**, 314-316.
- Bondey, A. N., Karle, B. G., Deshmukh, M. S., Tekale, K. V. and Patil, V. P., 2004, "Effect of different organic residues on physico-chemical properties of soil in cotton soyabean intercropping in vertisols", *J. Soils and Crops.*, **14**, 112-115.
- Brahma, R., Janawade, A. D. and Palled, Y. B., 2007, "Effect of irrigation schedules, mulch and anti-transpirant on growth, yield and economics of wheat (cv. DWD-1006)", Karnataka, *J. Agric. Sci.*, **20**, 6-9.
- Gupta, A. K., Gupta, M. and Singh, P., 2007, "Production potential of wheat (*Triticumaestivum*) cultivars under late and very late sown conditions in Jammu", *Env. Eco.*, **25**, 1198-1200.
- Gupta, R., Gopal, R. and Jat, H. L., 2010, "Wheat productivity in Indo-Gangetic plains of India during 2010 : terminal heat effects and mitigation strategies", *Conserv. Agric. News Lett.*, PACA **14**, 9.
- Huang, Y., Chen, L., Fu, B., Huang, Z. and Gong, J., 2005, "Wheat yields and water-use efficiency in the Loess Plateau: straw mulch and irrigation effects", *Agric. water Manage.*, **72**, 209-222.
- Hussain, A., Ghaudhry, M. R., Wajad, A., Ahmed, A., Rafiq, M. and Ibrahim, M., 2004, "Influence of water stress on growth, yield and radiation use efficiency of various wheat cultivars", *Int. J. Agric. Biol.*, **6**, 1074-1079.
- IPCC, 2013, "Working Group 1, fifth assessment report on climate change, The physical science basis, Geneva, Switzerland.
- Kale, S. T., Kadam, S. R., Gokhle, D. N. and Waghmare, P. K., 2015, "Response of wheat varieties to different levels of fertilizer on growth and yield under late sown condition", *Int. J. of Agri. Sci.*, **11**, 77-80.
- Kibe, A.M. and Singh, S., 2003, "Influence of irrigation nitrogen and zinc on productivity and water use by late sown wheat (*Triticumaestivum* L.)", *Indian J. Agron.*, **48**, 186-191.

- Kingra, P. K. and Mahey, R. K., 2009, "Moisture extraction pattern and ET-yield models in wheat under different management practices in central Punjab", *J. Agrometeorol.*, **15**, 51-57.
- Kumar, R. and Ahmed, A., 2015, "Effect of irrigation scheduling on growth and yield of wheat genotype", *J. Agron.*, **35**, 199-202.
- Laghari, G. M., Oad, F. C., Gandahi, S. T. A. W., Siddiqui, M. H., Jagirani, A. W. and Oad, S. M., 2010, "Growth, yield and nutrient uptake of various wheat cultivars under different fertilizer regimes", *J. of Agri.*, **26**, 489-497.
- Malik, A. U., Haji, M. A., Bukhsh, A., Hussain, I., Athar, M. A. and Ali, M., 2009, "Comparative performance of some new wheat cultivars in agro-ecological zone of Dera Ghazi Khan", *J. Animal & Plant Sci.*, **19**, 78-81.
- Meena, R. K., Parihar, S. S., Singh, M. and Khanna, M., 2015, "Influence of date of sowing and irrigation regimes on crop growth and yield of wheat (*Triticumaestivum* L.) and its relationship with temperature in semi-arid region", *Ind. J. Agron.*, **60**, 92-98.
- Mishra, V., Mishra, R. D., Singh, M. and Verma, R. S., 2003, "Dry matter accumulation at pre and post anthesis and yield of wheat (*Triticumaestivum* L.) as affected by temperature stress and genotypes", *Indian J. Agron.*, **48**, 277-281.
- Mukherjee, D., 2012, "Effect of different sowing dates on growth and yield of wheat (*Triticumaestivum* L.) cultivars under mid hill situation of West Bengal", *Indian J. Agron.*, **57**, 152-156.
- Pal, S. K., Verma, U. N., Thakur, R., Singh, M. K. and Upasani, R. R., 2000, "Dry matter partitioning of late sown wheat under different irrigation schedules", *Indian J. Agric. Sci.*, **70**, 831-834.
- Pal, S. K., Verma, U. N., Thakur, R., Singh, M. K. and Upasani, R. R., 2000, "Dry matter partitioning of late sown wheat under different irrigation schedules", *Indian J. Agric. Sci.*, **70**, 831-834.
- Pandey, D. S., Kumar, D., Misra, R. D., Prakash, A. and Gupta, V. K., 1997, "An integrated approach of irrigation and fertilizer management to reduce lodging in wheat (*Triticumaestivum*)", *Indian J. Agron.*, **42**, 86-89.
- Pandey, S. N. and Sinha, B. K., 2006, "Plant physiology", 4th Edition. Vikas Publishing House Pvt. Ltd, New Delhi, 485-487.
- Rahman, M. A., Karim, A. J. M. S., Haque, M. M. and Eqashira, K., 2006, "Effect of irrigation and nitrogen fertilization on plant growth and root characteristics of wheat on a clay terrace soil of Bangladesh", *J. Faculty of Agric.*, **45**, 301-308.
- Reddy, K. R. and Hodges, H. F., 2000, "Climate change and global crop productivity", (Reddy, K. R. and Hodges, H. F. eds.) CAB International Wallingford U.K. 1-5.
- Sardana, V., Sharma, S. K. and Randhawa, A. S., 2002, "Performance of wheat under different sowing dates and nitrogen level in the sub-montane region of Punjab", *Indian J. Agron.*, **47**, 372-377.
- Shirazi, S. M., Yusop, Z., Zardari, N. H. and Ismail, Z., 2014, "Effect of Irrigation Regimes and Nitrogen Levels on the Growth and Yield of Wheat", *Advances Agric.*, 1-6.
- Shirpurkar, G. N., Kashid, N. V. and Pisal, A. A., 2007, "Effect of different sowing dates and varieties on yield and yield attributes of wheat", *Agric. Sci. Digest*, **27**, 68-70.
- Shivani, Verma, U. N., Kumar, S., Pal, S. K. and Thakur, R., 2003, "Growth analysis of wheat (*Triticumaestivum* L.) cultivars under different seeding dates and irrigation levels in Jharkhand", *Indian J. Agron.*, **48**, 282-286.
- Singh, A., Singh, D., Kang, J. S. and Aggarwal, N., 2016, "Management practices to mitigate the impact of high temperature on wheat", A review. *IIOABJ*, **2**, 11-22.
- Singh, Sukhvir and Kingra, P. K., 2015, "Evapotranspiration and water productivity of wheat under different hydrothermal regimes", *Agric. Res. J.*, **52**, 48-53.
- Zhang, P., Geng, M., Wang, C., Hongfang, L., Shasha, L. and Yingxin, X., 2017, "Effect of irrigation and nitrogen application on grain amino acid composition and protein quality in winter wheat", *J. Agron.*, **12**, 152-159.
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