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Agrometeorological indices, heat use efficiency and productivity of wheat (*Triticum aestivum*) as influenced by dates of sowing and irrigation

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Abstract
A field experiment was conducted during *Rabi* 2007-08, 2008-09 and 2009-10 at Instructional Farm, Rajasthan College of Agriculture, Udaipur. The treatment comprised of four sowing dates (7th November, 19th November, 4th December and 19th December) and four irrigation levels (three, four, five and six). Result revealed that the magnitude of reduction in number of tillers/m row was more due to higher minimum temperature. The maximum heat units of 1701 degree days were recorded under 19th November sown crop with six irrigation. The increase in 6.0 ^{0}C mean temperature between 90 to 105 DAS caused reduction in number of effective tillers/m/row at 105 DAS by 15.0 per cent. The highest grain yield was obtained under 19th November sown crop followed by 7th November sown crop during both the years. The mean temperature experienced during heading to milking was in the range of 14.5-15.0 ^{o}C, 18.0-19.0 ^{o}C and 18.1-19.1 ^{o}C during 2007-08, 2008-09 and 2009-10 respectively. The delay sowing caused reduction of 25.7 and 41.9 per cent grain yield in 4th December (D_3) and 19th December (D_4) sown crop, respectively as compared to 19th November sown crop (D_2). The highest heat use efficiency for total dry matter and grain yield (8.94 and 2.74 kg/ha/ ^{0}C) was recorded under 7th November sown crop.

Keywords: Temperature, yield, wheat, irrigation, heat unit efficiency, heat units

Introduction
Central Temperature is an important environmental factor that affects plant growth, development and yield. Changes in seasonal temperature affect the productivity through the changes in phenological development process of the crop. Winter crops are especially vulnerable to thermal stress particularly in reproductive phase and differential response of temperature change to various crops has been noticed under different production environment (Kalra *et al* 2008) [5]. Hundal (2004) [3] also observed that increase of temperature by 2 ^{0}C in wheat resulted in 15-17 per cent reduction in grain yield. Next to paddy, wheat is an important winter season crop in the northern India. Cool weather during vegetative period and warm weather during maturity are ideal requirement for wheat. Wheat grain yields generally decline as temperature increases. Temperature stress intensity is severe under late sowing, causing reduction in the duration of later growth phases (Mavi and Tupper, 2005) [6]. Various phenophases of wheat is also sensitive to temperature. In recent past, the area and productivity of wheat in India is fluctuating due to climate change. Among the climatic variable air temperature is the most important that affects plant life. Taking cognizance of the fact mentioned above, present investigation was carried out to assess the impact of temperatures on growth and productivity of wheat.

Materials and Methods
A field experiment was conducted at Instructional Farm, Rajasthan College of Agriculture, Udaipur (Rajasthan) during *Rabi* season of 2007-08, 2008-09 and 2009-10. The geographical co-ordinates of the station are 24^{0} 34'N latitude, 73^{0} 42'E longitude and altitude of 582.2 m above mean sea level. The mean annual rainfall of the centre is 600.8 mm most of which (91.5 %) is contributed by south west monsoon during June to September. The winter rains contributed very negligible amount. The weekly mean maximum and minimum temperatures ranges from 23.3 to 33.0 ^{0}C and 5.1 to 14.9 ^{0}C, respectively during *Rabi* season. The soil was clay loam in texture having 240 kg N, 20.0 kg P_2O_5 and 290.6 kg K_2O/ha with pH 8.1 and EC of 1.12 d sm^{-1} at 25 ^{0}C. The experiment consisted of four sowing dates viz. 7th November (D_1), 19th November (D_2), 4th December (D_3) and

19th December (D_4), and four irrigation levels viz. three (I_3), four (I_4), five (I_5) and six (I_6). The experiment was laid out in spilt plot design with four replications. The wheat variety Raj-3077 was fertilized with 120 kg N, 40 kg P_2O_5/ha using a seed rate of 125 kg/ha.

Results and Discussion

Agrometeorological indices

Growing degree days (GDD) heat unit requirement, was worked out by using field experiment data (2007-08 to 2009-10), for completion of maturity stage of wheat variety Raj-3077 were varied with different levels of irrigation. Accumulated GDD were recorded with six irrigation and requirement of GDD were decreased with the decreasing levels of irrigation (Fig.1)

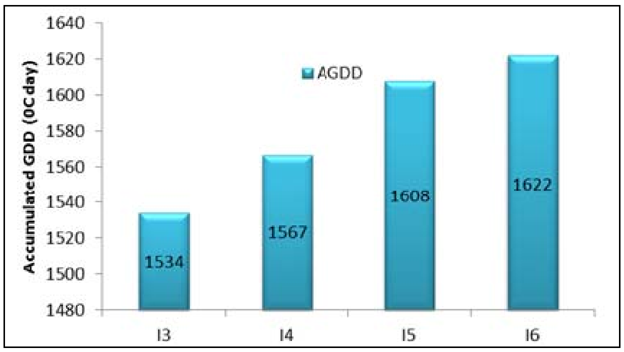

Fig 1: Effect of irrigation levels on Accumulated GDD in wheat

Heat use efficiency

Heat use efficiency was influenced due to different weather conditions and irrigation levels (Table-1). The highest heat use efficiency for total dry matter and grain yield (9.62 and 2.84 kg/ha/^{0}C day) was recorded under normal sowing i.e. 17th November sown crop. Subsequent delay in sowing resulted in decreased in heat use efficiency. Timely sowing of wheat crop seems to be essential for harnessing the good impact of prevailing weather conditions. Pragyan Kumari *et al* (2009) [8] also reported that timely (normal) wheat crop exhibited maximum heat use efficiency of 2.23 kg grain/ha/degree day. Further it was noted that heat units increase with increasing level of irrigation from 3 to 4. The maximum heat units (1570.9 ^{o}C day), heat use efficiency for total dry matter (9.36 kg/ha/^{o}C day) and heat use efficiency for grain yield (2.69 kg/ha/^{o}C day) were recorded under six irrigations.

Table 1: Accumulated heat units and Heat unit efficiency of wheat (Three years' mean)

Sowing date	GDD (^{o}Cday)	HUE of total dry matter (Kg/ha/^{0}Cday)	HUE for grain yield (Kg/ha/^{0}Cday)
7th November	1621	8.58	2.87
17th November	1637	9.04	2.82
4th December	1572	8.48	2.28
19th December	1501	8.60	1.80
Irrigation levels			
Three	1534	8.13	2.12
Four	1567	8.54	2.53
Five	1608	8.83	2.59
Six	1622	9.19	2.77

Effect of temperature

Mean temperature experienced during different phenophases of wheat are presented in Table-3. Data revealed that year 2008-09 experienced higher mean temperature during tillering to heading stage and heading to milking stage as compared to that experienced in 2007-08 in each sowing date. Later sowing dates i.e. 4th December and 19th December experienced higher mean temperature during heading to milking stage and milking to dough stage during both the years. In the year 2007-08, 4th December and 19th December sown crop experienced 6.3 and 8.5 ^{o}C higher mean temperature, respectively over 4th November sown crop (14.6 ^{0}C) during heading to milking stage. Similarly, these two dates also experienced higher mean temperature by 4.6 and 6.5 ^{0}C over 4th November sown crop (19.4 ^{0}C) during milking to dough stage. Similar, trends were also recorded during the year 2008-09. It was observed that year 2008-09 experienced more temperature throughout the crop season and it was above normal and 2007-08 in each meteorological week. The deviation in maximum and minimum temperatures was more during 2009 as compared to 2008. With regards to effective tillers/m row length (Table-3), the highest number of effective tiller/m row at 90 DAS was recorded in 19th November sown crop (D_2).

Table 2: Mean temperature during different phenophases of wheat (Mean of three years)

Sowing dates	Tillering to heading stage	Heading to milking stage	Milking to dough stage
7th November	18.8	16.9	18.8
19th November	17.4	17.3	20.4
4th December	16.7	19.7	22.6
19th December	17.1	21.7	23.5

It has been reported that an average temperature of 15 ^{0}C during grain formation is optimum for maximum grain weight (Chowdhary and Wardlaw, 1978 and Fischer, 1985) [1, 2]. The deviation in maximum and minimum temperatures above and below optimum value is found to influence the plant activities in many ways, the cumulative effects of which are observed in yield. Temperatures above 25 ^{0}C during this period tend to depress grain weight. When temperature is high, too much energy is lost through the process of transpiration by the plant and reduced residual energy results in poorer grain formation and lower yields. Until maximum tillering stage wheat crop sown on all the dates grew in a moderate air temperature regime but after this stage all later stages of later sown crops from late jointing onwards, were exposed to comparatively higher temperature regimes and causing earlier maturity of crops.

Table 3: Effective tillers/m row at 90 DAS as influenced by temperatures (Three years mean)

Sowing dates	Effective tillers/m 90 DAS	Temperature between 75 to 90 DAS (^{0}C)		
		Maximum	Minimum	Mean
7th November	170	26	8	17
19th November	173	26	8	17
4th December	167	32	12	22
19th December	151	34	14	24

DAS = Days after sowing

Heading to milking stage, the most thermally sensitive stage, late sown crops were exposed to higher air temperature (19.7^{0}C to 21.7 ^{0}C) compared to earlier sown crops (16.9 to 17.3 ^{0}C) and it was further increased till maturity of the crop (Table-2) with every delay in wheat sowing beyond normal date the risk of sterility increases. The risk would be more in case of the abnormal rise in temperature. Hence, timely sowing (19th November) of wheat crop may escape the risk of temperature rise and sterility at flowering stage. Pragyan Kumari *el al* (2009) [8] also reported that the maximum differences of 7.5 ^{0}C in temperature were observed at the milking stage between very late and normal sown conditions.

Effect of temperature on phenological stage

The following predictive equation was developed for predicting days taken for emergence based on mean temperature experienced during emergence period of wheat.

$Y = 10.04 - 0.23\ X$ $\quad R^2 = 0.634$

Where, Y = Number of days required to emergence

X = Mean temperature (^{0}C) during emergence

It was observed that days taken for emergence have negative relationship with the mean temperature. The higher air temperature lesser the time taken for emergence and vice versa.

Vegetative phase v/s mean temperature

The vegetative phase i.e. the period from sowing to heading of wheat show negative relationship with mean temperature during that period (Fig -2). Increase in mean temperature by 1 ^{0}C resulted in reduction of vegetative period by about 3 days. The regression equation to predict vegetative phase was as under

$Y = -3.3515\ X + 124.21$ $\quad R^2 = 0.739$

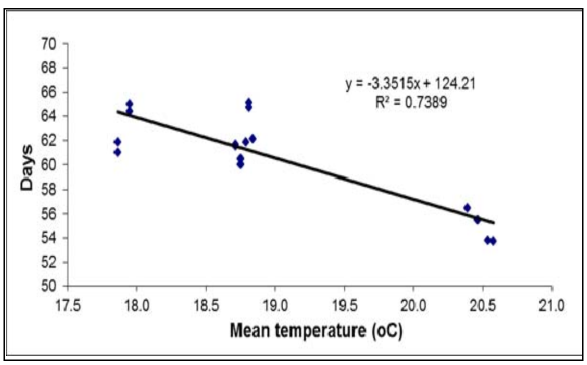

Fig 2: Vegetative phase of wheat as influence by mean temperature (mean of 2007-08, 2008-09 and 2009-10)

The relationship between mean temperature and duration of reproductive period presented in Fig. 3 which shows that reproductive period i.e. the period between heading and maturity of the crop shows negative relationship during reproductive period. An increase in mean temperature during reproductive period by 1 ^{0}C reduces the reproductive period by 4.6 days.

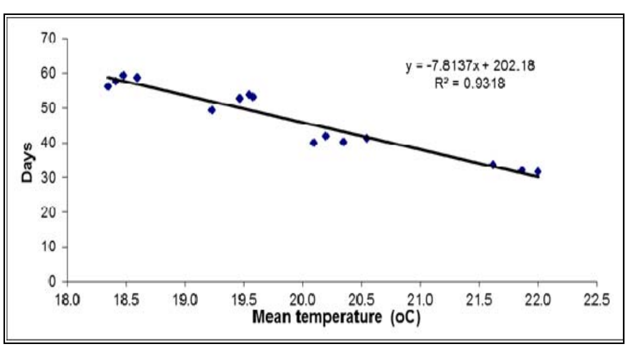

Fig 3: Reproductive phase of wheat as influence by mean temperature (mean of 2007-08, 2008-09 and 2009-10)

It was noted that lower mean temperature during 75 to 90 DAS resulted into higher number of effective tillers m/row (Fig. 4). The effective tillers at 90 DAS were reduced under D3 and D4 sowing due to higher maximum, minimum and mean temperature between 75 -90 DAS. Higher temperatures between 90-105 DAS resulted into lower number of effective tillers/m row at 105 DAS.

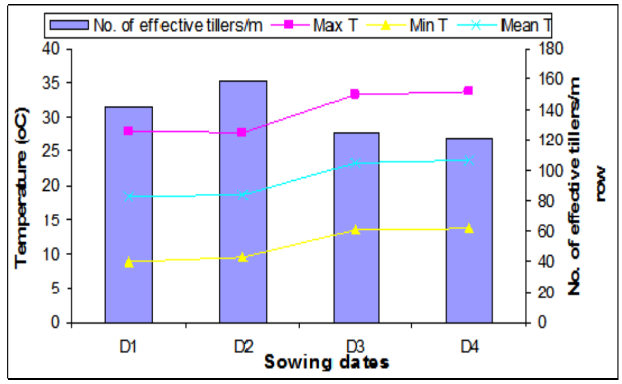

Fig 4: Number of effective tillers /m row at 90 DAS as affected by temperature between 75-90 DAS

Correlation studies

Data in Table-4 show that minimum, maximum and mean temperatures have negative correlation with number of tillers/m row at all the growth stages of the crop. However, magnitude of reduction in number of tillers/m row was more due to higher minimum temperature. This evidenced by strong negative correlation with minimum temperature experienced between 30 to 45 DAS (r = -0.745). Thus, favourable temperature during 30 to 45 DAS, which is peak period of tillering comparatively, play an important role than day temperature. The maximum tillering occurred between 30 to 45 DAS. Thereafter it starts declining.

Table 4: Correlation coefficient between number of tillers and temperatures at successive growth stages of wheat.

Temperature	15 – 30 DAS	30 – 45 DAS	45 – 60 DAS
Maximum	-0.362	-0.518	-0.267
Minimum	-0.446	-0.745*	-0.259
Mean	-0.389	-0.640	-0.263

Yield

On the basis of two years pooled data, it was observed that higher grain yield of wheat obtained when the mean temperature of 18.2 to 18.8 ^{0}C experienced during reproductive phase of the crop (Fig. 5). The increases in temperature during reproductive phase above this limit caused drastic reduction in grain yield by 23.2 to 42.2 per cent over the highest yield that achieved at the mean temperature of 18.2 ^{0}C during reproductive phase of the crop. It was also observed that an increase in mean temperature by 1.0 ^{0}C during reproductive phase of the crop caused reduction in grain yield of about 7 q/ha.

Grain yield was significantly influenced by different sowing dates and irrigation levels. The highest grain yield was recorded in 19th November sown crop, which was at par with 7th November sown crop. The crop sown on 4th December and 19th December significantly reduced grain yield by 25.7 and 41.9 percent in 2007-08 and 27.9 and 45.9 per cent in 2008-09, respectively (Table 5).

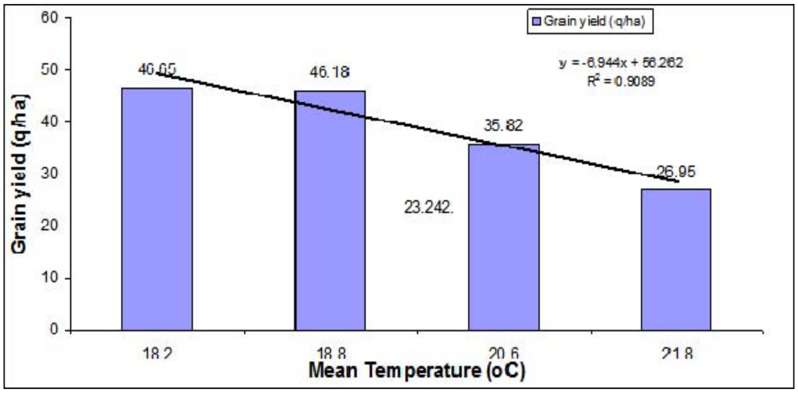

Fig 5: Effect of mean temperature during reproductive period on grain yield of wheat (mean of 2007-08, 2008-09 and 2009-10)

Table 5: Effect of sowing dates and irrigation levels on yield and harvest index of wheat

	Grain yield (kg/ha)				Harvest index (%)			
	2007-08	**2008-09**	**2009-10**	**Pooled**	**2007-08**	**2008-09**	**2009-10**	**Pooled**
Sowing dates								
7th November	4543	4076	5375	4665	30.57	28.99	34.74	31.43
19th November	4573	4473	4809	4618	28.83	30.19	31.77	30.26
4th December	3399	3382	3966	3582	25.00	27.87	29.93	27.60
19th December	2659	2587	2840	2695	21.16	22.67	24.26	22.70
S Em	122.3	116.7	150.6	1309	0.558	0.927	1.432	0.772
CD (P= 0.05)	391.3	373.3	481.6	418.6	1.7896	2.964	4.580	2.469
Irrigation levels								
Three	2636	3123	3792	3184	20.94	24.45	30.00	25.13
Four	3842	3669	4143	3885	28.21	28.29	30.24	28.91
Five	4141	3818	4295	4085	27.89	28.21	29.73	28.61
Six	4555	3908	4759	4407	28.52	28.77	30.71	29.33
S Em	112.8	79.1	114.6	100.6	0.665	0.597	1.003	0.635
CD (P= 0.05)	312.6	219.1	317.5	279.3	1.842	1.655	2.779	1.759

The maximum harvest index of 30.6 per cent was recorded under 7th November sown crop during 2007-08 while in year 2008-09, 19th November sown crop recorded the maximum harvest index of 29.2 per cent. The harvest index indicates the magnitude of allocation of dry matter from leaves and stems to sink (grain). The present study show that the allocation of dry matter (photosynthates) to sink was drastically reduced due to temperature. This is evidenced that higher temperatures were experienced during heading to milking stage and milking to dough stage during both the years (Table-2). Temperature during these two phenophases also adversely affected number of tillers/m row and test weight. Reduction in these two yields attributes under later sowing dates proved the low translocation of photosynthates which resulted in drastic yield reduction. High temperature stress at grain filling stage decreased grain yield and test weight of wheat from 19.7 % to 28.3 % (Zhang *et al*., 2008) [10]. Rane and Nagarajan (2004) [4] also reported that high temperature at the time of grain filling is one of the major constraints in increasing productivity of wheat in tropical countries like India. Tripathi *et al.* (2001) [7] also reported that late sowing beyond December 10th (< 17.6 ^{0}C) progressively decreased the grain yield of wheat due to shorter duration and high temperature during grain formation stage. Vishwanathan and Chopra (2001) [9] reported the late sown crop experienced 6-8 ^{0}C warmer temperature during grain development than crop sown at normal time. Grain yield was increased with successive increase in irrigation level during both the years. Application of six irrigations resulted significantly increased grain yield as compared to other irrigation levels during both years.

Conclusion

The above findings on the response of wheat crop to different weather environments, suggest that normal sowing (around 7th to 19th November) of wheat crop has to be advocated under the agro climatic conditions of Rajasthan state so that the farmers get improved yield. The mean temperature of 17.5 to 19.0 ^{0}C during reproductive phase found conducive for getting higher grain yield of wheat.

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