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Influence of meteorological parameters on wheat yield under different sowing conditions

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सार – भारतीय कृषि अनुसंधान संस्थान, नई दिल्ली के अनुसंधान फार्म में 2016-17 और 2017-18 रबी के दौरान गेहूं की तीन किस्मों (PBW-723, HD-2967 और HD-3086) को फसल के विभिन्न चरणों के दौरान अलग-अलग मौसम की स्थिति पैदा करने के लिए तीन अलग-अलग तिथियों पर बोया गया। प्राप्त परिणामों से पता चला कि फसल वृद्धि के प्रारंभिक चरणों के दौरान मृदा नमी की मात्रा अधिक थी और मृदा के तापमान का मान कम था तथा फसल के विकास के चरण की प्रगति के साथ, ऊपरी परत में नमी कम हो गई और मृदा के तापमान में निचली परतों की तुलना में काफी वृद्धि हुई। फसल में कल्ले और गिरह पड़ने की अवस्था के दौरान,कैनोपी के भीतर हवा का तापमान अधिक था और सापेक्षिक आर्द्रता कम थी जबकि फूल आने और अनाज भरने की अवस्था के दौरान कैनोपी के भीतर हवा का तापमान कम था तथा देर से और बहुत देर से बोई गई फसल की तुलना में समय पर बोई गई फसल की तुलना में सापेक्षिक आर्द्रता अधिक थी। विकिरण उपयोग दक्षता और पत्ती में जल की मात्रा का सापेक्षिक मान काफी अधिक था, जबकि समय पर बोई गई फसल की पत्ती में जल क्षमता का मान देर से और बहुत देर से बोई गई फसल में कम था। सभी मौसमों में HD-3086 किस्म की उपज सबसे अधिक थी और उसके बाद HD-2967 और PBW-723 में थी । बहुत देर से बोई जाने वाली फसल में विशेष रूप से फूल आने और अनाज भरने की अवस्थाओं में कैनोपी में हवा के तापमान के अंतर का सकारात्मक प्रभाव था। यह उपज में परिलक्षित होता है। देर से और बहुत देर से बोई गई फसल की तुलना में समय पर बोई गई फसल में उपज अधिक होती है।

ABSTRACT. Field experiments were conducted on the research farm of IARI, New Delhi during *Rabi* 2016-17 and 2017-18. Three varieties of wheat (PBW-723, HD-2967 and HD-3086) were sown on three different dates for generating different weather condition during various phenological stages of crop. Results showed that during early crop growth stages soil moisture had higher value and soil temperature had lower value and with progress of crop growth stage, the moisture in the upper layer decreased and soil temperature increased significantly as compared to the bottom layers. During tillering and jointing stage, air temperature within canopy was more and relative humidity was less while during flowering and grain filling stage, air temperature within canopy was less and relative humidity was more in timely sown crop as compared to late and very late sown crop. Radiation use efficiency and relative leaf water content had significantly higher value while leaf water potential had lower value in timely sown crop followed by late and very late sown crop. Yield had higher value in HD-3086 followed by HD-2967 and PBW-723 in all weather conditions. Canopy air temperature difference had positive value in very late sown crop particularly during flowering and grain-filling stages. This reflects in the yield. Yield was more in timely sown crop as compared to late and very late sown crop.

Key words – Radiation use efficiency, Canopy air temperature difference, Relative leaf water content, Leaf water potential, Yield.

1. Introduction

Agriculture is highly susceptible to weather conditions. Weather variability causes substantial fluctuations in any crop production. More frequent heat waves, warm and humid weather causes increase in the intensity of pests, diseases and impoverishment of crops. Crop production should be increased by reducing the risk and losses in agricultural production. Temperature and radiation are among main environmental factors affecting the growth and development of wheat. It influences the crop phenology and quality and quantity of yield. To mitigate the effects of weather variability, modification in micro environment during different growth stages could be one option for optimizing the growth and seed yield. In order to optimize the crop growth and yield, quantification of crop-weather relationships should be done at different phonological stages of the crops and this could help in determining proper time for sowing. Some studies showed that adaptations of cultivars in different sowing date, the climate change and global warming effect in the past decades have advance wheat phenology and reduced the wheat growth duration (Wang *et al*., 2013), increased terminal heat stress and extreme temperature decline wheat production (Liu *et al*., 2014). The effect of high temperature during post-heading stages period reduced the grain filling duration (Zhao *et al*., 2007; Lobell *et al*., 2012). Because due to the higher sensitivity of crop to high temperature, global warming leads to develops critical threatened to wheat production over the Globe (Asseng *et al*., 2015). Siebert and Ewert (2014) reported that the impacts of high temperature on wheat production is severe. It revealed that higher temperature during crop growth period responsible for negative impacts on yield production in different scales are still unknown, especially at large spatio-temporal scales (Asseng *et al*., 2011). To quantify the impacts of extreme temperature conditions on crop growing under field conditions is actually unknown with different vulnerable state and farmers will adjust their sowing date, crop varieties and management practices from climatic threatened**.** The impacts of temperature change on wheat growth and yields are complex and diverse (Siebert and Ewert, 2014). Quantification of actual impacts of unfavourable and extreme temperature conditions on crop growth under field conditions is also confronted with uncertainties because farmers will undoubtedly adjust their crop varieties and management methods to cope with typical threats from weather conditions (Reidsma *et al*., 2010; Tao *et al*., 2015). Keeping in view of above points a study was done to characterize the micrometeorology under different weather conditions and its effect on wheat yield.

2. Materials and method

Field experiments were conducted during *Rabi* 2016-17 and 2017-18 at IARI, New Delhi (28° 35' N, 77° 12' E and 228.16 m above mean sea level).Three varieties of wheat (PBW-723, HD-2967 and HD-3086) were sown on three different dates (timely, late and very late sown conditions) for generating different weather condition during various phenological stages of crop. Crop sown on different dates have different weather for various phenological stage. Periodic observations on soil moisture, soil temperature at different depth, air temperature, relative humidity within crop canopy, leaf area index, biomass, radiation use efficiency relative water content, canopy air temperature difference, leaf water potential was measured at different time interval. No of days for different phenological stages was observed and different thermal indices were calculated at physiological maturity under different sowing conditions. Soil moisture at different depths (0-15, 15-30, 30-45, 45-60 cm) and at different phenological stage (at different time interval) was estimated by gravimetric method. Soil samples were collected with screw-auger in aluminum cans were weighted and kept in hot oven at 105 °C for 24 hours. Dried samples were weighed and the moisture content on mass basis was calculated using the following formula:

$$\text{Soil moisture}(\%) = \frac{(\text{Wet weight of soil}) - (\text{Dry weight of soil})}{\text{Dry weight of soil}} \times 100$$

Soil temperature at different depths and at different time interval was measured by soil thermometer. Different thermal indices were calculated from sowing up to harvest of the crop as given by the following equations

Growing degree days $(\text{GDD}) = \sum \left\{ \left[(T\max + T\min)/2 \right] - T_{base} \right\}$, where Tmax is the daily maximum temperature, Tmin is the daily minimum temperature and T_{base} is the base temperature. The base temperature varies crop to crop and its value is derived from the growth behaviours of each and specific crop. Base temperature is the temperature below which plant growth is zero. Wheat base temperature is taken as 5 °C. Negative value of GDD is taken as zero.

Helio-thermal units $(\text{HTU}) = \sum (\text{GDD} \times \text{SSH})$, where SSH is the bright sunshine hour

Heat use efficiency = Yield/GDD

Photo thermal index (PTI) = GDD / crop growing day

Air temperature and relative humidity within crop canopy were measured at two heights (up and bottom) of canopy with the help of a pocket weather tracker (Model : Kestrel 4000) around 1430 hours (*i.e*., time of occurrence of daily maximum temperature). Measurements of LAI were carried out using Plant Canopy Analyzer (LAI-2000, LI-COR, USA). Three LAI readings were recorded in each plot. For calculating biomass three plants were selected randomly in each plot and cut at ground level. Those plants were oven dried at 65 °C for 48 hours and weighed by using electrical digital balance until a constant weight was achieved. For calculating radiation use efficiency both incoming and outgoing photosynthetically active radiation (PAR) values were measured using line quantum sensor (LICOR-3000) at top of crop canopy, middle of crop height and bottom of crop throughout the crop growing season. To get reflected radiation from top and bottom ground, the sensor was held in inverse position. The above measurements were taken in different

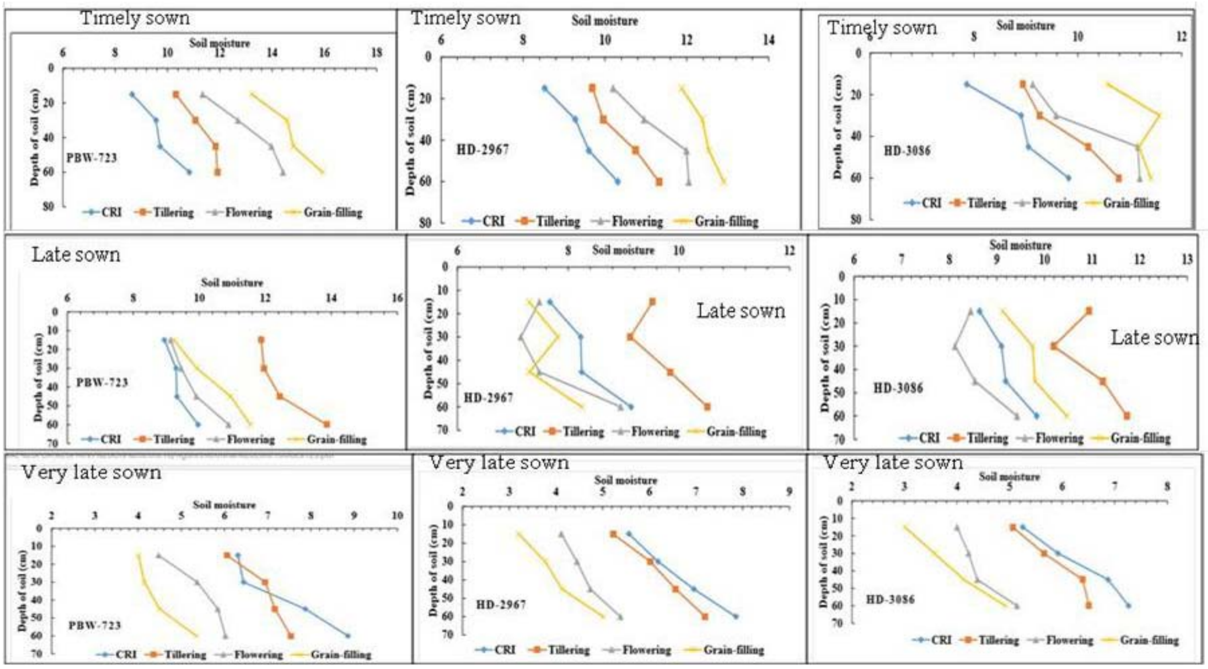

Fig. 1. Spatio-temporal variation of soil moisture content under different sowing conditions

growth stages between 1130 and 1200 hours IST on clear days when disturbances due to leaf curling, leaf shading and solar angle was minimum.

Radiation use efficiency (RUE) of the crop was calculated using the following formula.

$$\text{Radiation use efficiency (RUE)} = \frac{\text{Amount of dry matter produced } (\text{g/m}^2)}{\text{Amount of cumulative light absorbed } (\text{MJm}^{-2})}$$

Infrared thermometer (Model AG-42, Telatemp Crop, USA) was used to measure canopy temperature with 8° field of view. The data were taken at an angle of view 45° to the horizontal. Data were recorded around midday at regular intervals during crop growth period. For estimating relative water content discs of 1cm diameter were taken from middle portion of fully developed leaf from chosen plants of each replicate under different treatments. Fresh weight was measured immediately and these leaves dices were floated on distilled water for around 5 h then turgid weights of leaves discs were measured after drying excess surface water with paper towels. Dry weights (DW) of discs were obtained after drying at 75 °C for 48 h. Following formula was used to calculate Relative water content (RWC).

$$\text{RWC (Relative water content)} = \frac{\text{Fresh wt} - \text{Dry wt } (\text{g/m}^2)}{\text{Turgid wt} - \text{Dry wt}}$$

Leaf water potential was measured with the help of pressure bomb (PMS Instruments Co, USA). Leaves were plucked from field and brought in packed humid polythene bags to minimize the evaporation losses. These leaves were kept insides the pressure bomb apparatus and pressure were applied till the first droplet of water oozed out at the out end. The pressure applied was read from the meter. This was repeated for all the samples. Yield parameters were measured after harvest.

The data were analyses using the software SPSS 16.0 and MS Office Excel. Computation of correlation coefficients, critical difference and student *t* test was carried out using Excel and SPSS packages

3. Results and discussion

3.1. *Spatio-temporal variation of Soil Moisture content and Soil temperature under different sowing conditions*

The temporal and spatial distributions of mean volumetric soil moisture content (SMC) in different cultivars under different sowing conditions are shown in Fig. 1. The effects of different moisture stress were clearly

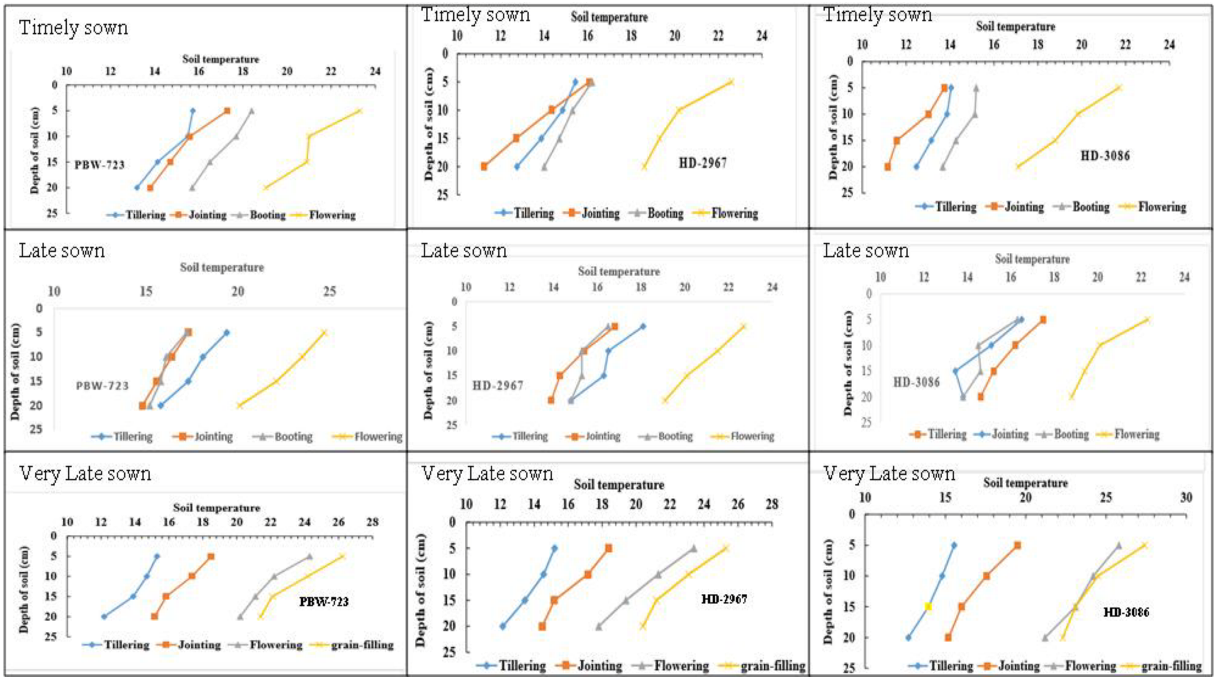

Fig. 2. Spatio-temporal variation of soil temperature (°C) under different sowing conditions

seen among different cultivars under different sowing conditions. During the initial period, there was not so much difference in soil moisture content among the different treatment but with the progress of season and crop growth, the moisture content decreased. Soil moisture content decreased more at grain-filling stages in all cultivars under different sowing conditions as compared to the CRI, tillering and flowering stage. It was observed that the soil moisture was generally higher in early crop growth development stages of the season. With progress of the season the moisture in the upper layer (0 to 15 cm) decreased significantly as compared to the bottom layers. It was found that the percent reduction is more in very late sown crop as compared to the timely sown crop due to higher ambient air temperature. The percent reduction of soil moisture varied between 8.5 to 9.1, 8.2 to 11.3 and 14.6 to 22.1% in upper layer (10 cm) in timely, late and very late sown crop respectively. Results showed that higher soil moisture was different at the time of grain-filling stages in all cultivars under different sowing conditions.

The temporal and spatial distribution of soil temperature changes in different cultivars under different sowing conditions are shown in Fig. 2. It was observed that the soil temperature was generally lower in early growth stages of the season. With progress of the season temperature in the upper layer (10 cm) increased significantly and attained higher temperature as compared to the bottom layers at the end of the season. This condition occurred during grain-filling stage. It was observed that percent reduction in very late sown crop was more as compared to the timely sown crop due to higher ambient air temperature. The percent reduction in soil temperature varied between 3 to 6, 5 to 8 and 4 to 16% in upper layer (10 cm) in timely, late and very late sown crop respectively. Results showed that the higher soil temperature occurred at the time of grain-filling. During early crop growth stages, soil moisture had higher value and soil temperature had lower value and with progress of crop growth stage, the moisture in the upper layer decreased and soil temperature increased significantly as compared to the bottom layers. Moisture stress, an important environmental stress, that negatively affects the crop growth and development, finally it limits crop production.

3.2. *Thermal indices in different cultivars of wheat crop under different sowing conditions*

Different thermal indices for different cultivars of wheat crop under different sowing conditions are presented in Table 1. Wheat crop required GDD around 1516, 1493 and 1476 °C for PBW-723 and 1676, 1547 and 1511 °C for both HD-2967 and HD-3086 to reach sowing to harvesting under timely, late and very late sown crop. Timely sown had slightly more GDD followed by late and very late sown conditions. Cultivars HD-2967 and

TABLE 1

Thermal indices for different varieties of wheat under different sowing conditions

Date of sowing	Varieties	GDD (°C)	HUE (kg/ha / °C day)	PTI (°C day / day)	PTU (°C day) / hour)	HTU (°C day hour)
Timely sown	PBW-723	1516	2.86	11.07	17710	9810
	HD-2967	1676	2.92	11.24	18801	10534
	HD3086	1676	3.04	11.24	18801	10534
Late sown	PBW-723	1493	2.74	11.30	17015	9924
	HD-2967	1547	2.65	11.36	18015	10854
	HD3086	1547	2.98	11.36	18015	10854
Very late sown	PBW-723	1476	2.08	11.70	16644	10211
	HD-2967	1511	2.27	12.31	17544	10978
	HD3086	1511	2.31	12.31	17544	10978

HD-3086 had more value of total GDD as compared to corresponding value for PBW-723 in all sowing conditions. Cultivar HD-2967 and HD-3086 had same number of crop growing period and more crop growing period than PBW-723. HUE was found to be higher value in timely sown crop followed by late and very late sown crop. Cultivar HD-3086 had higher value of heat use efficiency (3.04, 2.98 and 2.31 Kg/ha/°C day) followed by HD-2967 (2.92, 2.65 and 2.27Kg/ha/°C day) and PBW-723 (2.86, 2.74 and 2.08 Kg/ha/°C day) in timely, late and very late sown conditions. PBW-723 had lower value of PTI (11.07, 11.30 and 11.70 °C day /day) compared to corresponding value for HD-2967 and HD-3086 (11.24, 11.36 and 12.31 °C day /day) in timely, late and very late sown conditions. PTI was found to be higher value in very late sown crop followed by late and timely sown crop. Similar to GDD, PTU was found to be higher value in timely sown crop followed by late and very late sown crop. Cultivar HD-3086 and HD-2967 had higher value of photo thermal unit (18801, 18015 and 17544 °C day /hour) followed by PBW-723 (17710, 17015 and 16644 °C day /hour) in timely, late and very late sown conditions. HTU had similar trend as PTI. HTU was found to be higher value in very late sown crop followed by late and timely sown crop. Cultivar HD-3086 and HD-2967 had higher value of photo thermal unit (10534,10854 and 10978 °C day hour) followed by PBW-723 (9810, 9924 and 10211 °C day hour) in timely, late and very late sown conditions. Total growing period for cultivar PBW-723 was 135, 122 and 112 days, however for cultivar HD-2967 and HD-3086 it was 140, 128 and 117 days for timely, late and very late sown crop. Total growing period was less by 13 and 23 days for cultivar PBW-723 and less by 12 and 23 days for HD-2967 and HD-3086 resulting reduced in grain yield in late and very late sown conditions. This is due to increase in temperature during gain filling to physiological maturity stage in very late sown crop, total number of crop growing days reduced in very late sown crop followed by late and timely sown crop. Kumar *et al.* (2010) reported that air temperature based agro meteorological indices, *viz*., growing degree days (GDD) and pheno thermal index (PTI) has been used to describe changes in phonological behaviour and growth parameters. Crop phenology is primarily affected by the air temperature and secondarily by the soil temperature.

3.3. *Temporal variation in air temperature and relative humidity (%) within wheat crop canopy at different phenological stage under different sowing conditions*

There was significant difference in air temperature within canopy at different growth stage under different sowing conditions. Air temperature within canopy ranged between 19.9 to 25.1 °C at tillering stage, 24.9 to 34.4 °C at jointing stage, 28.9 to 39.0 °C at flowering stage and 33.3 to 38.3 °C at grain filling stage under different sowing conditions. Differences in the temperature within canopy in late sown crop as compared to corresponding value in timely sown crop was less by 2.5 and 0.7 °C in PBW-723, 1.6 and 0.4 °C in HD-2967, 1.1 and 0.6 °C in HD-3086 during tillering and jointing stage. However it was more during flowering and grain filling stage by 2.8 and 3.4 °C in PBW-723, 2.7 and 3.3 °C in HD-2967, 2.7 and 3.0 °C in HD-3086. Differences in the temperature within canopy in very late sown crop as compared to corresponding value in timely sown crop was more by 2.6, 7.5, 9.2 and 4.5 °C in PBW-723, 2.5, 8.7, 8.6 and 4.8 °C in HD-2967, 2.3, 8.7, 8.3 and 4.2 °C in HD-3086 during tillering, jointing, flowering and grain filling stage

TABLE 2

Temporal variation in air temperature (°C) within wheat crop canopy at different phonological under different sowing conditions

Date of sowing	Varieties	Tillering stage	Jointing stage	Flowering stage	Grain-filling stage
Timely sown	PBW-723	22.4	25.6	29.8	33.8
	HD-2967	22.6	25.5	29.1	33.4
	HD-3086	22.8	25.7	28.9	33.3
Late sown	PBW-723	19.9	24.9	32.6	37.2
	HD-2967	21.0	25.1	31.8	36.7
	HD-3086	21.7	25.1	31.6	36.3
Very late sown	PBW-723	25.0	33.1	39.0	38.3
	HD-2967	25.1	34.2	37.7	38.2
	HD-3086	25.1	34.4	37.2	37.5
LSD at 5%		0.04	0.06	0.05	0.07

TABLE 3

Temporal variation in Relative Humidity (%) within the wheat crop canopy at different phonological stage under different sowing conditions

Date of sowing	Varieties	Tillering stage	Jointing stage	Flowering stage	Grain-filling stage
Timely sown	PBW-723	55.5	38.4	28.7	22.2
	HD-2967	55.6	42.8	30.4	24.7
	HD-3086	57.1	39.4	31.4	24.1
Late sown	PBW-723	66.5	44.0	28.4	20.4
	HD-2967	73.8	47.3	29.2	20.8
	HD-3086	72.5	46.4	29.4	21.0
Very late sown	PBW-723	45.2	29.1	27.1	18.1
	HD-2967	41.1	27.8	28.7	19.4
	HD-3086	43.1	27.5	26.1	18.9
LSD at 5%		0.04	0.05	0.06	0.06

(Table 2). Air temperature in HD-3086 within canopy was found to be more value during tillering and jointing stage and less value during flowering and grain filling stage followed by HD-2967 and PBW-723 in different sowing conditions. Differences in the temperature within canopy in late sown crop as compared to corresponding value in timely sown crop was more during grain filling stage followed by flowering, tillering and jointing stage for all the cultivars. Differences in the temperature within canopy in very late sown crop as compared to corresponding value in timely sown crop was more during flowering followed by jointing, grain filling and tillering for PBW-273 and more during jointing followed by flowering, grain filling and tillering for cultivar HD-2967 and HD-3086.

Relative humidity measured within the canopy was higher than the value measured above the canopy in different treatments because of shading effect of leaves, lesser transmission of solar radiation, less air movement and accumulation of high water vapour from evapotranspiration. Differences in the relative humidity within canopy in late sown and very late sown crop as compared to corresponding value in timely sown crop was more during tillering followed by jointing, grain filling and flowering stage for all the cultivars. Relative humidity

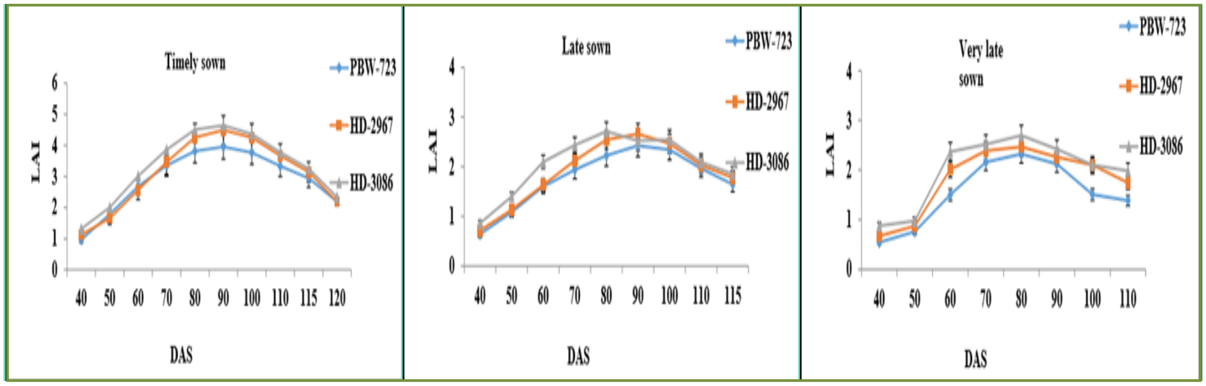

Fig. 3. Leaf area index of different wheat cultivars under different sowing conditions

(RH) profile showed opposite trend with respect to that of temperature profile, *i.e.*, RH measured within the canopy was higher than the value measured above the canopy in different treatments because of shading effect of leaves, lesser transmission of solar radiation, less air movement and accumulation of high water vapour from evapotranspiration.

Relative humidity within canopy ranged between 41.1 to 73.8% at tillering stage, 27.5 to 47.3% at jointing stage, 26.1 to 31.4% at flowering stage and 18.1 to 24.7% at grain filling stage under different sowing conditions. Differences in the relative humidity within canopy in late sown crop as compared to corresponding value in timely sown crop was more by 11 and 5.6% in PBW-723, 18.2 and 4.5% in HD-2967, 15.4 and 7.1% in HD-3086 during tillering stage and jointing stage. However it was less during flowering and grain filling stage by 0.3 and 1.8% in PBW-723, 1.2 and 3.9% in HD-2967, 2.0 and 3.1% in HD-3086. Differences in the relative humidity within canopy in very late sown crop as compared to corresponding value in timely sown crop was less by 10.3, 9.3, 1.6 and 4.1% in PBW-723, 14.5,15.0,1.7 and 5.3 in HD-2967, 14,11.9,5.3 and 5.2% in HD-3086 during tillering, jointing flowering and grain filling stage (Table 3). HD-3086 had higher value of relative humidity in all sowing conditions followed by corresponding value in HD-2867 and PBW-723.

3.4. *Leaf Area Index (LAI) of wheat crop under different sowing conditions*

Among the plant growth parameters, leaf area index is the most important parameters exhibiting overall performance of the growth and development under varying weather conditions. Leaf area index is an important parameter for the crop growth studies since it is useful in interpreting the capacity of a crop for producing dry matter in terms of the intercepted utilization of radiation and amount of photosynthesis synthesized. The seasonal profile of wheat LAI under different sowing conditions is shown in Fig. 3. In case of all the sowing conditions LAI profile showed a typical pattern of first increasing during vegetative phase, then reaching a peak at flowering stages and then decreasing due to senescence. Timely sown crop showed highest LAI as compared to the late and very late sown crop. The peak LAI values were 3.82, 4.32, 4.51 under timely sown crop, 2.32, 2.55, 2.74 under late sown crop and 2.21, 2.45, 2.58 under very late sown crop in PBW-723, HD-2967 and HD-3086 respectively. The date of attaining maximum LAI varied among different sowing conditions. It was 90 DAS for both timely and late sown crop and 80 DAS in very late sown crop respectively, which indicates that the terminal heat stress caused faster development of leaf area but with a lower value. The reduction of leaf area in terms of percentage was higher in very late sown crop as compared to the timely sown crop was 44 to 58%, 41 to 52% and 34 to 47% in PBW-723, HD-2967 and HD-3086 respectively. Very late sown crop attained peak LAI much earlier with lower vale than the timely and late sown crop. This indicates that delay in sowing resulted in significant growth loss and shortening of length of crop growing period. It was observed that the leaf area index (LAI) was higher in HD-3086 followed by HD-2967 and PBW-723. HD-3086 had 14.1, 10.5 and 13.4% more value of LAI than PBW-723 and 3.1, 6.5 and 4.6% more value of LAI than HD-2967 in timely, late and very late sown conditions. In this study leaf area are drastically reduced in very late sown crop due to the higher terminal heat stress prevailing during crop growth period. The reduction of leaf area index may be due to the changes in the plant water status which in terns reduced photosynthetic activity as well as stunted growth of the crop. The Increased temperature rate during very late sown crop leaf senescence occurred due to decrease in the water content

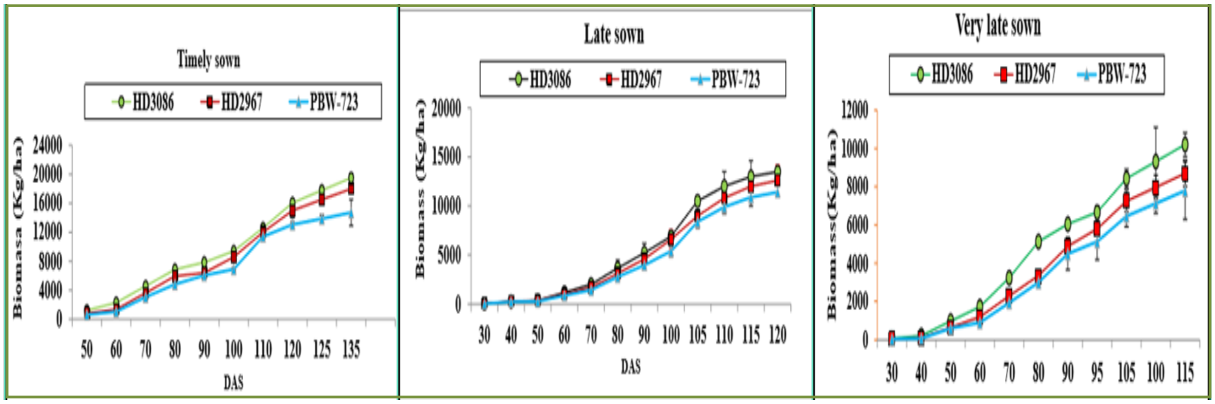

Fig. 4. Biomass of different wheat cultivars under different sowing conditions

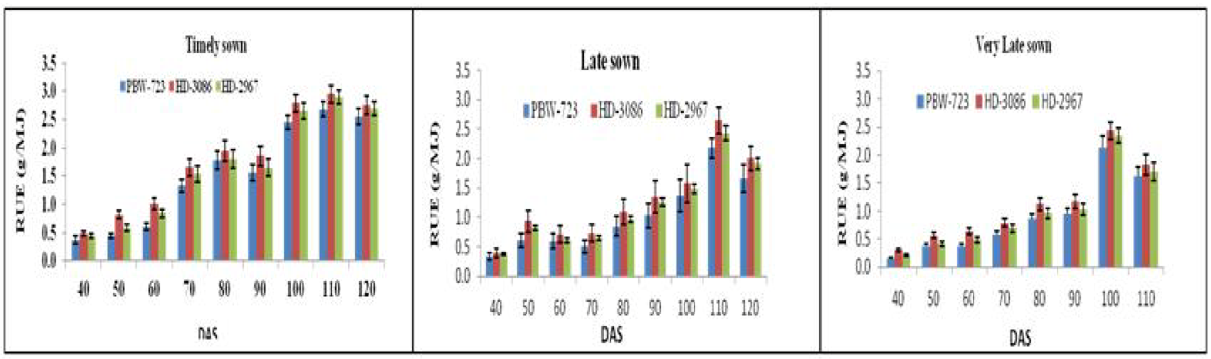

Fig. 5. Radiation use efficiency of different wheat cultivars under different sowing conditions

in leaf as a result of decrease in leaf area index. Similar observation was reported by Vashisth *et al*. (2011) in mustard that the maximum LAI was found at flowering stage and thereafter declined towards maturity and timely sown crop had higher value of LAI as compared to late sown and very late sown crop in all sowing conditions.

3.5. *Biomass production of wheat crop under different sowing conditions*

Biomass production of the plant is the process of organic substance formation from carbohydrates, the products of photosynthesis and from small quantity of inorganic substance absorbed by roots from the soil. The timely accumulation of dry matter by the crop is important as it is followed by adequate translocation of assimilates to the sink resulting in higher yield. The higher biomass in the first sowing dates may be due to favourable weather during crop growth period. Total biomass production observed during different growth stages under different sowing conditions are shown in (Fig. 4**).** In this study the changes in biomass were significantly decrease in very late sown crop as compared to the late and timely sown crop. Biomass production varied from 46 to 60, 47 to 56, 43 to 51% in PBW-723, HD-2967, HD-3086 under very late sown crop as compared to the timely sown crop. Greater reduction in biomass was observed in PBW-723 as compared to HD-3086 and HD-2967 in all sowing conditions. Biomass production varied from 121 to 13880, 141 to 16400,152 to 17765 kg/ha under timely sown crop, 70 to 10800, 75 to 12100, 84 to 13100 kg/ha under late sown crop and 51 to 7820, 60 to 8650,72 to 10150 kg/ha under very late sown crop at different growth stages in PBW-723, HD-2967 and HD-3086 respectively. Thus, it may be inferred that biomass production was higher in timely sown crops as compared to late sown and very late sown crops, which might be due to more favourable weather condition for first sown crop as compared to other two dates during crop growing period. Results showed that HD -3086 had higher value of biomass followed by HD-2967 and PBW-723. Timely sown crop had higher value of growth parameters compared to late and very sown crop which might be due to higher leaf area index, leaf area duration and more proliferating nature. The reduction of biomass production due to late sowing was also reported by Vashisth *et al*. (2011 and 2012) in

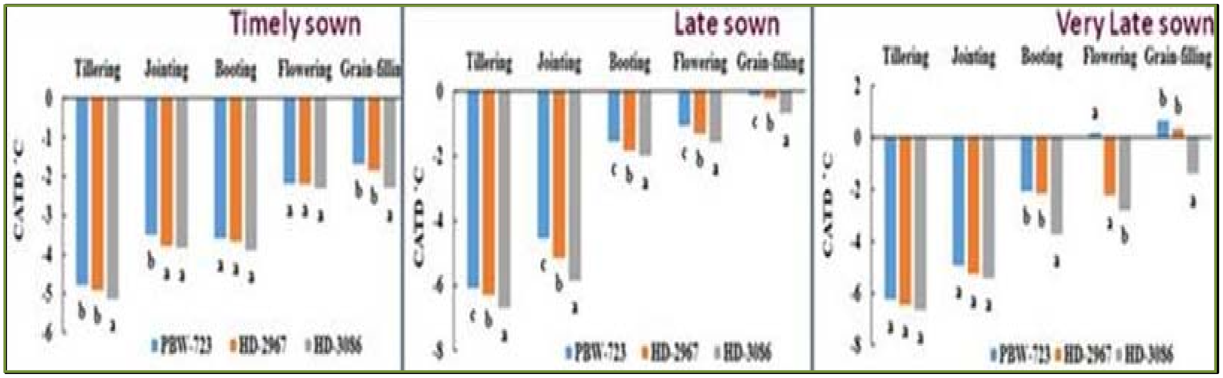

Fig. 6. Canopy air temperature Difference (CATD) of different wheat cultivars under different sowing conditions

different crops. The biomass production levels obtained in the present study and the reduction of biomass production due to late sowing are in conformity with the work done in other crops in earlier findings (Kar and Chakravarty, 2001; Vashisth *et al*., 2011, 2012).

3.6. *Radiation use efficiency (RUE) of wheat crop under different sowing conditions*

The biomass radiation use efficiency (RUE) of different cultivars of wheat under different sowing conditions is sown in Fig. 5. The significance of difference was tested by Duncan's Multiple Range Test (DMRT) at 95% confidence level (p = 0.05). Radiation use efficiency varied between 2.03, 2.41, 2.64 g MJ^{-1} in PBW-723, HD-2967, HD-3086 which is significantly higher than the late and very late sown crop. Even though the total intercepted photosynthetically active radiation was generally higher but RUE was lower in most treatments due to low biomass produced. The highest RUE of 2.99 g MJ^{-1} were observed in case of HD-3086 followed by HD-2967 and PBW-723 in timely sown crop. The peak value of RUE was 2.16, 2.65 and 2.99 in timely sown crop, 1.76, 2.20 and 2.60 in late sown crop and 1.38, 1.95 and 2.31 in very late sown crop in PBW 723, HD-2967 and HD-3086 respectively. The percentage reduction in peak value of RUE in late sown crop as compared to corresponding value in timely sown crop was 18, 16 and 10% in PBW 723, HD-2967 and HD-3086 respectively. The reduction was further increased in very late sown crop as compared to timely sown crop by 34, 25 and 19 % in PBW 723, HD-2967 and HD-3086 respectively. The reduction was less in HD-3086 followed by HD-2967 and PBW-723. Gimenez *et al.* (1994) concluded that, for any given canopy size (LAI), canopy structure (leaf angle and orientation) determines the fraction of intercepted radiation, interception of PAR and its utilization efficiency with which, PAR drives photosynthetic gain in terms of productivity. During the crop season the RUE (g/MJ) for the timely sown crop had higher value as compared to late sown and very late sown crop. The results are in conformity with the earlier findings of researchers done in other crops (Vashisth *et al*., 2012).

3.7. *Canopy air temperature Difference (CATD) of wheat crop under different sowing conditions*

Canopy air temperature difference (CATD) measured any type of abiotic or biotic stress and is usually expressed as canopy temperature minus air temperature (CATD). The positive value of CATD indicates that crop is in stress conditions. More value means more stress in the crop. CATD had less value during tillering followed by jointing, booting, flowering and grain-filling in all sowing conditions. CATD had positive value in very late sown crop particularly in case of PBW-723 during flowering and grain-filling stages and for HD-2967 during grain-filling stage (Fig. 6). CATD had more value in very late sown crop followed by late sown and timely sown crop. This reflects in the yield. Although all three varieties were grown under similar weather conditions as well as irrigations and nutrients levels but PBW-723 showed higher value of CATD followed by HD-2967 and HD-3086 in all sowing conditions. Cultivar PBW-723 showed higher value of CATD followed by HD-2967 and HD-3086 in all sowing conditions.

3.8. *Relative leaf water content (RWC) of wheat crop under different sowing conditions*

Relative leaf water content was relatively higher in case of timely sown crop followed by late and very late sown crop but the reduction in terms of percentage is more in very late sown crop followed by late and timely sown crop.

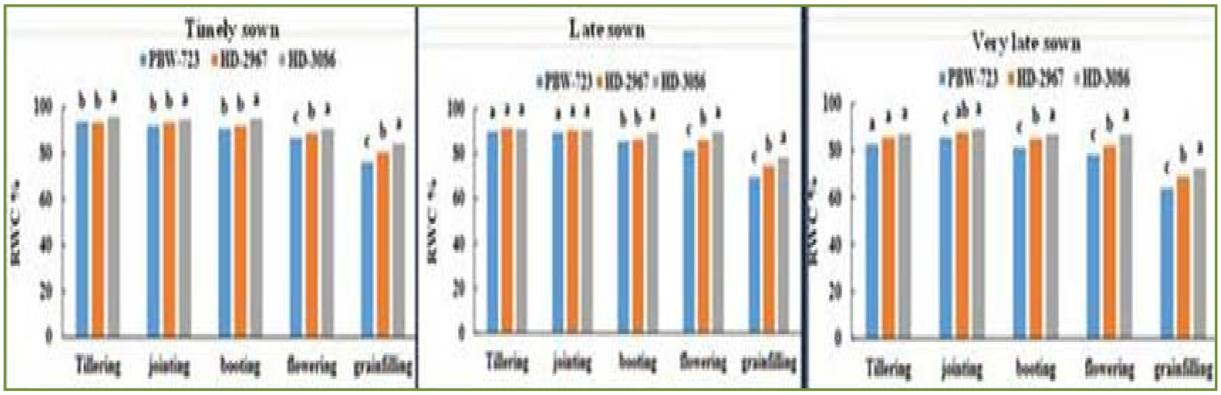

Fig. 7. Relative water content (RWC) of different wheat cultivars under different sowing conditions

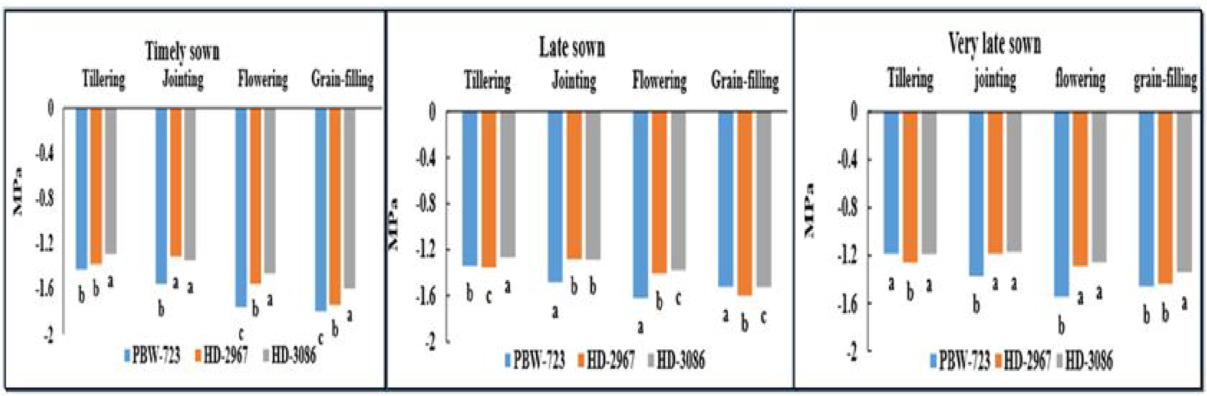

Fig. 8. Leaf water potential of different wheat cultivars under different sowing conditions

TABLE 4

Correlation of grain yield with RWC during different phenological stages

	RWC at Tillering stage	RWC at flowering stage	RWC at grain filling stage	Grain Yield
RWC at Tillering stage	1.00	-	-	-
RWC at flowering stage	0.95**	1.00	-	-
RWC at grain filling stage	0.98**	0.90*	1.00	-
Grain Yield	0.97**	0.88*	0.97**	1.00

***Correlation is significant at the 0.05 level , ** Correlation is significant at the 0.01 level

Grain yield had significant positive correlation with relative water content, 0.97 at tillering, 0.88 at flowering and 0.97 at grain filling sage respectively Table 4. The percentage reduction in very late sown crop as compared to the timely sown crop was 12, 7, 11, 10 and 16% in PBW-723, 8, 6, 8, 9 and 15% in HD-2967, 9, 6, 9, 4 and 14% in HD-3086 at tillering, jointing, booting, flowering and grain-filling stages respectively (Fig. 7). Relative leaf water content was found to be higher in the varieties HD-3086 followed by HD-2967 and PBW-723 at all stages in all sowing conditions. This also reflects the yield.

TABLE 5

Yield attributes at different dates of sowing for different varieties

Date of Sowing	Varieties	Spike length (cm)	No of grain /spike	1000 seed weight (g)	Grain Yield (kg /ha)
Timely sown	PBW-723	14.1	27.0^{A}	58.3	4550.0^{C}
	HD-3086	15.0	29.3^{A}	62.0	5020.0^{A}
	HD-2967	14.7	28.3^{A}	60.3	4743.3^{B}
Late sown	PBW-723	13.5	24.0^{B}	53.0	4163.3^{E}
	HD-3086	14.6	28.0^{A}	57.3	4693.3^{BC}
	HD-2967	13.8	27.0^{A}	55.0	4390.0^{D}
Very late sown	PBW-723	12.7	22.0^{C}	49.7	3823.3^{F}
	HD-3086	14.0	25.3^{BA}	55.0	4391.0^{D}
	HD-2967	13.5	25.0^{ABC}	53.0	4023.3^{E}
LSD at 5 %		NS	3.8	NS	155.1
CV %		8.5	6.2	6.05	6.45

3.9. *Leaf water potential in wheat crop under different sowing conditions*

Leaf water potential measured in the leaf of the plant grown under different sowing condition in wheat crop was found to be higher in third sown crop as compared to the timely sown crop. The percent reduction as compared to timely sown crop was found to be 11 to 19% in PBW-723, 6 to 17% in HD-2967 and 7 to 15% in HD-3086 at tillering, jointing, flowering and grain-filling stages respectively (Fig. 8). Leaf water potential measured the stress in the plant. Percentage reduction of leaf water potential in very late sown crop as compared to the late sown crop was 5 to 12% in PBW-723, 5 to 10% in HD-2967, 4 to 9% in HD-3086 at tillering, jointing, flowering and grain-filling stages respectively. This showed that due to higher terminal heat stress in the very late sown crop, plants were in more stress than the plant grown in timely sown crop.

3.10. *Grain yield of wheat crop under different sowing conditions*

The final grain yield varied significantly in different sowing conditions. The grain yield was 4550, 5020, 4743 kg/ha for timely sown crop, 4163, 4693, 4390 kg/ha for late sown crop and 3823, 4391, 4023 kg/ha for very late sown crop in PBW-723, HD-3086, HD-2967 respectively (Table 5). The final grain yield production at harvest was significantly reduced in very late sown crop as compared to the timely sown and late sown crop. It was observed that the percent reduction of yield was 8.1, 6.3 and 7.1% in PBW-723, HD-3086, HD-2967 under late sown crop compared to the timely sown crop, the maximum yield reduction occurred in PBW-723 under all sowing conditions followed by HD-2967 and HD-3086, this may be due to the higher temperature reduced vegetative growth. Percent reduction in yield in the very late sown crop as compared to the timely sown crop was 15.3, 12.1 and 14.6% in PBW-723, HD-3086 and HD-2967 respectively. Vashisth *et al*. (2011) reported that delay in sowing of mustard reduced the yield. Spike length varied from cultivars to cultivars in all sowing conditions. Maximum spike length was found in HD-3086 followed by HD-2967 and PBW-723. Percent reduction in spike length as compared to the timely sown crop in late sown crop was 8.1, 6.3, 7.1% and in very late sown crop was 15.3, 12.1, 12.8% in PBW-723, HD-3086 and HD-2967 respectively. Percentage reduction was more in PBW-723 cultivars in all sowing conditions. This was due to higher temperature during reproductive stage reduced biomass yield as well as spike length. Seed number per spike varied significantly in all sowing conditions. Percent reduction in number of seeds per spike as compared to the timely sown crop in late sown crop was 10.7, 4.5 and 4.6% and in very late sown crop was 17.9, 13.2 and 11.4% in PBW-723, HD-3086 and HD-2967 respectively. Percentage reduction was more in PBW-723 cultivars. HD-3086 had maximum number of seeds per spike followed by HD-2967 and PBW-723. Thousand seed weight was 58.3, 62, 60.3 g in timely sown crop, 53, 57.3, 55 in late sown conditions and 49.7, 55, 53 in very late sown conditions in PBW-723, HD-2967 and HD-3086 respectively. Thousand seed weight was found maximum in HD-3086 followed by HD-2967 and PBW-723. Percent reduction in thousand seed weight as compared to the timely sown crop in late sown crop was 9.0, 7.4 and 8.7% and in very late sown crop was 14.6, 11.1 and 12.0% in PBW-723, HD-3086 and HD-2967 respectively. Percentage reduction was more in PBW-723 cultivars.

Timely sown crop had higher seed yield than late sown and very late sown crop in all varieties due to more maximum and minimum temperature during vegetative and flowering stage and less maximum and minimum temperature during maturity stage. Reduction in seed yield under late sown conditions might be attributed to increase in temperatures at the time of flowering and grain filling stage, which reduced the dry matter accumulation into the seed and shortened the seed filling period. The yield attributes and yield of wheat significantly decreased in late sown crop. The results are in conformity with the earlier findings of researchers (Neog, 2005 and Vashisth *et al*., 2011) who reported a reduction in seed yield due to delay of week /fortnight from the normal sowing.

4. Conclusions

Crop growth and seed yield were relatively higher in the timely sown crop because of more congenial weather conditions during the entire crop growth period. Crop growth parameters, radiation use efficiency, relative water content was found to be higher value and leaf water potential had lower value in timely sown crop as compared to late and very late sown crop. Delay in sowing time reduces the yield significantly because canopy air temperature difference had positive value in very late sown crop particularly during flowering and grain-filling stages followed by late and timely sown crop. From this study it is concluded that crop micro environment was changed due to different sowing dates, which was reflected during different phenological stages and crop yield. Seed yield therefore could be optimized by doing appropriate management practices during different phenological stages for obtaining favorable weather condition for crop growth.

Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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