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Effect of weather variability on growth and yield of wheat crop under semi-arid region of India

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ABSTRACT

For generating different weather conditions during various phenological stages, experiments were conducted on two varieties of wheat (HD-2967 and HD-3086) sown on three different dates at the research farm of IARI, New Delhi during *rabi* 2015-16 and 2016-17. Soil temperature, soil moisture, leaf area index, biomass, chlorophyll content, radiation interceptions were measured during different crop growth stages. Number of days taken for each phenological stage was observed and thermal time for different phenological stages were calculated. Results showed that first sown crop had higher value of crop growth parameters and yield as compared to second and third sown crop.HD-3086 had higher value of LAI, biomass and yield than HD-2967. Grain yield had significant positive correlation with growing degree days during grain filling stage. Soil temperature measured at 2.21 PMat 5, 10, 15, 20 cm depth had 1-5°C lower value than the air temperature. Soil moisture measured at 0-15, 15-30, 30-45 and 45-60 cm depths had slightly higher soil moisture for HD-3086 as compared to corresponding value in HD-2967 during emergence, flowering and grain filling stages. Percentage relative water content in HD-2967 was found to be higher in first sown crop followed by second and third sown crop. However, in HD-3086, percentage relative water content was found to be higher in first sown crop followed by third and second sown crop. Grain yield had significant positive correlation with relative water content during different phenological stages. HD-3086hadhigherradiation use efficiency as compared to HD-2967 in all weather conditions.

Key words: Leaf area index, biomass, radiationuse efficiency, relative water content, yield

Temperature and radiation are among the main environmental factors affecting the growth and development of wheat (Bal *et al.,* 2018). It influences the crop phenology and yield of crop. Seed yield therefore could be optimized by appropriate management practices during different phenological stages for obtaining favorable weather condition for crop growth.Wheat is one of the most important staple foods. Among all commercially grown crops in India, it occupies largest land area, i.e., more than 240 million ha and also it ranks highest in terms of production. In this 21th century, a major concern to humankind is the Global Warming. Continuously changing pattern of climate has great influence on the world crop production.Nowadays impact of future climate change on agricultural production and food security has been given considerable attention (Lobell *et al*., 2012). Wheat production has been adapting to climate change through shifts of sowing dates, cultivars and agronomic management practices (Jalota *et al.,* 2013; Tao *et al*., 2015; Pramod *et al.,* 2017).The growth of winter wheat is generally threatened by high temperature during post-heading stages (from anthesis to maturity) which are the warmest periods during the growing season of this crop (Bapuji Rao *et al.,* 2015). The major influence of higher average temperature during this period is shortening of the grain filling duration (Zhao *et al*., 2007; Lobell *et al*., 2012; Garg *et al*., 2013). Because of the high sensitivity of crop growth to temperature, global warming has already led to critical threats for winter wheat production throughout the world (Asseng *et al*., 2015). In addition, predicted warming trend in future climate scenarios suggests increasing risk of heat stress for winter wheat growth, especially for regions with currently favourable environment (Ortiz *et al*., 2008; Asseng *et al*., 2015), highlighting the importance of understanding, estimating and coping with the impacts of heat stress. The impacts of temperature change on wheat growth and yields are complex and diverse (Siebert and Ewert, 2014). Quantification of actual impacts of unfavorable 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; Farooq *et al*., 2011; Tao *et al*., 2015). Keeping in view of above points a study was carried out to understand the effect of weather variability on radiation use efficiency at different growth stages and yield of wheat crop.

MATERIALS AND METHODS

Field experiment was conducted during *rabi* 2015-16 and 2016-17 at ICAR-IARI, New Delhi. Two varieties (HD 2967 and HD 3086) of wheat were sown on three (Timely sown, late sown and very late sown) different sowing conditions.Different micrometeorological and biophysical parameters such as soil temperature, soil moisture, leaf area index, biomass, crop phenology, photosynthetic active radiation was measured at different crop growth stages. Radiation use efficiency and relative water content were calculated at different growth stages.Measurements of LAI were carried out using LAI- 2000 Plant Canopy Analyzer (LI-COR, USA). Three LAI readings were recorded in each plot and then averaged out to represent each plot LAI. 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 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 hrs 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 hrs. Following formula was used to calculate Relative water content (RWC).

$$\text{Relative water content (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \text{ X 100}$$

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 growth stages between 12:00 and 1:00 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.

$$\text{Radiation use effeciency} = \frac{\text{Amount of dry matter produced}}{\text{Total intercepted PAR}}$$

Soil moisture at different depth (0-15, 15-30, 30-45, 45-60 cm) was measured by gravimetric method under different weather conditions.

The pooled analysis was made from two years data to assess the effects on growth and yield. No of days for different phenological stages was observed and thermal time for different phenological stages were calculated. Yield parameters were measured after harvest.

RESULTS AND DISCUSSION

Crop phenology

First sown crops took more time to reach maturity than the late sown crops.The crop growing period for HD-3086 was 136, 127 and 117 days and for HD-2967 was 139, 129 and 118 days in first, second and third sown crop,respectively (Table 1). Crop growth took lesser time under late sowing due to higher mean temperature during different phenophases compared to early sown crops. Total growing degree days were 1664.8, 1592.8 and 1562.1°C for HD-3086 and 1734.9, 1635.4 and 1586.6 °C for HD-2967 in first, second and third sown crop respectively.Similar results were also reported by Sikder (2009).

Biomass accumulation

Biomass production of the plants was higher in the first sowing dates, may be due to favourable weather during crop growth period. Maximum above ground biomass was observed in first sowing, in HD-3086 (1213.2 gm^{-2}) followed by HD-2967 (1146.8 gm^{-2}). Similar pattern of biomass production was observed, in case of second sowing, under HD-3086 (920 gm^{-2}) followed by HD-2967 (880gm^{-2}). In third sown crop, the corresponding values of biomass production were 884.4 gm^{-2} for HD-3086 and 373.2 gm^{-2} for HD-2967 (Fig. 1). The reduction in the magnitude of maximum biomass production in second sown crop as compared to first sown crop was 24.2 and 23.3 % in HD-3086 and HD-2967 respectively. Biomass production reduced in third sown crop to 26.8% in HD-3086 and 67.5% in HD-2967 as compared to corresponding value in first sown crop. Results showed that among the varieties, HD-3086 had higher value of biomass than HD-2967. First sown crop recorded higher LAI and vigorous growth, which ultimately converted into higher biomass. The reduction of biomass production due to

Table 1: No of days and thermal time required for different phenological stages in wheat under different sowing conditions

Phenological stage	First sowing		Second sowing		Third sowing	
Variety	HD-3086	HD-2967	HD-3086	HD-2967	HD-3086	HD-2967
Number of days						
Emergence	7	8	8	9	12	13
Tillering	47	50	45	49	44	46
Flowering	94	102	96	98	90	93
Grain filling	115	119	112	113	102	103
Physiological maturity	130	132	122	124	113	114
Harvesting	136	139	127	129	117	118
Thermal time(°C)						
Emergence	90.6	107.1	80.8	90.8	102.8	109.9
Tillering	408.9	430.45	331.8	348	283.6	294.5
Flowering	464.8	534.3	593.9	597.9	585.3	615.5
Grain filling	291.2	236	241.1	230.7	245.4	222
Physiological maturity	263.2	245.4	232.2	259.7	252.9	250
Harvesting	146.1	167.4	113	108.3	92.1	94.7
Total Thermal Time	1664.8	1734.9	1592.8	1635.4	1562.1	1586.6

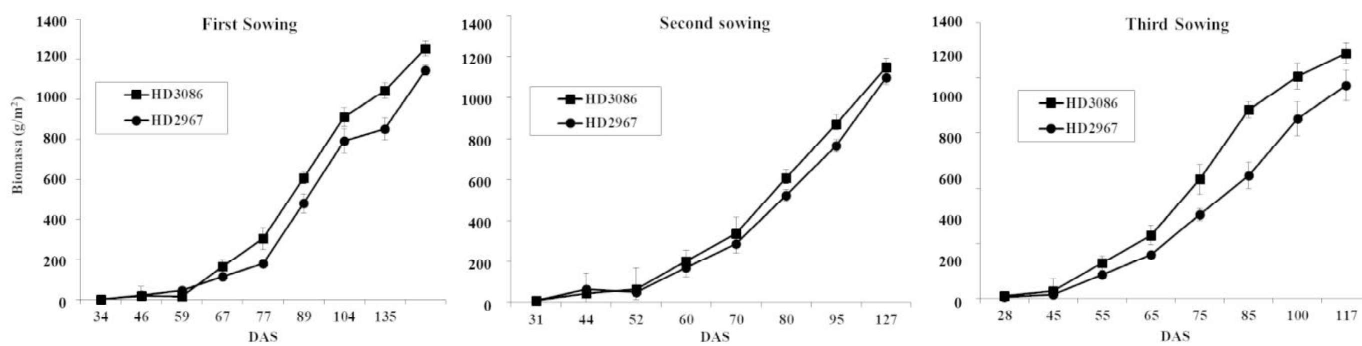

Fig. 1: Biomass in different varieties of wheat under different sowing conditions

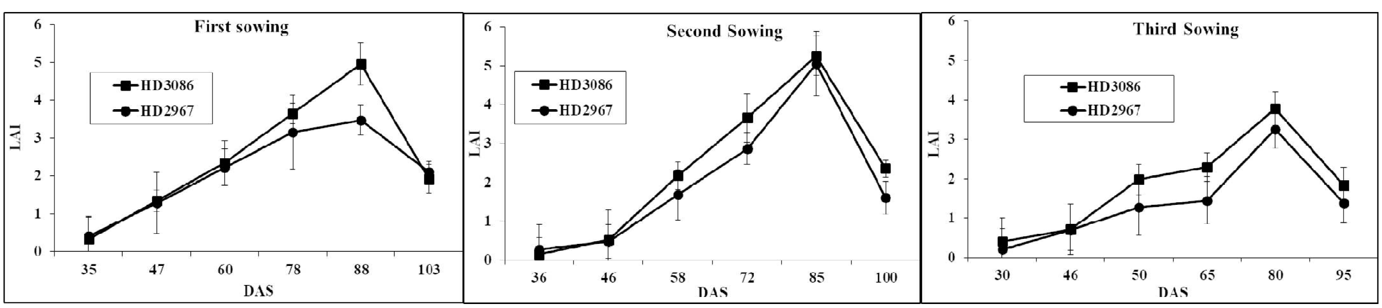

Fig. 2: LAI in different varieties of wheat under different sowing conditions

late sowing was also reported in soybean by Vashisth *et al.* (2012) and Joshi *et al*. (2016). Pal *et al*. (2012) also concluded that, the maximum biomass was recorded in wheat sown on mid-November than that sown in early January.

Leaf area index (LAI)

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

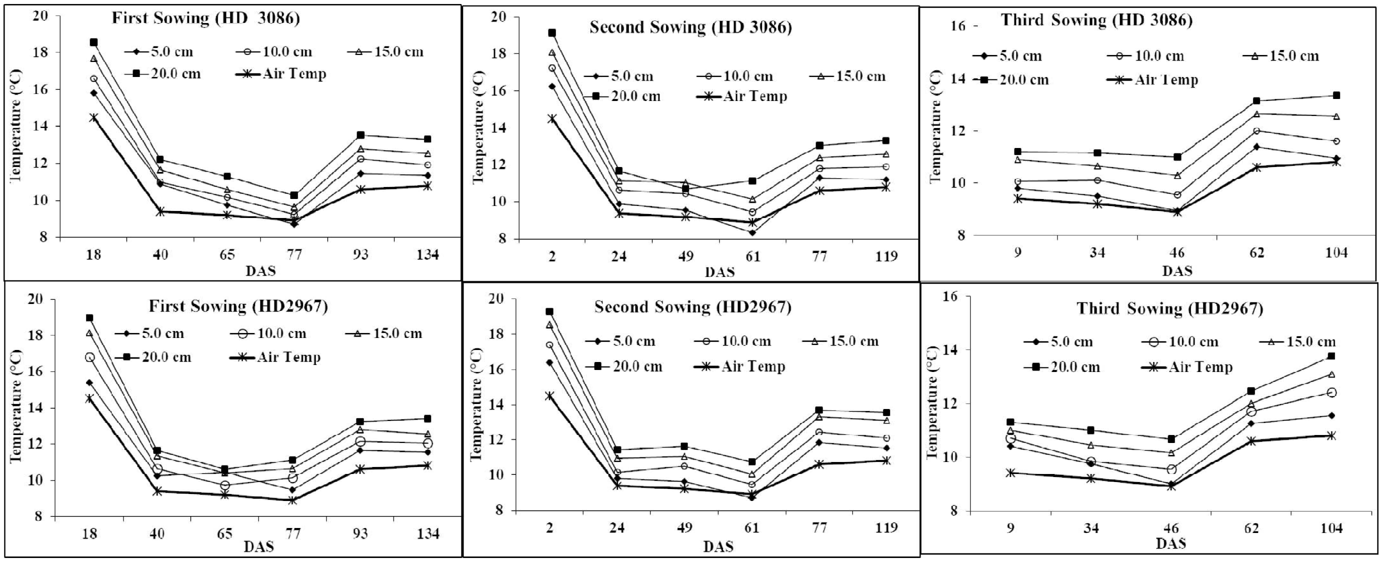

Fig. 3: Soil temperature measured at different depth under different sowing condition

utilization of radiation and amount of photosynthesis synthesized. During the crop season, the maximum leaf area index under different weather condition was found to be 5.26 and 5.05 for first sown crop, 4.97 and 3.48 for second sown crop, 3.78 and 3.25 for third sown crop in HD-3086 and HD-2967 wheat varieties, respectively at 50 % flowering (Fig. 2). The peak LAI occurred at 88 days after sowing in first sown crop, 85 days after sowing in second sown crop and 80 days after sowing in third sown crop indicating that delay in sowing of crop reduced the leaf area index in both the varieties. Cultivar HD-2967 had lower value of leaf area index as compared to HD-3086 in both the years under variable weather conditions. High temperature condition is responsible for drastic reduction in leaf are index for late sowing condition. The results showed conformity with Pal *et al*. (2012).

Soil moisture and soil temperature at different depth under different sowing conditions

Soil moisture was measured on dry weight basis at different depths up to 60 cm in both the varieties under different weather conditions. In HD-3086, at the time of emergence the moisture was found in between 5-6, 4-6 and 5-6 percentage, during tillering in between 5-6, 6-8 and 7-9 percentage, at flowering in between 6-8, 5-6 and 6-8 percentage, during grain filling stage in between 6-7 percentage and at physiological maturity in between 1-3 percentage (Fig 3).In the varieties HD-2967 the soil moisture at the time of emergence was found in between 5-6, 3-5 and 5-6 percentage, during tillering in between 5-7, 6-7 and 6-8 percentage, at flowering in between 4-6, 4-6 and 4-5 percentage, during grain filling stage in between 4-7, 5-6 and 5-6 percentage and at physiological maturity in between 1-3 percentage at different depth under different weather conditions.It implies that soil moisture uptake (consumptive use) by HD-3086 was significantly higher than that of HD-2967 for all date of sowing which is related to higher biomass and seed yield. Pradhan *et al*. (2014) also reported that treatment with higher biomass yield had lower soil moisture storage.

Soil temperature measured at different depth 5 cm, 10 cm, 15 cm and 20 cm in different varieties under different weather conditions. Soil temperature measured at 2.21 PM was found to be 1-5°C lower than the air temperature and with increase in the depth the soil temperature decreased in both the varieties (Fig 4). Soil had sufficient soil moisture hence the soil temperature at surface was lower than air temperature. Variety HD-3086 had 0.1-0.7°C higher soil temperature than HD-2967. Soil temperature from sowing to final emergence in different treatments ranged from 15 to 32°C. The low value of soil temperature was responsible for delay in germination under late sowing. Apart from that the high value of soil temperature at the time of maturity was responsible for short growing period in late sowing. Prasad *et al*. (2006) observed the similar result while working on peanut.

Relative water content

Percentage relative water content (RWC) was found to be higher in HD-3086 as compared to HD-2967 at all stages of first, second and third sown crop (Fig.5). The value of percentage RWC in HD-2967 was found to be higher in

Table 2: Correlations between grain yield and relative water content (RWC)in wheat

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

Table 3: Radiation use efficiency(gMJ^{-1}) in wheat under different sowing conditions

Date of sowing	Varieties	45 DAS	75 DAS	90 DAS	110DAS
First sowing	HD-3086	1.81±0.012	2.57±0.019	3.97±0.073	3.90±0.083
(Timely)	HD-2967	1.78±0.014	2.49±0.015	3.88±0.008	3.82±0.022
Second sowing	HD-3086	1.65±0.016	1.27±0.016	2.88±0.009	2.75±0.024
(Late)	HD-2967	1.59±0.009	2.20±0.009	2.80±0.026	2.79±0.029
Third sowing	HD-3086	1.31±0.013	1.88±0.007	2.44±0.029	2.41±0.011
(Very late)	HD-2967	1.29±0.015	1. 70±0.091	2.32±0.016	2.30±0.022

Table 4: Percentage deviation of observed yield from predicted yield done by thermal time at grain filling stage in wheat crop

Date of sowing	Varieties	Predicted yield	Observed yield	% Deviation
First sowing (Timely)	HD-3086	5089.9	4916	3.5
	HD-2967	4176.9	4131	1.1
Second sowing (Late)	HD-3086	4261.3	4566	-6.7
	HD-2967	4089.2	4028	1.5
Third sowing (Very late)	HD-3086	4332.4	4645	-6.7
	HD-2967	3945.4	3606	9.4
Average	4315.9	4315.3	0.01	

Table 5: Wheat yield and protein content of wheat under different sowing conditions

Date of sowing	Variety	Yield (kg ha^{-1})	Protein content(%)	Harvest index
First sowing (Timely sown)	HD-3086	4916 ± 3.06	11.16^{a}± 0.23	0.40
	HD-2967	4131 ± 2.99	11.48 ^{a} ± 0.86	0.36
Second sowing (Late sown)	HD-3086	4566 ± 2.13	9.94 ^{a} ± 0.45	0.49
	HD-2967	4028 ± 2.34	10.19 ^{a} ±0.15	0.45
Third sowing (Very late sown)	HD-3086	4645 ± 2.01	13.94 ^{b} ± 0.09	0.52
	HD-2967	3606 ± 1.90	14.89 ^{b} ± 0.61	0.55

first sown crop followed by second and third sown crop. However, in HD-3086, the value of percentage RWC was found to be higher in first sown crop followed by third and second sown crop. There was significant positive correlation (0.88 to 0.97) between grain yield and RWC during different phenological stages (Table 2).

Radiation use efficiency

The radiation use efficiency (RUE) was significantly higher in HD-3086 than in HD-2967 for all dates of sowing (Table3). The peak value of RUE at 90 days after sowing was 3.97, 2.88, 2.44g MJ^{-1} and 3.88, 2.80, 2.32 g $MJ^{-1}$for HD-3086 and HD-2967 in first, second and third sown crop respectively. The percentage reduction of peak value of radiation use efficiency was 27.5 and 27.8 %, 38.5 and 40.2 % for HD-3086 and HD-2967, respectively in second and third sown crop as compared to first sown crop. The highest RUE overlapped with highest value of LAI at 90 DAS. Gimenez *et al.* (1994) concluded that PAR drives

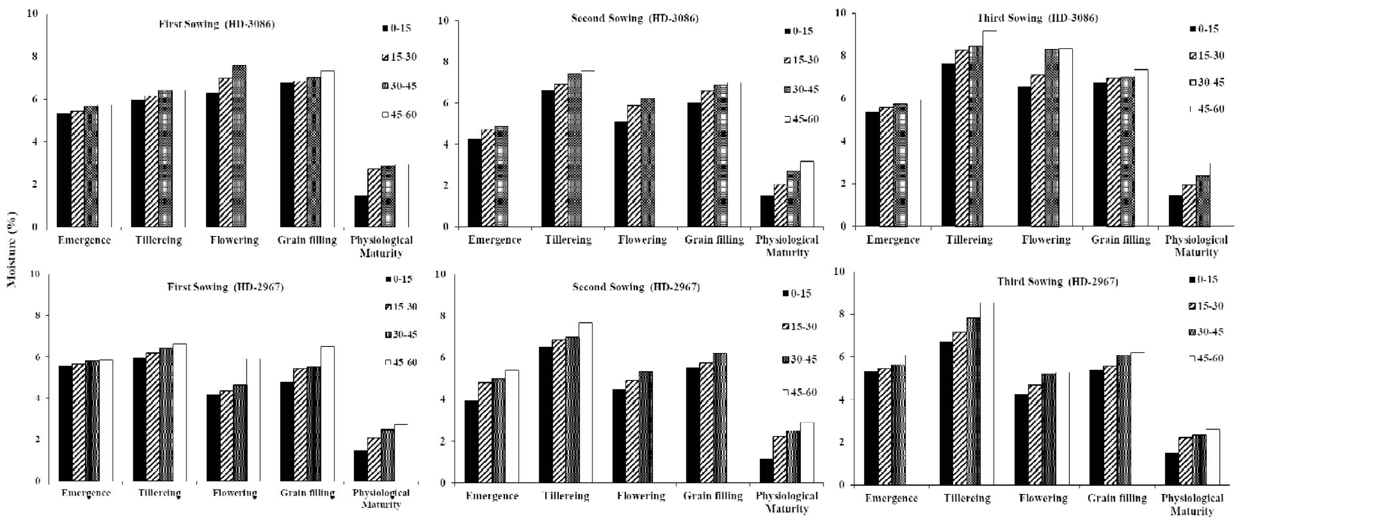

Fig. 4: Soil moisture measured at different depth under different sowing condition

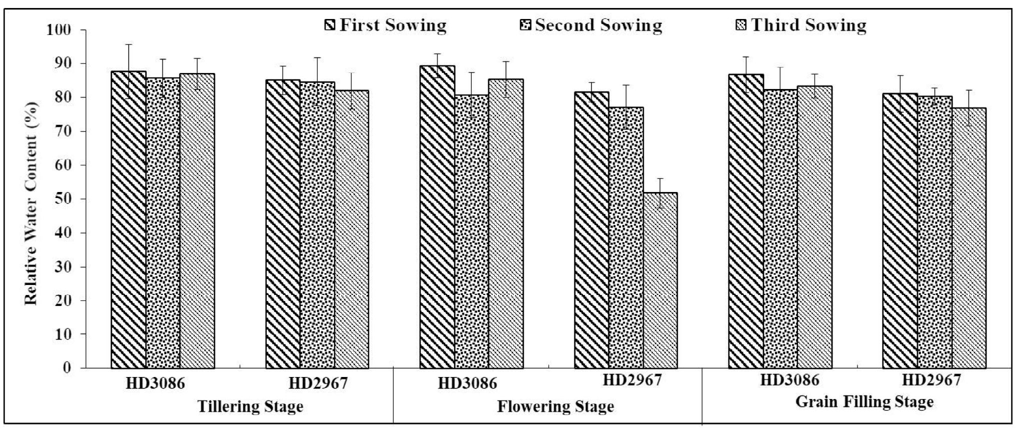

Fig. 5: Relative water content (%)under different sowing conditions

photosynthetic gain in terms of productivity for any given canopy size (LAI), while canopy structure (leaf angle and orientation) determine the fraction of intercepted radiation and its utilization efficiency.

Yield prediction by thermal time

Temperature is one of the key factors which influences growth rate, development and productivity of crop. Grain yield had significant positive correlation (0.839*) with thermal time(GDD) during grain filling stage. The results are in conformity with those of Goyal*et al.* (2015) who reported that thermal indices such as GDD, PTU and HTU show good correlation with biophysical parameters and grain yield. The thermal time thus is useful for prediction of yield potential of a crop in a particular environment. The model developed for wheat yield forecasting with the help of thermal time was as follows:

Yield =273.47 +16.54*X

Whereas, X= thermal time during grain filling stage for both the varieties. Percentage deviation of observed yield from predicted yield done by thermal time at grain filling stage in wheat crop was 1-9 % under different weather conditions (Table 4).

Seed yield, protein content and harvest index

During the crop season the seed yields of HD-3086 and HD-2967 was 4916 and 4131 kgha^{-1},4566 and 4028 kgha^{-1},4645 and 3606 kgha^{-1} in first,second andthird sown crop,respectively (Table 5). Delay of 15 days in sowing decreased seed yield to the extent of 7.1 % in HD-3086 and 2.5% in HD-2967 respectively.Further delay in sowing by 15 days reduced the yield to 2.5 % in HD-3086 and 12.7% in HD-2967. In HD-2967, early sown crop yielded higher seed yield than late sown crop however in case of HD-3086, first sown crop had higher yield followed by third and second sown crop.This is because in HD-3086, the value of percentage RWC was found to be higher in first sown crop followed by third and second sown crop. This indicates that crop was in leas water stress during first sown crop followed by third and second sown cropin HD-3086. The seed yield was found to be higher in HD-3086 as compared to the corresponding value in HD-2967under all three dates of sowing.HD-3086 had16, 11.8 and 22.4% higher grain yield than HD-2967 in first, second and third sown crop respectively.Crop was in less stress conditions during tillering, flowering and grain filling stages in mid-November sowing as compared to later sowing, the yield was more in first sown crop than that oflate sown crop. Earlier studies have also reported that exposure to higher temperatures during flowering and grain filling stage can significantly reduce grain yield (Joshi *et al.*, 2016; Vashisth *et al.*, 2011).Protein content found in cultivars HD-3086 and HD-2967 was 11.66 and 11.48 in first sown crop, 9.94 and 10.19 in second sown crop and 13.94 and 14.89 in third sown crop (Table 5). Delay in sowing increased the protein content to 19.6% in HD-3086 and 29.7% in HD-2967. However, we observed that the second sowing resulted in less protein due to high stress condition during flowering and grain filling period in terms of relative water content.More protein content under late planting indicates that higher temperatures have been the main cause of higher protein content and early maturity in the grain in the late sown wheat crops. These results are in conformity with those of Reynolds *et al*. (2001).Harvest index is genetic coefficient of any crop but it may vary with different weather situations (Table 5). The harvest index in general was found to be 5 to 12% higher for HD-3086 cultivar than that in HD-2967.

CONCLUSION

Crop growth and seed yield were relatively higher in the first sown wheat crop varieties because of more congenial weather conditions during the entire crop growth period. Radiation use efficiency was found to be higher in first sown crop as compared to late sown crop. Delay in sowing time reduces the yield significantly. From this study it was concluded that crop micro environment changed due to different sowing dates, strongly influences different phenological stages and crop yield. Seed yield therefore could be optimized by doing appropriate management practices during different phenological stages for obtaining favorable microclimatic conditions for crop growth.

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