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The effect of canopy temperature depression in Barley crop on different environmental sowing conditions in Trans-Gangetic plains of India

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Abstract

A study on barley crops was carried out at the research farm of the Department of Agricultural Meteorology during the Rabi season of 2019-20 and 2020-21. The trial objective was to understand the effect of various meteorological, plant and soil parameters on the Canopy Temperature Depression (CTD) of barley crops under varying growing environmental conditions. Four dates of sowings were selected for both *rabi* seasons of 2019-20 and 2020-21, *i.e.,* D_1- 15th November 2019, D_2- 30th November 2019, D_3- 15th December 2019 and D_4- 30th December 2019 and D_1- 28th November 2020, D_2- 14th December 2020, D_3- 28th December 2020 and D_4- 8th January 2021. The meteorological parameters were taken from the agrometeorological observatory at the research farm of CCS HAU, Hisar. Plant and soil parameters were recorded and calculated during the field trials conducted on barley crops in both seasons (2019-20 and 2020-21). The CTD of the barley crop was observed using a hand-held infrared thermometer at different phenological stages. It was observed that the CTD of D_1 and D_2 sown crops was majorly influenced by meteorological and soil parameters, respectively. The plant parameters majorly influenced the CTD of D_3 and D_4 sown crops.

Keywords

crop; barley; canopy temperature depression; soil parameters

Introduction

Barley (*Hordeum vulgare L.*) is a major *Rabi* season crop. Barley cultivars are classified into three distinct species: *H. vulgare L.* (six-rowed barley), *H. distichon L.* (two-rowed barley) and *H. irregular L.* (two-rowed barley) (1). It is cultivated in a broad range of soils which varies from saline to poor textured soils under different climatic conditions. The Barley crop is predominantly cultivated in semi-arid conditions for pasture and cereal production (1).

In the year 2021-22, barley crop was cultivated in 592 thousand ha area, with a total production of 1656 thousand tonnes and an average yield of 2.8 t/ha in India (2). In Haryana (2020-21), barley crop was grown in an area of 19.4 thousand ha with a total production was 73.9 thousand tonnes and an estimated yield of 3803 kg/ha (3). Barley crop is predominantly produced in states, such as Rajasthan, Uttar Pradesh, Madhya Pradesh, Jammu and Kashmir, Himachal Pradesh, Haryana and Punjab.

Barley is one of the essential cereal crops grown in almost all parts of the world except the tropical regions. It serves as a major food source for a larger number of people living in the cooler, semi-arid regions of the world, whereas wheat and other cereals are less adapted. In recent years, the consumption of barley crop has increased due to its nutritional value and health benefits. Its adaptability to various agro-climatic conditions makes it an attractive crop for human consumption and livestock (4). With the increase in world population, there has been a call to increase food production to alleviate food shortages through improved water management.

Evapotranspiration (ET) is the combined amount of water lost from soil (evaporation) and the plant (transpiration) (5, 6). The water requirement for barley crops range from 390-430 mm (2009) which can be met through rainfall.

Canopy temperature (CT) helps in assessing the drought tolerance of crops and CTD shows a high correlation with the rate of transpiration from the crop. CTD can be positive or negative based on the air temperature (AT) surrounding the canopy of the crop. When the CT is lower than AT, it indicates higher transpiration from the crop surface and results in a negative CTD. On the contrary, CT more than AT attributed to restricted transpiration from the crop canopy due to closed stomata in leaves of the crop caused by increased evaporative demand, resulting in a positive CTD. A negative CTD indicated that the crop has ample water present in the root zone which fulfills its physiological demand. A positive CTD indicates water stress in the crop due to lower water content in the root zone, which is about to reach the wilting point. This allows plants to restrict water flow inside the plant parts due to the closing of stomatal pores which increases the CT (7-9).

In the present study, efforts have been made to understand the effect of meteorological, plant and soil factors on the CTD of the crop under various sowing conditions. Also, the effect of delayed sowing of barley crop was correlated with different factors to understand the effect on CTD of the crop. This study indicates the evapotranspiration in plants due to weather, physiological and soil factors. The CTD can be an important indicator in assessing the surface temperature of the crop reflecting the water stress in plants. This is important to understand the time of irrigation application in plants along with the amount of irrigation application. Therefore, this experiment was conducted to study the effect of different factors on water loss from the plant surface.

Materials and Methods

2.1 Location of the experimental site

The study was conducted in the research field of the Department of Agricultural Meteorology, CCS HAU, Hisar. The experimental site is located at 29˚10'N latitude and 75˚46'E longitude with an altitude of 215.2 msl.

2.2 Climatic conditions

The climatic conditions of Hisar are characterized by the continental climate which is located on the periphery of the monsoon zone. It is in a semi-arid and subtropical zone. The monsoon arrives in the summer season from the first week of July to the second week of September by south-westerly winds. In winter season, rainfall occurs due to Western Disturbance. From October to June, the climate remains mostly dry, the summer season remains hot while the winter season remains cold. The maximum temperature of the region is observed to cross 45˚C during the June month and during the winter season minimum temperature can go below 0˚C (freezing point) during January. Extreme temperature fluctuations are observed in the region diurnally. Due to western disturbance, two to three light showers are received which is followed by lower temperature. Frost occurrence is common in the region on certain days during the winter season. The average rainfall in the region is 450 mm where much of the rainfall amount is contributed by the south-west monsoon.

2.3 Technical details of the experiment

For the experimental trial, four sowing dates were selected for *the Rabi seasons* of 2019-20 and 2020-21, which are described in Table 1.

The experimental design selected for the study was Randomized Block Design (RBD) with three replications, 16 treatment combinations and 48 plots (5.0 m × 3.6 m).

Table 1. Different dates of sowing in *Rabi* season 2019-20 and 2020-21.

Date of Sowing	*Rabi* 2019-20	*Rabi* 2020-21
D_1	15th November 2019	28th November 2020
D_2	30th November 2019	14th December 2020
D_3	15th December 2019	28th December 2020
D_4	30th December 2019	8th January 2021

2.4 Meteorological Data

The meteorological data, such as the maximum and minimum temperature, were used to derive the mean temperature. Morning and evening relative humidity were used to derive mean relative humidity. Rainfall, bright sunshine hour and pan evaporation were taken from the meteorological observatory in the research field of the Department of Agricultural Meteorology, CCS HAU, Hisar.

2.5 Irrigation application

The first irrigation was applied on 6 January 2020 for all sowing dates and on 17 January 2021 in D_1 and D_2. The second irrigation was applied in D_3 and D_4 on 25 February 2020 and 27 February 2021 for the respective seasons. The depth of irrigation (water level) provided was 6 cm and the method adopted for irrigation was flood irrigation.

2.6 Canopy Temperature Depression (CTD)

To calculate CTD, CT and ambient AT were observed on different phenophases of the barley crop on an hourly basis. CT and ambient AT were observed on an hourly basis from 9:00 to 17:00 hrs using an infrared thermometer (Model AG-45, Telatemp. Corp. CA) focussed at the top of the canopy during tillering, jointing booting, anthesis, hard dough and physiological maturity. The CTD is calculated as

$$CTD = Tc - Ta \qquad (2.1)$$

Where, Tc is canopy temperature (˚C) and Ta is ambient air temperature (˚C) (8,9).

2.7 Leaf Area Index (LAI)

The leaves were extracted from plant samples collected from individual plots to compute the LAI for barley crops. An LAI meter (LI-3000 Area meter, LI-COR Biosciences, Nebraska, USA) was used to measure the green leaf area (cm^2). The LAI observations for tillering, jointing, booting, anthesis, hard dough and physiological maturity stages were recorded. This formula was used to calculate LAI:

$$LAI = \frac{\text{Leaf Area } (cm^2)}{\text{Total land area covered by plants } (cm^2)} \quad (2.2)$$

2.8 Soil moisture

Soil moisture content was measured by gravimetric method using soil samples taken at 0 – 15 and 15 –30 cm depth. Observations were recorded using the soil auger during sowing, seedling emergence, CRI, tillering, booting, anthesis, milking, hard dough and physiological maturity.

The soil samples were collected in air-tight aluminium containers to measure the soil moisture using the gravimetric method. The collected soil samples were weighed immediately after they were extracted from the field and later dried using a hot air oven at 105 ˚C for 24 hours. After removing them from the oven, they were cooled at room temperature and weighed again. The difference obtained in the weight of the sample before oven drying and after oven drying indicated the moisture content in the soil. The soil moisture content was calculated using the following formula:

$$\text{Moisture Content on weight basis} = \frac{\text{Fresh Weight - Dry Weight}}{\text{Dry weight}} \times 100\% \quad (2.3)$$

2.9 Statistical Analysis

To understand the variation in CTD and LAI between different sowing dates (D_1, D_2, D_3 and D_4), ANOVA was used to statistically analyze the data collected for different sowing dates and different phenophases of the crop. The F-test was used to test the significance of the effect of treatment at 5 % probability. The critical difference (C.D.) was used to test the significant difference between the mean of the two treatments.

$$CD = \sqrt{2 \times \frac{EMS}{n}} \times t - \text{value at } 5\,\% \quad (2.4)$$

Where, EMS = Error mean sum of the square, n = Number of observations, t = value of t- distribution at 5% level of error of degree of freedom

Correlation coefficients and regression analysis were derived to understand the relationship between CTD and LAI. The correlation coefficient was computed by dividing the sum of the squares of the product of deviation from the mean by the square root of the product of the sum of the squares of deviations from the respective mean of two variables and its significance was tested at a 5 % level.

$$r = \frac{\sum(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum(x_i-\bar{x})^2 \sum(y_i-\bar{y})^2}} \quad (2.5)$$

Where, r = Correlation Coefficient, x = Independent variable, y = Dependent variable

Linear regression equation describes the relationship between independent variables, which includes meteorological, plant and soil parameters and dependent variables i.e. CTD, which can be understood by the equation:

$$Y = mX + b \quad (2.6)$$

Where, x = Independent variable, y = Dependent variable, m = estimated slope and b = estimated intercept. To understand the effect of different parameters on the CTD of the crop under different growing environments using regression analysis various statistical methods were derived such as coefficient of determination (R^2), regression coefficient (RC) and standard error (SE) for all the treatment combinations.

Result and Discussion

3.1 Meteorological data

Fig. 1 & 2 depict weather conditions prevailing under different sowing environments (D_1 to D_4) for 2019-20 and 2020-21, respectively.

When comparing the mean temperature for different growing environments for 2019-20, it was observed that the mean temperature kept increasing with delay in the sowing date. The average mean temperature for the entire growing season was 14.4 ˚C for D_1, 14.6 ˚C for D_2, 15.1 ˚C for D_3 and 16.7 ˚C for D_4. Mean RH decreased with delay in the sowing date, where the average mean RH for the entire growing season was 76.5 % for D_1, 76.1% for D_2, 75.3 % for D_3 and 71.6 % for D_4. Cumulated rainfall increased with delay in the sowing date, but it was observed to be the maximum during the D_2 growing environment. The total cumulative rainfall for the growing season was 114.3 mm for D_1, 122.9 mm for D_2, 118.4 mm for D_3 and 119.2 mm for D_4. Cumulated pan evaporation was observed to increase with delay in sowing. Total cumulated pan evaporation for the growing season was 233.7 mm for D_1, 253.8 mm for D_2, 262.2 mm for D_3 and 294 mm for D_4. Bright sunshine hours (BSSH) increased with a delay in sowing. The average BSSH for the growing season was 4.8 hrs for D_1, 5.1 hrs for D_2, 5.3 hrs for D_3 and 6.0 hrs for D_4. Prevailing weather conditions for the 2020-21 *Rabi* season observed that mean temperature kept on increasing with delay in the sowing date where the average mean temperature for the entire growing period was observed to be 16.4 ˚C for D_1, 16.6 ˚C for D_2, 18.2 ˚C for D_3 and 19.2 ˚C for D_4. Mean RH decreased with delay in the sowing date, where the average mean RH for the growing season was 70.8% for D_1, 69.8% for D_2, 66.9% for D_3 and 64.2% for D_4. Cumulated rainfall remained the same for D_1, D_2 and D_3 and decreased for the D_4 growing environment, i.e. 23.2 mm for D_1, D_2 and D_3 and 14.8 mm for D_4. Cumulated pan evaporation increases with delay in sowing and total cumulative pan evaporation for the growing season was 288.9 mm for D_1, 289.2 mm for D_2, 339.6 mm for D_3 and 365.1 mm for D_4. BSSH increases with delay in sowing. The average BSSH for the entire growing season remains the same for D_1 and D_2 i.e. 5.9 hrs, 6.1 hrs for D_3 and 6.6 hrs for D_4 growing season. When comparing prevailing weather conditions in both seasons, it was observed that 2020-21 had a higher mean temperature, lower mean RH, lower cumulative rainfall, higher cumulative pan evaporation and higher BSSH.

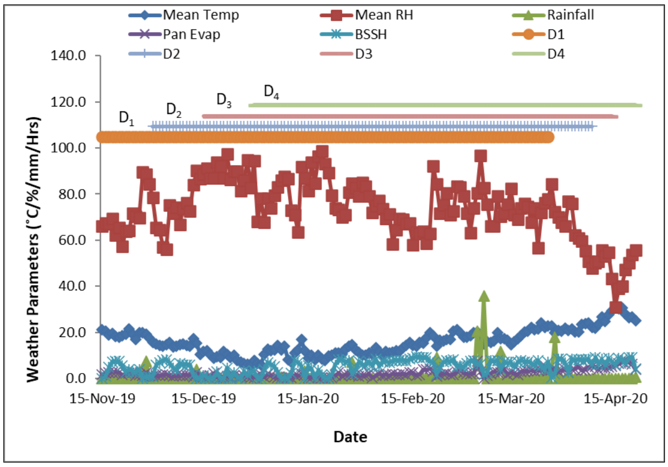


Fig. 1 Weather Parameters under different growing environments for *Rabi* 2019-20.

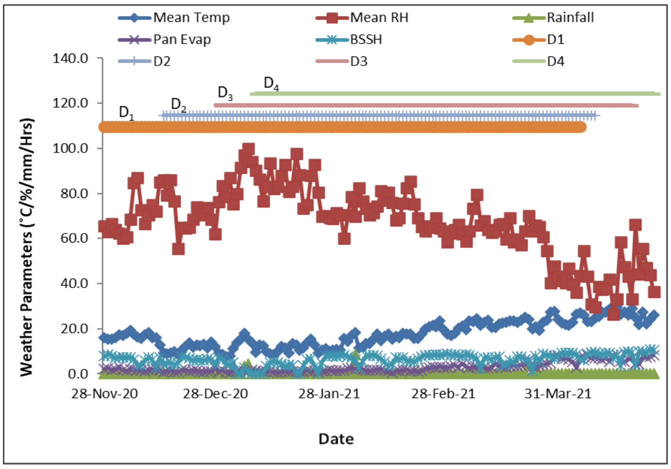


Fig. 2. Weather Parameters under different growing environments for *Rabi* 2020-21.

3.2 Plant Parameters

3.2.1 Leaf Area Index (LAI): The data given in Table 2 describes the LAI recorded during various phenophases. LAI recorded in barley crop increased with the advancing plant age until the anthesis stage after which LAI of the plant reduces again till physiological maturity is attained. Maximum LAI was recorded in D_1 treatment followed by D_2, D_3 and the least LAI was recorded in D_4 treatment. During the anthesis stage, D_1 treatment recorded LAI of 3.86 and 3.79, followed by D_2 which recorded the LAI of 3.61 and 3.53, D_3 treatment recorded LAI of 3.53 and 3.46 and the least LAI was recorded by D_4 treatment *i.e.* 3.33 and 3.28 for 2019-20 and 2020-21, respectively. When comparing both the crop growing season 2019-20 recorded higher LAI than 2020-21 for all the selected phenophases.

The data given in Table 2 describes the LAI recorded during various phenophases. LAI recorded in barley crops increased with the advancing plant age until the anthesis stage, after which LAI of the plant reduces again until physiological maturity is achieved. Maximum LAI was recorded in the D_1 treatment, followed by D_2 and D_3 and the least LAI was recorded in the D_4 treatment. During the anthesis stage, the D_1 treatment recorded LAI of 3.86 and 3.79, followed by D_2, which recorded an LAI of 3.61 and 3.53; the D_3 treatment recorded an LAI of 3.53 and 3.46 and the least LAI was recorded by D_4 treatment, *i.e.* 3.33 and 3.28 for 2019-20 and 2020-21, respectively. When comparing both crop-growing seasons, 2019-20 recorded higher LAI than 2020-21 for all the selected phenophases.

3.2.2 Dry matter accumulation: Table 3 depicts that total dry matter accumulation was maximum in the D_1 treatment, followed by D_2 and D_3 and the lowest dry matter was recorded in the D_4 treatment in all the phenological stages. During physiological maturity, D_1 recorded total dry matter accumulation of 1076.28 g/m^2 followed by D_2 treatment *i.e.*1064.34 g/m^2, D_3 treatment, i.e.1020.91 g/m^2 and the lowest was recorded in D_4 treatment, *i.e.* 991.53 g/m^2. In the 2020-21 crop growth season in all the phenological stages of the crop, D_1 treatment recorded maximum dry matter followed by D_2, D_3 and D_4. During physiological maturity, D_1 recorded total dry matter accumulation of 1058.79 g/m^2 followed by D_2 treatment *i.e.*1041.89 g/m^2, D_3 treatment *i.e.* 999.88 g/m^2 and the lowest was recorded in D_4 treatment *i.e.* 970.58 g/m^2. The reason for the same was a decrease in duration for the crop to complete its lifecycle, which resulted in lower photosynthate accumulation of the crop and less moisture available for the crop due to lower rainfall and higher temperature in the late sown crop during reproductive and senescence phase resulting in lower biomass production and leaf area of the crop (10-13). In the crop growth season 2019-20, more dry matter accumulation was observed than in 2020-21 in all the crop phenological stages.

3.3 Soil Moisture

3.3.1 Soil Moisture (%) at 15 cm depth: Table 4 indicates the soil moisture content on a weight basis during various phenological stages at 15 cm depth for the 2019-20 and 2020-21 seasons, respectively. It was observed that soil moisture content decreased with the advancing phenological stage except when irrigation was provided to the crop, which caused increased soil moisture at the given depth. In the 2019-20 and 2020-21 seasons, the highest soil moisture content was observed by D_3 and D_1crop *i.e.* 16.51% and 16.01% during the booting stage, respectively. Low soil moisture content was observed in D_4 treatment, i.e. 11.54% and 10.75% in 2019-20 and 2020-21, respectively. Overall soil moisture content was

Table 2. Leaf area index (LAI) of different barley varieties at various phenophases under different growing environments.

	Rabi 2019-20						*Rabi* 2020-21					
Treatments	**Tillering**	**Jointing**	**Booting**	**Anthesis**	**Hard Dough**	**Physiological Maturity**	**Tillering**	**Jointing**	**Booting**	**Anthesis**	**Hard Dough**	**Physiological Maturity**
D_1	2.48	3.18	3.53	3.86	1.87	1.03	2.43	3.09	3.45	3.79	1.41	0.92
D_2	2.32	3.09	3.19	3.61	1.65	0.98	2.26	3.04	3.12	3.53	1.39	0.90
D_3	2.13	3.02	3.07	3.53	1.58	0.91	2.08	2.91	3.01	3.46	1.35	0.87
D_4	1.92	2.86	2.96	3.33	1.42	0.89	1.87	2.79	2.87	3.28	1.34	0.85
Mean	2.21	3.04	3.19	3.58	1.63	0.95	2.16	2.96	3.11	3.52	1.37	0.89
SE(m)	0.03	0.03	0.03	0.03	0.01	0.01	0.04	0.04	0.03	0.04	0.01	0.01
CD	0.01	0.02	0.02	0.01	0.01	0.03	0.02	0.02	0.01	0.02	0.01	0.03

SE(m)- Standard Error (mean); CD- Confidence Determination

Table 3. Dry matter accumulation in barley crop in 2019-20 and 2020-21 growing seasons.

Treatments	*Rabi* 2019-20						*Rabi* 2020-21					
	Tillering	Jointing	Booting	Anthesis	Hard Dough	Physiological Maturity	Tillering	Jointing	Booting	Anthesis	Hard Dough	Physiological Maturity
D_1	91.03	276.84	421.32	611.17	923.66	1076.28	86.12	263.48	416.90	599.70	885.44	1058.79
D_2	87.78	258.61	412.52	594.37	897.35	1064.34	81.53	251.98	408.07	582.90	859.18	1041.89
D_3	83.80	246.89	404.03	577.10	873.73	1020.91	76.45	239.66	399.82	565.62	835.75	999.88
D_4	77.40	235.26	393.51	560.93	852.18	991.53	71.24	227.13	389.01	550.06	804.21	970.58
Mean	85.00	254.40	407.85	585.89	886.73	1038.27	78.84	245.56	403.45	574.57	846.15	1017.79
SE(m)	0.13	0.14	0.12	0.12	0.15	0.23	0.10	0.12	0.15	0.08	0.06	0.15
CD	0.37	0.39	0.35	0.35	0.45	0.66	0.29	0.33	0.43	0.22	0.17	0.44

SE(m)- Standard Error (mean); CD- Confidence Determination

Table 4. Soil moisture content (%) at different growth stages in barley crops at 15 cm depth in 2019-20 and 2020-21.

Treatments	Soil Moisture Content (%) at 15 cm depth											
	Rabi 2019-20						*Rabi* 2020-21					
	Tillering	Jointing	Booting	Anthesis	Hard Dough	Physiological Maturity	Tillering	Jointing	Booting	Anthesis	Hard Dough	Physiological Maturity
D_1	11.98	10.89	16.64	14.37	12.88	12.35	11.36	10.45	16.01	13.48	11.90	11.31
D_2	16.42	16.38	16.22	14.05	12.61	12.08	15.52	15.12	14.86	12.94	11.58	11.10
D_3	14.93	14.87	16.51	15.31	12.74	11.87	11.03	10.87	14.99	13.90	11.46	10.93
D_4	13.88	12.78	16.30	15.00	12.38	11.54	10.76	10.41	14.81	13.72	11.31	10.75
Mean	14.30	13.73	16.42	14.68	12.65	11.96	12.17	11.71	15.17	13.51	11.56	11.02
SE(m)	0.09	0.11	0.05	0.11	0.09	0.07	0.18	0.08	0.16	0.07	0.05	0.04
CD	0.27	0.31	0.15	0.33	0.26	0.20	0.52	0.22	0.46	0.19	0.14	0.12

SE(m)- Standard Error (mean); CD- Confidence Determination

higher in 2019-20 than in 2020-21. The soil moisture content under different growing environments recorded statistically significant differences in various crop phenophases for both crop growth seasons except in the 2020-21 crop season booting stage. In the crop growth season 2019-20, soil moisture content was observed more in all the phenophases of the crop than in the season 2020-21.

***3.3.2 Soil Moisture (%) at 30 cm depth*:** The data in Table 5 indicates the soil moisture content on a weight basis during various crop phenological stages at 30 cm depth for the 2019-20 and 2020-21 seasons, respectively. Soil moisture content decreased with advancing phenological stages, except when irrigation was provided in the crops, which resulted in increased soil moisture content of the soil. In crop growth season 2019-20 and 2020-21, it was observed that maximum soil moisture content was observed in the D_3 sown crop during booting, *i.e.*, 17.18% in 2019-20 and the D_1 sown crop during the booting stage, *i.e.,* 16.88% in 2020-21. Minimum soil moisture content was observed during physiological maturity in D_4 treatment, with a soil moisture content of 13.80% in 2019-20 and 11.45% in 2020-21. The soil moisture content under different growing environments recorded statistically significant differences in crop phenophases for both crop growth seasons. In the crop growth season 2019-20, soil moisture content was observed more in all the phenophases of the crop than in the season 2020-21.

3.4 Canopy Temperature Depression (CTD)

The data given in Table 6 and Fig. 3 & 4 depict the canopy temperature depression (CTD) (CT-AT), which was calculated for seasons 2019-20 and 2020-21, respectively and its diurnal variation is depicted in graphical and table form for different growing environments *i.e.*, D_1-15th November 2019 and 28th November 2020, D_2- 30th November 2019 and 14th December 2020, D_3- 15th December 2019 and 28th December 2020 and D_4- 30th December 2019 and 8th January 2021. As observed in Table 6, as the physiological stages of the crop progress, the CTD of the crop increases and the reason for the same was an increase in vapour pressure deficit due to an increase in mean air temperature, which resulted in reduced mean RH in the air around the crop (14). In Table 6, CTD is depicted as an averaged form for respective dates of sowing and varieties for different crop growth stages. In the 2019-20 growing environment, the negative CTD was observed to be highest in the D_2 sown crop, *i.e.*, -5.92 in the tillering stage and the lowest negative CTD was observed in the D_2 sown crop, *i.e.*, -2.28 in the booting stage. The highest positive CTD was observed in the D_4 treatment at the time of physiological maturity, *i.e.,* 4.21 and the lowest positive

Table 5. Soil moisture content (%) at different growth stages in barley crops at 30 cm depth in 2019-20 and 2020-21.

Treatments	Soil Moisture Content (%) at 30 cm depth											
	*Rabi*2019-20						*Rabi* 2020-21					
	Tillering	Jointing	Booting	Anthesis	Hard Dough	Physiological Maturity	Tillering	Jointing	Booting	Anthesis	Hard Dough	Physiological Maturity
D_1	14.38	17.12	16.26	15.76	15.40	14.82	14.03	16.88	15.70	15.34	15.84	14.23
D_2	16.92	16.74	16.03	15.53	15.12	14.63	16.67	15.80	13.92	12.94	15.07	12.25
D_3	15.38	17.18	16.71	15.87	14.89	14.10	12.44	16.43	14.82	13.29	14.84	11.74
D_4	15.07	16.83	16.41	15.54	14.12	13.80	12.18	16.15	14.59	13.11	14.55	11.45
Mean	15.44	16.97	16.35	15.68	14.88	14.34	13.83	16.32	14.76	13.67	15.08	12.42
SE(m)	0.10	0.06	0.11	0.06	0.10	0.09	0.05	0.08	0.10	0.12	0.08	0.11
CD	0.28	0.16	0.32	0.18	0.30	0.27	0.13	0.22	0.28	0.34	0.23	0.31

SE(m)- Standard Error (mean); CD- Confidence Determination

Table 6. Canopy Temperature Depression (CTD) in barley crop for 2019-20 and 2020-21.

Treatments	Canopy Temperature Depression (CTD)											
	*Rabi*2019-20						*Rabi*2020-21					
	Tillering	Jointing	Booting	Anthesis	Hard Dough	Physiological Maturity	Tillering	Jointing	Booting	Anthesis	Hard Dough	Physiological Maturity
D_1	-4.75	-5.21	-4.77	2.38	2.57	3.08	-4.36	-5.51	-5.51	2.57	2.75	3.22
D_2	-5.92	-4.57	-2.28	2.48	3.35	3.69	-5.72	-3.90	-3.90	2.78	3.49	3.91
D_3	-4.74	-4.34	-3.56	0.91	2.74	3.93	-4.52	-4.70	-4.70	1.11	2.81	4.11
D_4	-3.55	-4.18	-3.27	1.51	3.85	4.21	-3.35	-4.45	-4.45	2.02	3.81	3.31
SE(m)	0.05	0.05	0.05	0.10	0.05	0.05	0.06	0.07	0.07	0.05	0.05	0.05
CD	0.14	0.15	0.14	0.29	0.15	0.13	0.17	0.21	0.20	0.14	0.14	0.14

SE(m)- Standard Error (mean); CD- Confidence Determination

CTD was observed during the anthesis stage in the D_3 treatment, *i.e.,* 0.91. The reason for the same was lower mean RH in the D4 sown crop due to initial higher transpiration from the crop surface. However, after the booting stage, when combined with higher mean temperature, it resulted in restricted transpiration from the crop surface, causing water stress in the soil and showed the highest positive CTD value and lowest negative CTD value during physiological maturity and tillering stage (15-17).

As depicted in Fig. 3 & 4, the canopy temperature was recorded to be lowest at 9:00 hrs and kept increasing until it reached maximum at 14:00 hrs. Then it started decreasing till 17:00 hrs. The reason for the same was an increase in vapour pressure deficit in surrounding air during afternoon hours, which resulted in the opening of the stomata and increased transpiration, which caused cooling of the canopy, further lowering CT than AT (14,18). Maximum negative CTD disparity, when canopy temperature (CT) was less than air temperature (AT) (CT<AT), was observed during the tillering stage of D_2 treatment, *i.e.,* -7.0˚C at 14:00 hrs and maximum positive CTD disparity when CT is more than AT (CT>AT) was observed in physiological maturity in D_4 treatment *i.e.,* 5.15˚C at 14:00 hrs. In crop growth season 2020-21, maximum negative CTD disparity was observed in D_2 treatment *i.e.*, -6.8˚C at 14:00 hrs during the tillering stage and maximum positive CTD disparity was observed in D_3 treatment *i.e.,* 5.08˚C during physiological maturity at 14:00 hrs. Comparing the CTD of the two crop growth seasons, it was found that the crop was more water-stressed in 2020-21 than in 2019-20. The crop's negative CTD during the tillering, jointing and booting stages was lower, while its positive CTD was higher during anthesis, hard dough and physiological

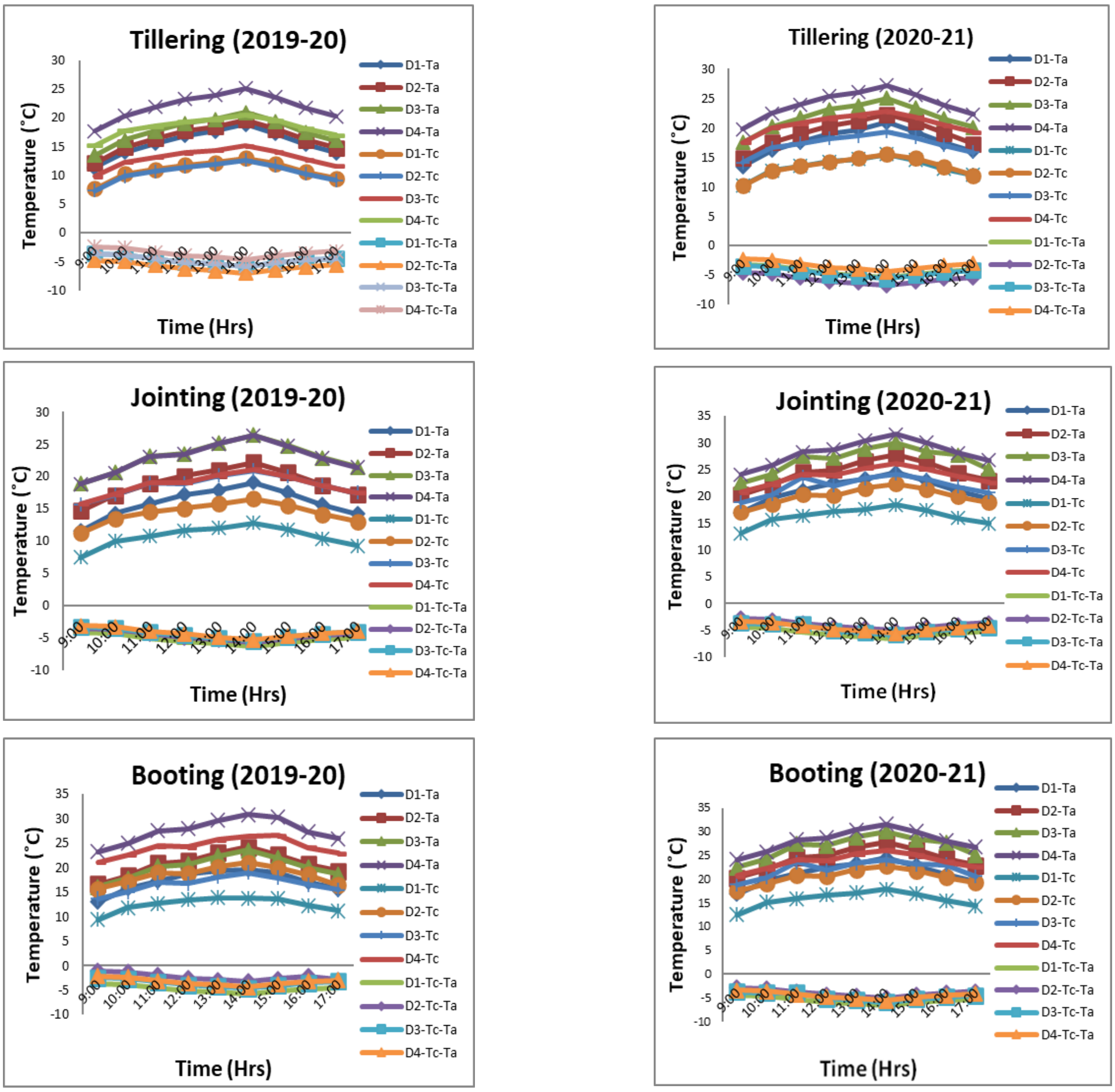


Fig. 3. Effect of different growing environments on CTD from tillering to booting over barley crop during 2019-20 and 2020-21.

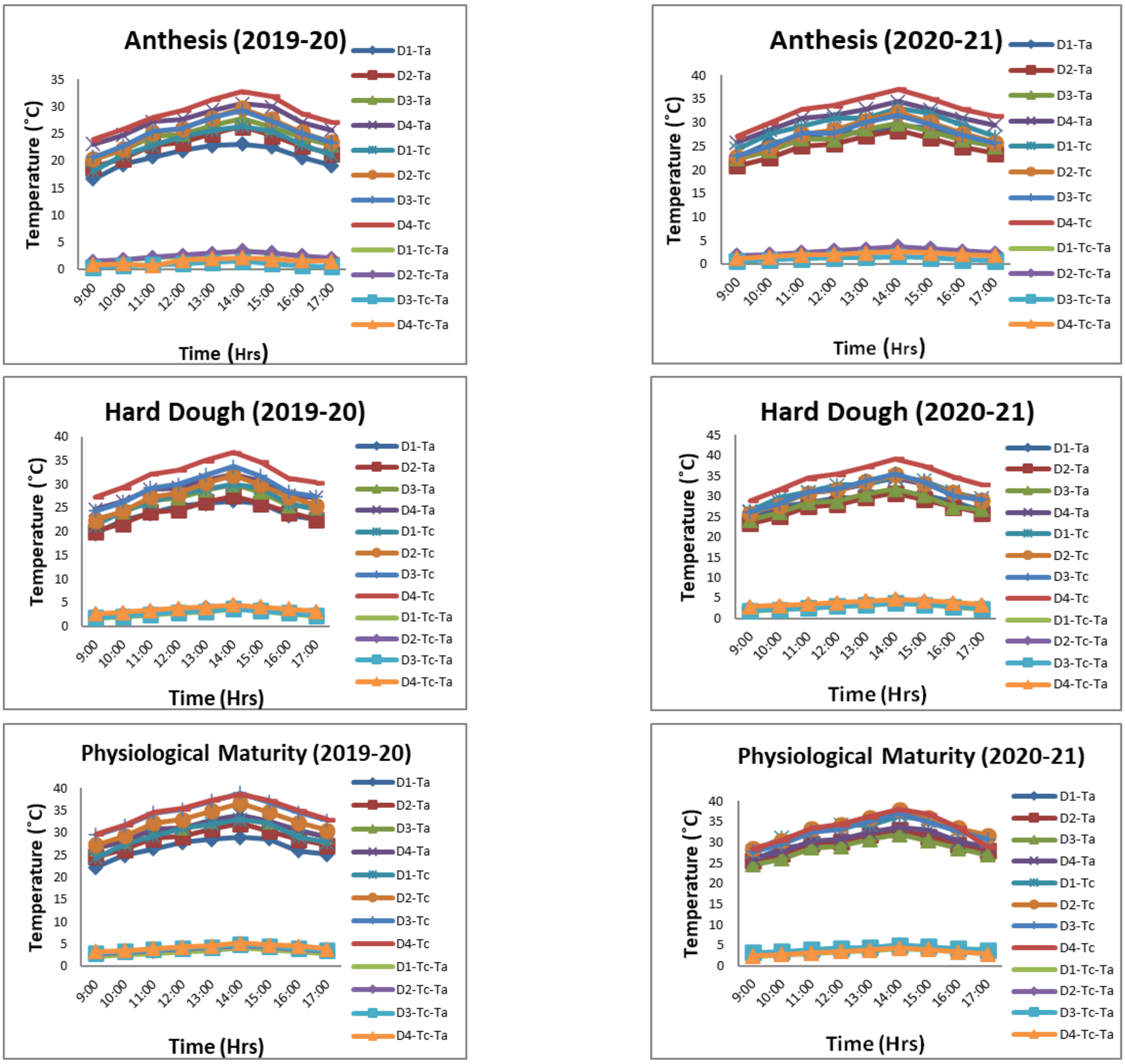


Fig. 4. Effect of different growing environments on CTD from anthesis to physiological maturity over barley crop during 2019-20 and 2020-21.

maturity (16). Mean RH was lower in 2020-21 than in 2019-20, causing more transpirational losses (19, 20), but there was less rainfall and irrigation supply during 2020-21, causing water stress in the soil. This water stress restricted the transpirational losses from the crop surface and increased the CT than ambient AT, resulting in higher positive CTD levels in the 2020-21 crop growth season (10, 11, 17, 21).

3.5 Correlation and Regression

***3.5.1 Correlation and regression analysis between CTD and weather parameters*:** As observed in Table 7, in the crop growth season of 2019-20, CTD has shown a stronger relationship with pan evaporation with D_1 and D_2 treatment followed by mean temperature, showing that there is a significant effect observed of evaporation and mean temperature on the CTD of D_1 and D_2. For D_3 and D_4, it was observed that mean temperature had a more significant effect on the CTD of the barley crop, followed by mean RH. The mean temperature strongly influenced the CTD of D_1 and D_3 sown crops more than the CTD of D_2 and D_4 sown crops and the reason for the same was that D_2 sown crop received the highest amount of rainfall in the crop growth season, which resulted in higher soil moisture (%) content in the root zone of the crop and showed the highest negative CTD value (16) in tillering stage (-5.92 in 2019-20) and in D_4 sown crop lower mean RH resulted in higher transpiration from the crop surface initially but after booting stage when combined with high mean temperature it resulted in restricted transpiration from crop surface causing water stress in soil and showed the highest positive CTD value and lowest negative CTD value during physiological maturity and tillering stage i.e., 4.21 and -3.55, respectively (15-17). Mean RH has shown a negative correlation, showing a decrease in CTD with an increase in RH. Mean RH showed a significant effect on CTD of D_3 and D_4 crops. The CTD of the D_4 crop showed a negative but the strongest correlation with mean RH due to restricted transpiration of water from the crop surface due to moisture stress in the soil, which resulted in increased canopy temperature of the crop than ambient air temperature (15-17). Rainfall showed an insignificant relationship with all the dates of sowing, showing an insignificant effect on the CTD of the crop. Pan evaporation showed a significant and positive effect on CTD of the D_1 and D_2 crops, showing high significance with the D_1 crop. The reason for the same was the lower mean temperature in the D_1 sown crop, which resulted in lower cumulative transpiration from the crop surface in comparison to consecutive dates of sowing where the mean temperature of the crop increased with the increase in temperature stress the transpiration of the crop increases (15). CTD of the D_2 crop showed a strong relationship with pan evaporation because of rapid transpiration from the crop surface due to sufficient soil moisture in the crop's root zone.

Table 7. Effect of Environmental factors on CTD depicted through correlation (2019-20)

Treatment	Mean Temperature	Mean RH	Rainfall	Pan Evaporation	Bright Sunshine Hours
D_1	0.936**	-0.352	0.601	0.970**	0.589
D_2	0.850*	-0.523	0.530	0.870*	0.076
D_3	0.928**	-0.871*	-0.410	0.664	0.476
D_4	0.901*	-0.916*	-0.415	0.711	0.732

*Significance at P=0.05 ** Significance at P=0.01

BSSH showed an insignificant effect on the crop's CTD.

As observed in Table 8, in crop growth season 2020-21 CTD has a positive and stronger relationship with mean temperature for D_1 and a negative and stronger relationship with mean RH for D_2 and D_3 where the effect of mean RH on CTD was observed to be highly significant for D_2 sown crop. Mean temperature showed a significant relation with CTD of barley crops for D_1 and D_3 crops showing a positive correlation i.e. increase in CTD with increase in mean temperature. The reason for the same was minimum temperature observed in 2020-21 was lower than in 2019-20 during the tillering stage of the D_1 sown crop due to a delay in sowing of the crop during 2020-21 than usual time (2019-20) (Fig. 1 and 2). The contrary to the D_2 and D_3 sown crop, D_1 sown crop underwent the lowest temperature causing lower transpirational losses than D_2 and D_3 sown crops hence showing a stronger correlation with mean temperature (14,21). Mean temperature showed an insignificant effect on D_2 and D_4 sown crops. Mean RH showed a negative correlation with CTD showing highly significant effect on D_2 and a significant effect on D_3 and D_1. It was observed that with an increase in mean RH, CTD of the barley crop reduced for all the sowing dates but it has shown an insignificant effect on the D_4 sown crop. Similar to 2019-20, it was observed that rainfall had an insignificant effect on the CTD of the crop. Similar to 2019-20 pan evaporation showed a positive a significant effect on the CTD of the barley crop for D_1 and D_2 showing that with an increase in evaporation in the atmosphere, the CTD of the barley crop increased. The effect of pan evaporation on D_3 and D_4 was observed to be insignificant. Relation with BSSH was observed to be significant and positive with D_3 and D_4 sown crops showing an increase in CTD with an increase in BSSH for D_3 and D_4 and an insignificant effect for D_1 and D_2 sown crops.

As observed in Table 8, in crop growth season 2020-21, CTD has a positive and stronger relationship with mean temperature for D_1 and a negative and stronger relationship with mean RH for D_2 and D_3, where the effect of mean RH on CTD was observed to be highly significant for D_2 sown crop. Mean temperature showed a significant relation with CTD of barley crops for D_1 and D_3 crops, showing a positive correlation, *i.e.*, an increase in CTD with an increase in mean temperature. The reason for the same was that the minimum temperature observed in 2020-21 was lower than in 2019-20 during the tillering stage of the D_1 sown crop due to a delay in sowing of the crop during the 2020-21 usual time (2019-20) (Fig. 1&2). Contrary to the D_2 and D_3 sown crops, the D_1 sown crop underwent the lowest temperature, causing lower transpirational losses than the D_2 and D_3 sown crops, hence showing a stronger correlation with mean temperature (14,21). Mean temperature showed an insignificant effect on D_2 and D_4 sown crops. Mean RH showed a negative correlation with CTD, showing a highly significant effect on D_2 and a significant effect on D_3 and D_1. It was observed that with an increase in mean RH, CTD of the barley crop was reduced for all the sowing dates, but it showed an insignificant effect on the D_4 sown crop. Similar to 2019-20, it was observed that rainfall had an insignificant effect on the CTD of the crop. Like 2019-20, pan evaporation showed a positive and significant effect on the CTD of the barley crop for D_1 and D_2, showing that with an increase in evaporation in the atmosphere, the CTD of the barley crop increased. The effect of pan evaporation on D_3 and D_4 was observed to be insignificant. Relation with BSSH was observed to be significant and positive, with D_3 and D_4 sown crops showing an increase in CTD with an increase in BSSH for D_3 and D_4 and an insignificant effect for D_1 and D_2 sown crops.

When comparing both crop growth seasons, the mean temperature effect on barley crop CTD was positive for both the sowing years but more significant in the 2019-20 crop growth season. Mean RH showed a negative correlation for both the crop growth seasons but higher significance in the 2020-21 cropping season. When comparing the CTD of both the crop growth seasons for all the crop growth seasons, it was observed that the negative CTD of the crop during tillering, jointing and booting stages was lower. The positive CTD was higher during anthesis, hard dough and physiological maturity, showing that the crop was more water-stressed in 2020-21 than in 2019-20 (16). This is because there was less rainfall and irrigation supply in 2020-21, which caused water stress in the soil, while mean relative humidity was lower in 2020-21 than in 2019-20, resulting in higher transpirational losses (16, 19, 22). The 2020-21 crop growth season had a greater positive CTD level due to this restriction of transpiration from the crop surface, which raised the CT above ambient AT (10,11,17,22). Rainfall showed an insignificant effect in both crop growth seasons. Pan evaporation showed a positive correlation in both crop seasons, but higher significance was observed in 2019-20 than in 2020-21.

Table 8. Effect of Environmental Factors on CTD depicted through correlation (2020-21)

Treatment	Mean Temperature	Mean RH	Rainfall	Pan Evaporation	Bright Sunshine Hours
D_1	0.896*	-0.845*	-0.136	0.876*	0.329
D_2	0.726	-0.939**	-0.149	0.861*	0.133
D_3	0.861*	-0.911*	-0.653	0.128	0.834*
D_4	0.676	-0.747	-0.337	0.296	0.820*

*Significance at P=0.05 ** Significance at P=0.01

BSSH showed a positive correlation in both the crop growth seasons, but the significance level was higher for 2020-21 than for 2019-20. The effect of BSSH on CTD of delayed sown crops, i.e. D_3 and D_4, was more than the D_1 and D_2 sown crops and with all the 2019-20 crop growth season sowing dates. With the increase in BSSH, transpiration from the crop surface increases, but it is reduced due to water stress in the crop, resulting in the closing of stomata in the leaves and increased CTD of the crop (23).

Tables 9 and 10 depict the regression analysis showing the relationship between CTD and weather parameters. Regression analysis showed that the R^2 value for weather parameters was observed to be highest for the D_1 sown crop (0.942 and 0.767, respectively) and it kept on reducing with delay in sowing except in the D_4 sown crop, where it showed a higher R^2 value than D_3 in both the crop growth seasons. RC value was observed to be highest for the D_2 sown crop in 2019-20 (0.177) and for the D_1 sown crop in 2020-21 (0.176). The lowest RC value was observed for the D3 sown crop in both the crop growth seasons (0.126 and 0.029). SE was observed to be highest for the D_3 sown crop for the cropping season (0.071 and 0.112) and the lowest SE was observed for the D_1 sown crop in 2019-20 (0.019) and D_2 sown crop in 2020-21 (0.034). It was observed from regression analysis that with delay in sowing, the effect of weather parameters was reduced over the CTD of the crop. The effect of the weather parameters on the crop's CTD was observed to be greater in 2019-20 than in 2020-21. The reason for the same was that the plant growth was higher during 2019-20 than the 2020-21 crop growth season, which resulted in lower plant parameters adversely affecting the CTD of the crop by providing less surface for the crop to transpire and hence increase positive CTD and reduced environmental effect of crop growth in 2020-21 than 2019-20 crop growth season (24).

3.5.2 Correlation and regression analysis between CTD and plant parameters: As depicted in Table 11, it was observed that the relationship between dry matter accumulation and LAI was positive and significant for D_1 and D_2 sowing dates and a highly significant relationship was observed for D_3 and D_4 with dry matter accumulation. D_3 sown crop showed the most vital relationship for dry matter accumulation and LAI relationship with CTD. This showed that the effect of plant parameters was observed to be highest on CTD of barley crop for D_3 sown crop followed by D_4, D_2 and D_1 sown crop for the 2019-20 crop growth season. The effect of dry matter accumulation was more on the barley crop's CTD than LAI. As depicted in Table 12, it was observed that all the dates of sowing showed a positive and significant relationship with plant parameters. When considering the relationship between dry matter accumulation and CTD, it was observed that D_3 and D_4 sowing dates had a highly significant relationship and D_1 and D_2 sowing dates observed a significant relationship where D_3 sowing date showed the most substantial relationship followed by D_4, D_2 and D_1 sowing date following a similar trend as 2019-20 crop growth season. LAI showed a highly significant relationship with D_3 and D_1 sown crops and a significant relationship with D_2 and D_4 sown crops. The most robust relationship was observed with D_3 sown crops, followed by D_1, D_4 and D_2 sown crops. D_1 sown crop showed a stronger relationship with LAI than dry matter accumulation; the rest of the dates of sowing have shown a stronger relationship with dry matter accumulation than LAI. In Table 12, CTD of D_1 sown crop resulted in higher correlation with LAI than biomass production in 2020-21 crop growth season and the reason for the same was the higher contribution of leaf in total biomass production and more leaf surface area in LAI in comparison with other sowing dates of 2020-21 crop growth season (D_2, D_3 and D_4) which combined with higher mean temperature, lower mean RH and higher pan evaporation resulted in higher transpiration rate from the leaf surface but crop growth season 2020-21 also witnessed lower rainfall and irrigation supply which contributed to higher negative CTD of the crop during timely sown conditions than CTD of barley crop in 2019-20 cropping season (14, 24). Tables 11 and 12 show that with a delay in sowing, the effect of dry matter accumulation and LAI increased on the CTD of the crop. The reason for the same was reduced biomass production and LAI, which reduced the CTD of the crop considerably due to the lower surface area available for the crop to transpire due to the lower number of stomata available for the crop to transpire (7, 24), whereas in D_1 sown crop, the plant parameters production was normal and had highest number of stomata to transpire and hence effect of environment was more on the D_1 sown crop. The effect of total dry matter accumulation was very high and LAI was high for the D_3 sown crop, where the effect of environmental factors was observed to be lowest. When comparing both plant parameters, it was observed that the

Table 9. Regression analysis for understanding the effect of environmental factors on CTD (2019-20)

Treatment	R^2	RC	SE
D_1	0.942	0.150	0.019
D_2	0.773	0.177	0.048
D_3	0.441	0.126	0.071
D_4	0.506	0.130	0.064

*Significance at P=0.05 ** Significance at P=0.01

Table 10. Regression analysis for understanding the effect of environmental factors on CTD (2020-21)

Treatment	R^2	RC	SE
D_1	0.767	0.176	0.049
D_2	0.742	0.115	0.034
D_3	0.016	0.029	0.112
D_4	0.088	0.039	0.062

*Significance at P=0.05 ** Significance at P=0.01

Table 11. Effect of plant parameters on CTD through correlation (2019-20)

Treatment	Total dry matter accumulation	Leaf Area Index (LAI)
D_1	0.896*	0.864*
D_2	0.910*	0.899*
D_3	0.948**	0.913*
D_4	0.937**	0.903*

*Significance at P=0.05 ** Significance at P=0.01

Table 12. Effect of plant parameters on CTD through correlation (2020-21)

Treatment	Total dry matter accumulation	Leaf Area Index (LAI)
D_1	0.886*	0.912**
D_2	0.908*	0.871*
D_3	0.952**	0.938**
D_4	0.928**	0.896*

*Significance at P=0.05 ** Significance at P=0.01

effect of total biomass production was more significant than LAI and the reason for the same was that total biomass production increased with progressing crop growth stages.

In contrast, the LAI was reduced with the progress of the crop growth stages. LAI, after senescence, starts reducing and hence reducing the transpiration of the crop. In contrast, in biomass production, the contribution of leaf to biomass will reduce after senescence. However, plant parts such as stem and ear keep increasing and hence provide increased surface for transpiration for the crop. When comparing the crop growth season, it was observed that except for the D_3 sown crop, all the dates of sowing have shown a stronger relationship between dry matter accumulation and CTD observed in barley crops grown in 2019-20 than in 2020-21. For LAI, D_2 and D_4 sown crops have shown a stronger relationship with the 2019-20 sown barley crop and D_1 and D_3 sown crops have shown a stronger relationship with the 2020-21 sown barley crop.

As depicted in Tables 13 and 14, regression analysis for 2019-20 and 2020-21 shows that the highest R^2 value was observed for the D_3 sown crop in both the crop growth seasons, *i.e.* 0.846 and 0.863 for 2019-20 and 2020-21. The lowest R^2 was observed for D_1 sown crop, *i.e.* 0.542 and 0.592 for 2019-20 and 2020-21. With the delay in sowing, the R^2 value was observed to increase till the D_3 sown crop, after which it reduced. RC value was also observed to be highest for D_3, *i.e.* 0.912 and 0.937 for 2019-20 and 2020-21, respectively. RC was observed to be lowest for the D_1 sown crop, *i.e.* 0.742 and 0.796, respectively, which kept increasing with delay in sowing, becoming highest in the D_3 sown crop in both the crop growth season and again decreased in the D_4 sown crop. SE was observed to be highest for the D_1 sown crop for both crop growth seasons, *i.e.* 0.134 and 0.121 and kept on decreasing till the D_3 sown crop in 2019-20 (0.054) and D_3 and D_4 sown crop in 2020-21 (0.110). From the regression analysis, it was observed that the effect of plant parameters increased with delay in the sowing of the barley crops. When comparing regression analysis for both years, it was observed that 2020-21 showed a higher effect of plant parameters on CTD of the crop than 2019-20 except for the D_4 sown crop and the reason for the same was lower plant parameters in 2020-21 cropping season than 2019-20 cropping season, where lower plant parameters affected the CTD of the crop in 2020-21 and increased the negative and positive CTD of the crop (14,24).

3.5.3 Correlation and regression analysis between CTD and soil moisture (%): As depicted in Tables 15 and 16, it was observed that all the dates of sowing show a positive but insignificant relationship with soil moisture (15 and 30 cm depth of sowing) except for the D_2 sown crop, which has shown a highly significant relationship showing the most potent effect on CTD by soil moisture at both 15 and 30 cm depth for 2019-20 and for 15 cm depth for 2020-21. The reason for the same was the highest rainfall received by D_2 sown crop in the 2019-20 crop growth season, resulting in higher soil moisture in the crop's root zone at both the selected depths. This resulted in higher transpiration from the crop surface and, hence, the highest negative CTD of the crop (-5.92) in 2019-20 (16,17, 25). In crop growth season 2020-21 (Table 16), the effect of soil moisture was highest on CTD at 15 cm depth of the D_2 sown crop and an insignificant effect at 30 cm depth of the D_2 sown crop was observed and the reason for the same is shallow depth of the root of the crop due to lower root biomass and lower soil moisture in the root zone of the crop due to lower rainfall and irrigation application in the 2020-21 crop growth season (25, 26). The results showed that with the increase in soil moisture, the CTD of the barley crop increased. When comparing both crop growth seasons, it was observed that CTD in 2019-20 showed a stronger relationship with soil moisture than in 2020-21. In Tables 17 and 18, regression analysis depicts that the R^2 value was observed to be highest for the D_2 sown crop, *i.e.* 0.925 for 2019-20 and 0.923 for 2020-21, which kept on decreasing with a delay of sowing (D_3 and D_4 sowing dates). RC value was observed to be highest for the D_2 sown crop, *i.e.* 0.886 and 0.916 for 2019-20 and 2020-21 and again decreased for D_3 and D_4 sowing dates, respectively. SE was observed to be highest for D_1 sown crop, *i.e.* 0.983 for 2019-20 and 0.982 for 2020-21. The lowest SE was observed for D_2 sown crop, i.e. 0.365 and 0.378 for 2019-20 and 2020-21, respectively and kept increasing with delay in sowing. When comparing both

Table 13. Regression analysis for understanding the effect of plant parameters on CTD (2019-20)

Treatment	R^2	RC	SE
D_1	0.542	0.742	0.134
D_2	0.754	0.814	0.109
D_3	0.846	0.912	0.054
D_4	0.837	0.862	0.072

*Significance at P=0.05 ** Significance at P=0.01

Table 14. Regression analysis for understanding the effect of plant parameters on CTD (2020-21)

Treatment	R^2	RC	SE
D_1	0.592	0.796	0.121
D_2	0.778	0.852	0.114
D_3	0.863	0.937	0.110
D_4	0.789	0.814	0.110

*Significance at P=0.05 ** Significance at P=0.01

Table 15. Effect of soil moisture (%) on CTD through correlation (2019-20)

Treatment	15 cm	30 cm
D_1	0.445	0.487
D_2	0.962**	0.923**
D_3	0.794	0.768
D_4	0.511	0.803

*Significance at P=0.05 ** Significance at P=0.01

Table 16. Effect of soil moisture (%) on CTD through correlation (2020-21)

Treatment	15 cm	30 cm
D_1	0.438	0.463
D_2	0.961**	0.705
D_3	0.421	0.489
D_4	0.356	0.397

*Significance at P=0.05 ** Significance at P=0.01

Table 17. Regression analysis for understanding the effect of soil moisture (%) on CTD (2019-20)

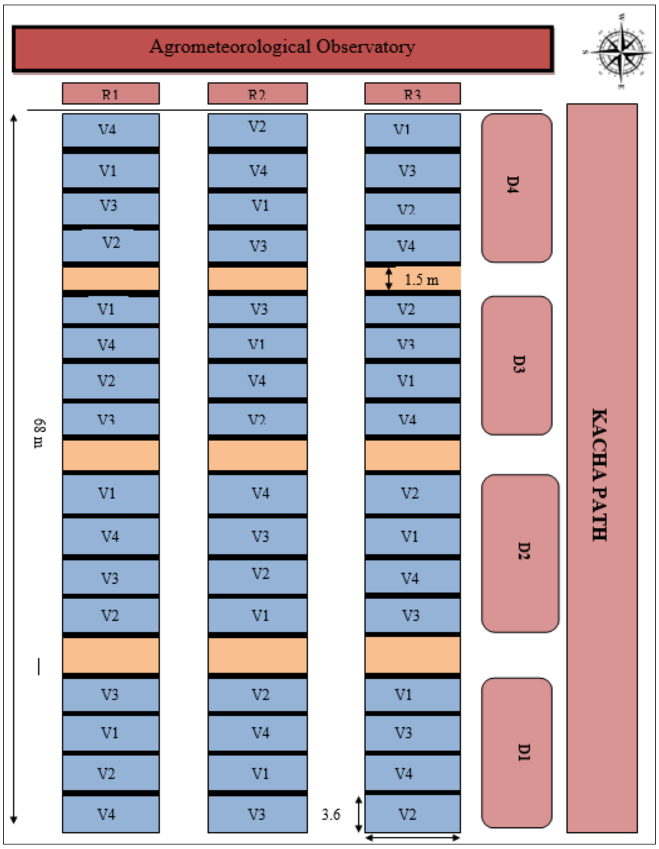
Treatment	R^2	RC	SE
D_1	0.505	0.667	0.983
D_2	0.925	0.886	0.365
D_3	0.623	0.741	0.675
D_4	0.544	0.691	0.954

*Significance at P=0.05 ** Significance at P=0.01

Table 18. Regression analysis for understanding the effect of soil moisture (%) on CTD (2020-21)

Treatment	R^2	RC	SE
D_1	0.467	0.689	0.982
D_2	0.923	0.916	0.378
D_3	0.439	0.702	0.765
D_4	0.404	0.449	0.967

*Significance at P=0.05 ** Significance at P=0.01



Map 1. Location map of research farm.

the crop growth seasons, it was observed that the R^2 value was higher in 2019-20 than in 2020-21. It was observed that the effect of soil moisture was more on CTD in 2019-20 than in the 2020-21 crop growth season and the reason for the same was higher rainfall and irrigation application to the crop sown in 2019-20 than in 2020-21.

Conclusion

The impact of heat stress and the changes in prevailing meteorological conditions across multiple sowing dates must be considered because the prevailing temperature, relative humidity and rate of evapotranspiration significantly control canopy temperature. Using information on the maximum temperature in connection to the amount of time the barley crop is susceptible to heat stress and the prevalent relative humidity, it is required to identify regions prone to heat stress.

Soil moisture content in the root zone significantly impacts the CTD. Increased plant transpiration results from optimal soil moisture in the root zone, which lowers canopy temperature and prevents plant heat stress. Because the soil contains the ideal amount of water, plants do not try to retain water in their parts. Stomatal pores stay open to facilitate the exchange of carbon dioxide and water.

The CTD is a crucial parameter in studying plant response to heat stress, water stress, drought tolerance and root and shoot development in plants. The current study aims to comprehend how various plant, environment and soil moisture factors affect the crop's CTD. In the present study, it was observed that with the delay in sowing, the effect of environmental factors was reduced and plant parameters increased on the CTD of the crop. The study found that for both crop growth seasons, environmental factors significantly impacted D_1 sown crops, soil moisture (%) on D_2 sown crops and plant characteristics on D_3 and D_4 sown crops.

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Authors' contributions

NB took the required data from the field, analyzed the data, wrote the paper and edited it. SS and CSD organized the field trials and checked the accuracy of the analysis of the desired results. PD helped in writing and editing the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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