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Effect of Different Environmental Conditions on Biometric Parameters and Yield of Broccoli

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ABSTRACT: The present study entitled "Effect of environmental conditions on biometric parameters and yield of broccoli" was carried out at the Experimental farm of the Department of Environmental Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh during *Rabi* 2021-22. In mid hills occurrence of fog is common, thus it is necessity to study the growth of broccoli under different environmental conditions as the yield potential of broccoli is more in the rabi season. The results revealed that treatment ($T_2M_1I_1$) *i.e.*, Mid-season transplanting (28th Oct) + Mulch + Irrigation recorded significantly higher on biometric parameters *i.e.*, Biometric attributes *i.e.*, Chlorophyll content (2.23 mg/g) and Leaf area index (5.10) showed significant highest values in treatment ($T_2M_1I_1$) Micrometeorological parameter *i.e.*, Evapotranspiration (2.48mm/day) was found in treatment ($T_2M_1I_1$). Plant canopy relative humidity and Soil moisture were also recorded. Agroclimatic indices *i.e.*, Crop phenology of 132 days were observed. Growing degree days of 140.10 days/hrs were accumulated in T_2. Helio-thermal units of 7248.74 days/hours were observed in T_2, Photo-thermal units of 10031.55 days/hrs were observed and, yield (10.44kg) per plot was observed in the treatment of $T_2M_1I_1$. Treatment $T_2M_1I_1$ is recommended for improving biometric attributes, micrometeorological parameters, agroclimatic indices, and yield attributes in Broccoli. Among different environmental conditions mulching and irrigation played an important role in the physiological and morphological characteristics of broccoli thus enhancing the crop yield.

Keywords: Chlorophyll, evapotranspiration, heat indices, Growing Degree Day, Helio-thermal Unit, Thermal Use Efficiency, leaf area index.

INTRODUCTION

Broccoli (*Brassica oleracea* var *italica* L.) is one of the most popular annual crops but a seed production purpose biennial crop in the Brassicaceae family. It is closely related to the "rapeseed crop group", with chromosome number of 2n=18. Broccoli is native to the Mediterranean region. The period of variation of broccoli is derived from the Latin word Brachium, meaning an arm or department Kumar *et al.* (2014). Botanically, it is classified as a distribution of Brassica oleracea which grows throughout the winter. The time period 'microgreens' has no prison definition however is used by marketers to explain a particular product class Palmitessa *et al.* (2022). Broccoli is a cross-pollinated crop. It is a highly nutritious crop with excellent dormancy, often attributed to high levels of vitamins (A, B, and C), minerals (K, P, Ca, and Fe), metabolites (omega-3 fatty acids), and fiber. That is why it is also called "the crown jewel of nutrition. It is an excellent source of indole, folic acid, sulforaphane, and glucosinolates. In

India, broccoli occupies nearly 4.5 lakh hectares of area with a production of 8.8 metric tons and productivity of 1.9 kg per ha (FAOSTAT, 2020). High consumption of broccoli has been shown to reduce the risk of cancer because it contains the compound sulforaphane and can also protect against heart diseases (Allen and Allen 2007).

Broccoli is widely grown in China, India, the USA, Spain, Mexico, Italy, and other parts of the world. In India, it is commonly grown in the Nilgiri Hills, Himachal Pradesh, Uttar Pradesh, Jammu, and Kashmir and is often referred to as 'green shoot broccoli' or 'Calabria' or 'hari gobhi of the northern plains. India is the second largest producer of broccoli after China. China and India together account for more than 75% of the world's total broccoli production. Broccoli grows best when the average daily temperature is between 17 and 23°C. Temperatures below the optimum range slow down ripening and lead to small buds. In addition, it does not tolerate high temperatures because it produces poor-quality bean sprouts (Anonymous, 2013). For irrigation scheduling and effective water management, an accurate estimation of evapotranspiration is required (López -Urrea *et al.,* 2009). However, factors that affect evapotranspiration such as humidity, solar radiation, wind speed, crop growth stages, and type of soils and their hydraulic and physical properties vary both in space and time. Evapotranspiration can be seen as an integrated response to all these factors and a major contributor to irrigation requirements. Plant cover greatly affects water use rates. Ritchie and Burnett (1968) found that a leaf area index of about 2.7 is required for water use equal to the potential rate for row crops. The green colour of the broccoli is due to the presence of chlorophyll a and chlorophyll b. Although the chlorophyll contents are measured on a fresh weight basis, the decline in water content is relatively consistent during the sampling period (Christ and Hortisteiner 2014). Among unique mulching treatments used during the heading and harvesting stages, the highest soil moisture and highest quality temperature with low evaporation and minimal warmness loss from the surface soil were observed with the black poly mulch remedies (Sharma, 2009). By mulching, the exposed part of the soil is the hole from where the vegetable plants grow upward. It prevents the loss of water in the soil by evaporation and makes it available to the surrounding environment of the plant root zones for promoting the soil microbial activities (He *et al.* 2021).

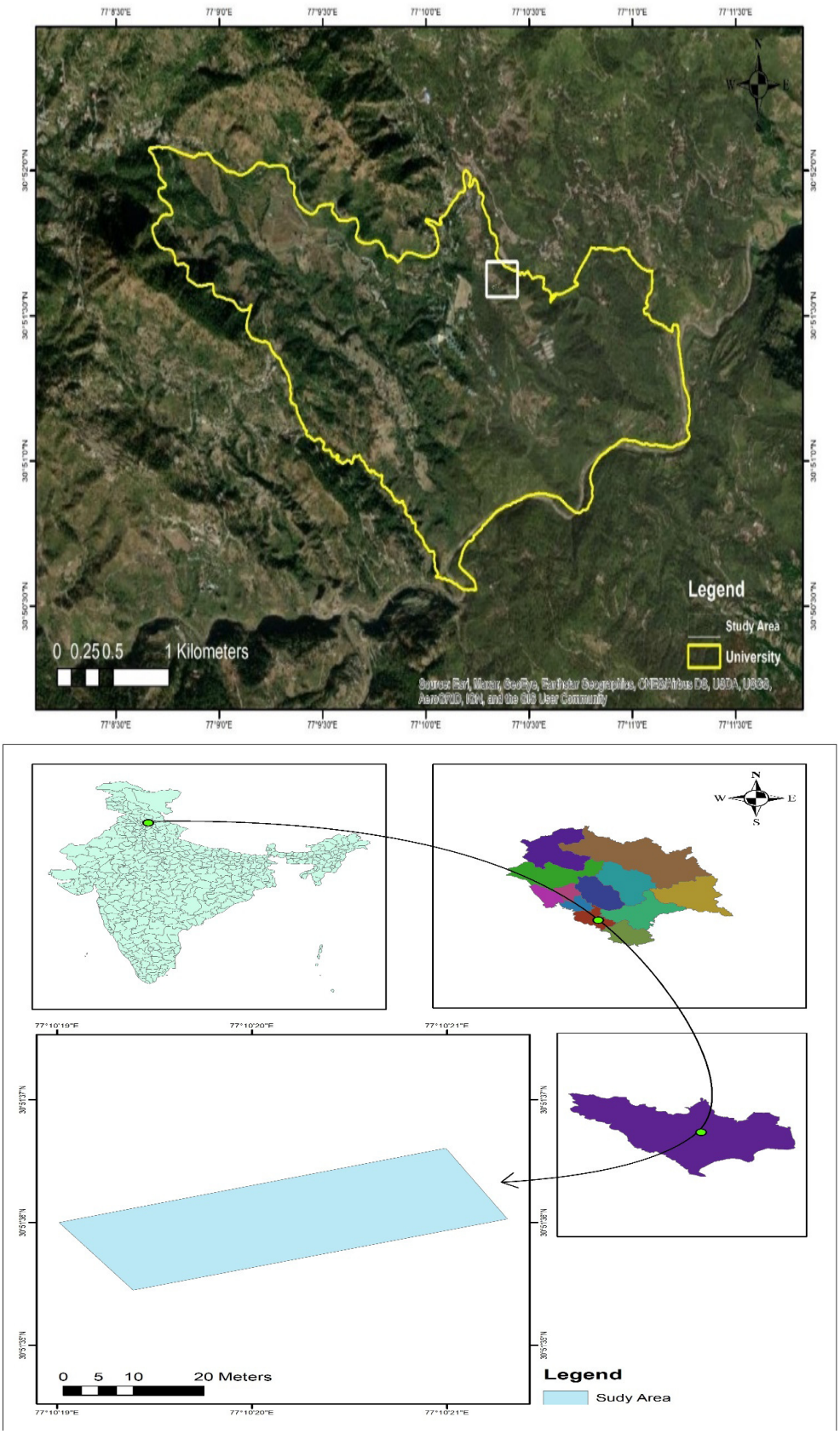
Temperature-based agrometeorological heat indices such as Growing Degree Day (GDD), Helio-thermal Unit (HTU), and Thermal Use Efficiency (TUE) are very useful for predicting the growth and yield of crops. The growing degree day is a simple tool to find out the relationship between plant growth, maturity, and mean air temperature. A degree day or a heat unit is the departure from the mean daily temperature above the minimum threshold temperature (Basu *et al.*, 2012). GDD requirement indicates the thermal status for the onset of a particular phenophase in the crop. The requirement of cumulative GDD is regulated by the ambient temperature as well as changes in the physiological stage of the crop regulated by hormonal activities (Nath *et al.,* 1999). Knowledge of accumulated GDD may project the developmental stages of a crop as well as its approximate date of harvest (Ketring and Wheles 1989; Bonhomme, 2000; Roy *et al.,* 2005). Soil moisture and temperature play an important role in plant growth and development that should remain at optimal levels during different stages of the growing crop plants. The commercial production of broccoli is an emerging challenge in the changing environmental conditions that makes it difficult for farmers to cultivate broccoli appropriately due to the lack of information to overcome these challenges.

Due to climate change, the occurrence of fog in low hills and plains is common, affecting the crop boom throughout the winter. In the middle hills, the occurrence of fog is not uncommon, so he moved to the need to look at the growth of broccoli under environmental conditions because the yield capacity of broccoli is more in the rabi season.

MATERIALS AND METHODS

A. Experiment site and Climate

The present field experiment on broccoli crops was conducted at the Research Farm Department of Environmental Science, College of Forestry, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh. The area is situated at 30.86°N latitude and 77.17°E longitude an altitude of 1275m above the mean sea level. The climate of the area is sub-tropical to sub-temperate and sub-humid characterized by cold winters and experiences distinguished major seasons in the year. The winter season commences from November to February and ends in March, summer season is from March to June followed by the monsoon period from July to September. The annual normal of maximum and minimum temperature, relative humidity, and rainfall of the area is 25.3°C, 11.4°C, 61 percent, and 111.9 cm, respectively.



Source: Based on the GIS location

Fig. 1. Location and field layout of the experimental farm.

B. Experimental methodology

The soils of the experimental field were brown in colour with a sandy loam texture. There were moderate drainage conditions having pH of 7.5, N-342.16 kgh^{-1}, P-41.93 kgh^{-1}, and K-234.24 kgh^{-1}. The Broccoli (*Brassica oleracea* var *italica* L.) crop with variety Saki (Fiesta) was sown in the main season, mid-season, and late season in the nursery on 12 September 2021, 02 October 2021, and 23 October 2021, respectively. respectively. The seeds were sown in well-prepared beds in lines 2-3 cm deep spaced 5 cm apart then covered well with fine soil to facilitate early and uniform germination. Manure completely decompose (FYM) was applied 45 days after transplanting at the rate of 10 kg per bed. Seedlings were ready to transplant in the field after one month of sowing in the nursery from their respective seasons. FYM and fertilizers were applied as per the package of practices for vegetable crops, Directorate of Extension Education, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan (HP).

Treatment details.

Sr. No.	Code	Treatments
1.	-	Control
2.	$T_1M_1I_1$	Main season transplanting (8th Oct) + Mulch + Irrigation
3.	$T_1M_1I_2$	Main season transplanting (8th Oct) + Mulch + Rainfed
4.	$T_2M_1I_1$	Mid-season transplanting (28th Oct) + Mulch + Irrigation
5.	$T_2M_1I_2$	Mid-season transplanting (28th Oct) + Mulch + Rainfed
6.	$T_3M_1I_1$	Late season transplanting (18th Nov) + Mulch + Irrigation
7.	$T_3M_1I_2$	Late season transplanting (18th Nov) + Mulch + Rainfed
8.	$T_1M_2I_1$	Main season transplanting (8th Oct) + No Mulch + Irrigation
9.	$T_1M_2I_2$	Main season transplanting (8th Oct) + No Mulch + Rainfed
10.	$T_2M_2I_1$	Mid-season transplanting (28th Oct) + No Mulch + Irrigation
11.	$T_2M_2I_2$	Mid-season transplanting (28th Oct) + No Mulch + Rainfed
12.	$T_3M_2I_1$	Late season transplanting (18th Nov) + No Mulch + Irrigation
13.	$T_3M_2I_2$	Late season transplanting (18th Nov) + No Mulch + Rainfed

T - Transplanting, M - Mulching, I-Irrigation

The field performance studies on the Effect of weather parameters on biometric parameters and the yield of broccoli. i.e. all parameters recorded at the transplanting, vegetative, heading, and harvesting stages after transplanting the height of six selected and tagged plants were measured. The average was calculated.

Chlorophyll content was estimated by using the method given by (Hiscox and Israeistam 2011). The fresh leaves were chopped to fine pieces under subdued light, 100 mg of chopped leaf samples were placed in vials containing 7 ml of Dimethyl sulphoxide, the vials were incubated at 65°C for half an hour, and the extract was then transferred to a graduated test tube and the final volume was made to 10 ml with Dimethyle sulphoxide. The optical density of the above extract was recorded on Spectrophotometer (Model: Spectronic-20) at 645 and 663 nm wavelength against Dimethyle sulphoxide blank.

The total chlorophyll content was calculated by using the formula:

$$\text{Total chlorophyll (mg} - 1) = \frac{20.2\,A645 + 8.02\,A663}{a \times 1000 \times w} \times V$$

Where;

V = volume of extract made

a = length of the light path in the cell (usually 1cm)

w = weight of the sample taken

A645 is an absorbance at 645nm, and A663 is an absorbance of 663nm.

The leaf area index is calculated by dividing the leaf area per plant by the land area occupied by the plant.

The leaf area index was calculated at the time of the different phenological stages.

$$\text{LAI} = \frac{\text{Leaf area}}{\text{Ground area}}$$

Evapotranspiration is the sum of evaporation from the land surface plus transpiration from plants. Evapotranspiration was estimated using the formula given by the Papadakis method: -

$$\text{ET} = 0.5262\,X\,(Emax - Emin - 2)X\left(\frac{10}{30}\right)$$

Whereas,

Emax: Saturation vapour pressure corresponding to average maximum temperature.

Emin-2: Saturation vapour pressure corresponding to average dew point temperature.

Tmax: Maximum temperature

Tmin: Minimum temperature

Soil temperature recorded 15cm depth was recorded at the minimum 07:30 AM and maximum 02:30 PM hours using a soil thermometer. The soil temperature was recorded at different phenological stages.

Relative humidity under the canopy of the crop (%) Hygrometer, the temperature was recorded at four phenological stages. Humidity on the recorded leaf surface was recorded at the minimum 07:30 AM and maximum 02:30 PM hours on using a hygrometer. The humidity was recorded at different phenological stages.

Soil moisture (%) Oven drying method: - Soil sample is collected in a moisture can and the wet weight of the sample is recorded. The soil sample is dried in a hot air oven at 105°C until a constant weight is obtained and the dry weight of the sample is recorded Kelly (2004).

$$\text{Moisture content (on weight basis)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Dry weight}} \text{X } 100$$

Crop Phenology The periodic biological events and their dates of occurrence in plant life in relation to the influence of weather are called phenology. The number of days taken by each phenophase.

The periodic biological events and their dates of occurrence in plant life with the influence of weather are called phenology.

Growing degree days (GDD)The degree-day or heat unit is the departure from the mean daily temperature above the minimum threshold or base temperature or critical temperature or it is the difference between the daily mean temperature and base temperature.

Growing degree days is calculated as

$$GDD = \frac{Tmax + Tmin}{2} - \text{Where, Tb is base temperature of crop}$$

Helio-thermal units (HTU) the Product of GDD and the number of actual bright sunshine hours on the day is called helio-thermal unit (HTU).

Helio-thermal units are calculated as a formula: -

HTU = GDD × Sunshine hours

Photo-thermal units (PTU)The product of GDD and maximum bright sunshine hours of any day is called a photo thermal unit.

Photo-thermal units are calculated as

PTU = GDD × Day length

Statistical Analysis. The data recorded were analyzed by using MS Excel, and OPSTAT. The mean values of each replication for all the traits under study were subjected to statistical analysis as per Randomized Complete Block Design (Factorial).

RESULTS AND DISCUSSION

The results obtained are presented character-wise as follows

A. Chlorophyll content (mg/g)

Chlorophyll content (mg/g) increased with the advancement of the plant age. The maximum chlorophyll content was estimated in T_2 (2.23 mg/g) followed by T_1 (1.91 mg/g) and T_3 (1.63 mg/g) at the heading stage which results in a higher yield per plot in T_2 (10.44 kg) followed by T_1 (8.58 kg) and T_3 (6.35 kg) under different environmental conditions. While maximum chlorophyll content was estimated with the application of mulch M_1 (2.13 mg/g) during the heading stage as compared to no mulch treatment M_2 (1.73 mg/g) which resulted in a higher yield per plot in M_1 (9.71 kg) followed by M_2 (7.21 kg). The chlorophyll content was maximum due to the application of irrigation I_2 (2.01 mg/g) at the heading stage as compared to rainfed conditions I_1 (1.84 mg/g) which resulted in a higher yield in I_1 (9.17 kg) followed by I_2 (7.76 kg).

The combined effect of interaction for second transplanting (T_2), with mulch (M_1) and good irrigation conditions (I_1), showed maximum chlorophyll content in T_2M_1 (2.53 mg/g), T_2I_2 (2.35 mg/g), M_1I_2 (2.27 mg/g) and $T_2M_1I_2$ (2.68 mg/g), while the minimum in third transplanting (T_3), with no mulch (M_2) and rainfed (I_2) conditions, were T_3M_2 (1.50 mg/g), T_3I_2 (1.56 mg/g), M_2I_1 (1.70 mg/g) and $T_3M_2I_2$ (1.26 mg/g). Similar findings were also recorded by Conversa *et al.* (2020). They obtained the chlorophyll contents (2.21mg/g) and (1.21mg/g) for black mulch in the initial heading and harvesting stages respectively. A relationship between chlorophyll and leaf area index in higher chlorophyll content was also recorded Table 1.

Table 1: Chlorophyll (mg/g) content during different phenophase of broccoli.

Treatment	Chlorophyll				
Date of Transplanting	**Transplanting**	**Vegetative**	**Heading**	**Harvesting**	**Yield/plot(kg)**
T_1	0.31	0.91	1.91	1.68	8.589
T_2	0.55	0.97	2.23	1.78	10.440
T_3	0.48	0.83	1.63	1.51	6.353
SE (m) ±	**0.01**	**0.01**	**0.05**	**0.02**	**0.09**
C.D 0.05	**0.03**	**0.04**	**0.14**	**0.05**	**0.26**
M_1 (Mulching)	0.47	0.94	2.13	1.69	9.714
M_2 (No Mulching)	0.43	0.86	1.73	1.62	7.207
SE (m) ±	**0.01**	**0.01**	**0.04**	**0.02**	**0.07**
C.D 0.05	**0.03**	**0.03**	**0.11**	**0.04**	**0.21**
I_1 (Irrigation)	0.45	0.94	1.84	1.73	9.166
I_2 (No Irrigation)	0.44	0.87	2.01	1.58	7.755
SE (m) ±	**0.01**	**0.01**	**0.04**	**0.02**	**0.07**
C.D 0.05	**NS**	**0.03**	**0.11**	**0.04**	**0.21**
Interaction (Tx M)					
T_1M_1	0.34	0.96	2.09	1.68	9.570
T_2M_1	0.56	1.03	2.53	1.80	12.355
T_3M_1	0.50	0.84	1.76	1.61	7.218
T_1M_2	0.28	0.87	1.74	1.68	7.608
T_2M_2	0.55	0.91	1.93	1.75	8.525
T_3M_2	0.45	0.82	1.50	1.42	5.487
SE (m) ±	**0.02**	**0.02**	**0.07**	**0.03**	**0.13**
C.D 0.05	**NS**	**0.06**	**0.19**	**0.08**	**0.37**
Interaction (Tx I)					
T_1I_1	0.32	0.97	1.70	1.71	9.145
T_2I_1	0.54	1.01	2.12	1.86	11.388
T_3I_1	0.49	0.85	1.71	1.61	6.965
T_1I_2	0.29	0.85	2.13	1.64	8.033

T_2I_2	0.57	0.93	2.35	1.70	9.492
T_3I_2	0.46	0.81	1.56	1.41	5.740
SE (m) ±	**0.02**	**0.02**	**0.07**	**0.03**	**0.13**
C.D 0.05	**NS**	**NS**	**0.19**	**0.08**	**0.37**
Interaction (Mx I)					
M_1I_1	0.48	0.98	1.98	1.73	10.479
M_2I_1	0.43	0.90	1.70	1.72	7.853
M_1I_2	0.46	0.91	2.27	1.66	8.950
M_2I_2	0.42	0.82	1.75	1.51	6.560
SE (m) ±	**0.01**	**0.02**	**0.05**	**0.02**	**0.10**
C.D 0.05	**NS**	**NS**	**0.16**	**0.06**	**NS**
Interaction (TxMxI)					
Control	0.21	0.68	1.42	1.33	5.100
$T_1M_1I_1$	0.36	1.04	1.89	1.72	9.990
$T_1M_1I_2$	0.32	0.87	2.29	1.64	9.150
$T_1M_2I_1$	0.29	0.90	1.51	1.70	8.300
$T_1M_2I_2$	0.27	0.83	1.97	1.65	6.917
$T_2M_1I_1$	0.55	1.07	2.38	1.85	13.293
$T_2M_1I_2$	0.57	0.99	2.68	1.75	11.417
$T_2M_2I_1$	0.53	0.94	1.85	1.86	9.483
$T_2M_2I_2$	0.56	0.87	2.02	1.64	7.567
$T_3M_1I_1$	0.51	0.83	1.68	1.62	8.153
$T_3M_1I_2$	0.49	0.85	1.85	1.59	6.283
$T_3M_2I_1$	0.47	0.87	1.74	1.60	5.777
$T_3M_2I_2$	0.44	0.77	1.26	1.24	5.197
SE (m) ±	**0.02**	**0.03**	**0.09**	**0.04**	**0.18**
C.D 0.05	**NS**	**0.08**	**0.27**	**0.11**	**0.52**

The maximum yield per plot was obtained in the combined effect of interaction for second transplanting (T_2), with mulch (M_1) and good irrigation conditions (I_2) i.e., T_2M_1 (12.36 kg), T_2I_1 (11.39 kg), M_1I_1 (10.48 kg) and $T_2M_1I_1$ (13.29 kg), while minimum in third transplanting (T_3), with no mulch (M_2) and rainfed (I_2) conditions i.e., T_3M_2 (5.49 kg), T_3I_2 (5.74 kg), M_2I_2 (6.56 kg) and $T_3M_2I_2$ (5.19 kg). Moreover, the yield per plot obtained in the control was significantly less (5.10 kg) as compared to the interactions.

B. Evapotranspiration

The maximum ET was estimated in T_3 (2.50mm) during the harvesting stage due to high temperature, followed by T_2 (2.48mm) and T_1 (2.38mm) at different transplanting stages and the higher yield per plot was obtained in T_2 (10.44kg) followed by T_1 (8.58kg) and T_3 (6.35kg) due to suitable climatic conditions. While maximum ET was estimated with the application of mulch M_1 (2.53mm) during the transplanting stage as compared to no mulch treatment M_2 (2.26mm) during the harvesting stage which results in a higher yield per plot in M1 (9.71kg) followed by M_2 (7.21kg). Table 2.

Table 2: Evapotranspiration (mm) during different phenophase of broccoli.

Treatment	**Evapotranspiration**				**Yield/plot (kg)**
Date of Transplanting	**Transplanting**	**Vegetative**	**Heading**	**Harvesting**	
T_1	2.38	1.72	1.74	2.10	8.589
T_2	2.48	2.19	1.57	2.36	10.440
T_3	2.17	1.60	1.90	2.50	6.353
SE (m) ±	**0.05**	**0.11**	**0.05**	**0.04**	**0.09**
C.D 0.05	**0.14**	**0.32**	**0.13**	**0.13**	**0.26**
M_1 (Mulching)	2.53	2.00	1.82	2.37	9.714
M_2 (No Mulching)	2.15	1.67	1.66	2.26	7.207
SE (m) ±	**0.04**	**0.09**	**0.04**	**0.04**	**0.07**
C.D 0.05	**0.11**	**0.26**	**0.11**	**0.10**	**0.21**
I_1 (Irrigation)	2.42	2.21	1.87	2.48	9.166
I_2 (No Irrigation)	2.27	1.46	1.61	2.16	7.755
SE (m) ±	**0.04**	**0.09**	**0.04**	**0.04**	**0.07**
C.D 0.05	**0.11**	**0.26**	**0.11**	**0.10**	**0.21**
Interaction (Tx M)					
T_1M_1	2.55	1.92	1.80	2.15	9.570
T_2M_1	2.60	2.46	1.68	2.47	12.355
T_3M_1	2.45	1.62	1.97	2.50	7.218
T_1M_2	2.21	1.53	1.68	2.04	7.608
T_2M_2	2.36	1.92	1.46	2.25	8.525

T_3M_2	1.89	1.57	1.83	2.50	5.487
SE (m) ±	**0.07**	**0.16**	**0.06**	**0.06**	**0.13**
C.D 0.05	**NS**	**NS**	**NS**	**NS**	**0.37**
Interaction (Tx I)					
T_1I_1	2.46	2.30	1.76	2.18	9.145
T_2I_1	2.45	2.58	1.76	2.54	11.388
T_3I_1	2.35	1.76	2.09	2.71	6.965
T_1I_2	2.30	1.15	1.72	2.01	8.033
T_2I_2	2.51	1.80	1.38	2.18	9.492
T_3I_2	2.00	1.44	1.72	2.29	5.740
SE (m) ±	**0.07**	**0.16**	**0.06**	**0.06**	**0.13**
C.D 0.05	**0.09**	**0.45**	**0.19**	**NS**	**0.37**
Interaction (Mx I)					
M_1I_1	2.62	2.40	1.92	2.53	10.479
M_2I_1	2.21	2.03	1.82	2.42	7.853
M_1I_2	2.45	1.60	1.72	2.22	8.950
M_2I_2	2.09	1.32	1.50	2.10	6.560
SE (m) ±	**0.05**	**0.13**	**0.05**	**0.05**	**0.10**
C.D 0.05	**NS**	**NS**	**NS**	**0.15**	**NS**
Interaction (TxMxI)					
Control	2.04	1.04	1.61	1.84	5.100
$T_1M_1I_1$	2.55	2.57	1.88	2.24	9.990
$T_1M_1I_2$	2.55	1.27	1.73	2.07	9.150
$T_1M_2I_1$	2.37	2.04	1.65	2.13	8.300
$T_1M_2I_2$	2.04	1.02	1.71	1.95	6.917
$T_2M_1I_1$	2.60	2.72	1.69	2.61	13.293
$T_2M_1I_2$	2.60	2.20	1.68	2.33	11.417
$T_2M_2I_1$	2.29	2.43	1.83	2.48	9.483
$T_2M_2I_2$	2.43	1.40	1.09	2.03	7.567
$T_3M_1I_1$	1.40	1.90	2.21	2.76	8.153
$T_3M_1I_2$	2.20	1.34	1.74	2.25	6.283
$T_3M_2I_1$	1.98	1.61	1.97	2.66	5.777
$T_3M_2I_2$	1.80	1.54	1.70	2.34	5.197
SE (m) ±	**0.09**	**0.22**	**0.09**	**0.09**	**0.18**
C.D 0.05	**NS**	**NS**	**0.26**	**NS**	**0.52**

The ET was maximum due to the application of irrigation in I_1 (2.48mm) at the harvesting stage as compared to rainfed conditions I_2 (2.27mm) at the transplanting stage which resulted in a higher yield in I_1 (9.17kg) followed by I_2 (7.76kg). The black polythene mulch performed well as compared to no mulch irrespective of irrigation treatments. These results support the findings of Thentu *et al.* (2016). They obtained an ET of 1.68mm and found a significantly higher effect of black polythene mulch and irrigation on ET in broccoli.

The maximum yield per plot was obtained in the combined effect of interaction for second transplanting (T_2), with mulch (M_1) and good irrigation conditions (I_1) i.e., T_2M_1 (12.36kg), T_2I_1 (11.39kg), M_1I_1 (10.48kg) and $T_2M_1I_1$ (13.29kg), while minimum in third transplanting (T_3), with no mulch (M_2) and rainfed (I_2) conditions i.e., T_3M_2 (5.49kg), T_3I_2 (5.74), M_2I_2 (6.56kg) and $T_3M_2I_2$ (5.19kg). Moreover, the yield per plot obtained in the control was significantly less (5.10kg) as compared to the interactions.

C. Leaf area index (LAI)

The maximum leaf area index was recorded in T_2 (5.10) followed by T_1 (4.19) and T_3 (3.03) at the harvesting stage. While the maximum leaf area index was obtained with the application of mulch M_1 (4.41) at the harvesting stage and the minimum was obtained with no mulch treatment M_2 (3.80). The variations in leaf area index under different irrigation treatments were statistically significant at all growth stages except the transplanting stage under I_1 (4.41) followed by I_2 (3.80) at the harvesting stage. Table 3.

The interaction between various factors under study was found to be non-significant at the transplanting stage for leaf area index but significant at other vegetative, heading, and harvesting stages. The combined effect of interaction for second transplanting (T_2), with mulch (M_1) and good irrigation conditions (I_1), showed maximum leaf area index in T_2M_1 (5.58),

T_2I_1 (5.41), M_1I_1 (4.74) and $T_2M_1I_1$ (5.87), while minimum leaf area index in third transplanting (T_3), with no mulch (M_2) and rainfed (I_2) conditions, were T_3M_2 (2.79), T_3I_2 (2.67), M_2I_2 (3.36) and $T_3M_2I_2$ (2.54).

Table 3: Leaf area index during different phenophase of broccoli.

Treatment	Leaf area index				Yield/plot (kg)
Date of Transplanting	Transplanting	Vegetative	Heading	Harvesting	
T_1	0.06	0.81	3.44	4.19	8.589
T_2	0.04	1.08	4.21	5.10	10.440
T_3	0.05	0.62	2.70	3.03	6.353
SE (m) ±	**0.002**	**0.020**	**0.016**	**0.028**	**0.09**
C.D 0.05	**0.007**	**0.059**	**0.047**	**0.081**	**0.26**
M_1 (Mulching)	0.04	0.93	3.83	4.41	9.714
M_2 (No Mulching)	0.05	0.74	3.07	3.80	7.207
SE (m) ±	**0.002**	**0.016**	**0.013**	**0.023**	**0.07**
C.D 0.05	**NS**	**0.048**	**0.038**	**0.066**	**0.21**
I_1 (Irrigation)	**0.05**	0.95	3.71	4.41	9.166
I_2 (No Irrigation)	**0.05**	0.72	3.19	3.80	7.755
SE (m) ±	**0.002**	**0.048**	**0.013**	**0.023**	**0.07**
C.D 0.05	**NS**	**0.016**	**0.038**	**0.066**	**0.21**
Interaction (Tx M)					
T_1M_1	0.05	0.91	3.75	4.52	9.570
T_2M_1	0.04	1.25	4.80	5.68	12.355
T_3M_1	0.05	0.63	2.93	3.26	7.218
T_1M_2	0.06	0.72	3.13	3.86	7.608
T_2M_2	0.04	0.90	3.62	4.52	8.525
T_3M_2	0.05	0.61	2.47	2.79	5.487
SE (m) ±	**0.003**	**0.029**	**0.023**	**0.039**	**0.13**
C.D 0.05	**NS**	**0.084**	**0.066**	**0.115**	**0.37**
Interaction (Tx I)					
T_1I_1	0.05	0.91	3.64	4.45	9.145
T_2I_1	0.03	1.25	4.51	5.41	11.388
T_3I_1	0.05	0.69	2.98	3.39	6.965
T_1I_2	0.06	0.71	3.24	3.94	8.033
T_2I_2	0.04	0.91	3.91	4.79	9.492
T_3I_2	0.04	0.55	2.43	2.67	5.740
SE (m) ±	**0.003**	**0.029**	**0.023**	**0.039**	**0.13**
C.D 0.05	**0.010**	**0.084**	**0.066**	**0.115**	**0.37**
Interaction (Mx I)					
M_1I_1	0.04	1.08	4.03	4.74	10.479
M_2I_1	0.05	0.82	3.39	4.09	7.853
M_1I_2	0.05	0.79	3.63	4.23	8.950
M_2I_2	0.04	0.66	2.76	3.36	6.560
SE (m) ±	**0.003**	**0.023**	**0.018**	**0.032**	**0.10**
C.D 0.05	**NS**	**0.068**	**0.054**	**0.093**	**NS**
Interaction (TxMxI)					
Control	0.04	0.46	2.23	3.18	5.100
$T_1M_1I_1$	0.05	1.04	3.88	4.62	9.990
$T_1M_1I_2$	0.06	0.78	3.62	4.43	9.150
$T_1M_2I_1$	0.05	0.79	3.41	4.28	8.300
$T_1M_2I_2$	0.06	0.64	2.86	3.45	6.917
$T_2M_1I_1$	0.03	1.51	4.97	5.87	13.293
$T_2M_1I_2$	0.04	1.00	4.63	5.48	11.417
$T_2M_2I_1$	0.04	0.99	4.04	4.94	9.483
$T_2M_2I_2$	0.03	0.82	3.19	4.09	7.567
$T_3M_1I_1$	0.05	0.68	3.23	3.73	8.153
$T_3M_1I_2$	0.04	0.58	2.63	2.79	6.283
$T_3M_2I_1$	0.05	0.69	2.72	3.04	5.777
$T_3M_2I_2$	0.04	0.52	2.22	2.54	5.197
SE (m) ±	**0.005**	**0.040**	**0.032**	**0.055**	**0.18**
C.D 0.05	**NS**	**0.118**	**0.094**	**0.016**	**0.52**

The maximum yield per plot was obtained in the combined effect of interaction for second transplanting (T_2), with mulch (M_1) and good irrigation conditions (I_1) i.e., T_2M_1 (12.36kg), T_2I_1 (11.39kg), M_1I_1 (10.48kg) and $T_2M_1I_1$ (13.29kg), while the minimum in third transplanting (T_3), with no mulch (M_2) and rainfed (I_2) conditions i.e., T_3M_2 (5.49kg), T_3I_2 (5.74), M_2I_2 (6.56kg) and $T_3M_2I_2$ (5.19kg). Also, the yield per plot obtained in the control was significantly lowered (5.10kg) as compared to the interactions. Olfati *et al.* (2010) showed a significant difference in leaf area index (LAI) for black mulch having a profound effect on plant growth, which resulted in an increase in the LAI for various growth stages.

D. Soil temperature

The soil temperature was recorded at different stages; transplanting, vegetative, heading, and harvesting. It is apparent from the data presented in Table 4 that during the transplanting stage, the maximum soil temperature was recorded in $T_1M_1I_2$ (31.73°C) and the minimum in $T_3M_1I_1$ (7.83°C). While during the vegetative stage, the

maximum soil temperature was recorded in $T_1M_1I_2$ (22.50 °C) and the minimum in $T_2M_1I_2$ (5.13 °C). During the heading stage, the maximum soil temperature was recorded in $T_3M_1I_2$ (17.00 °C) and the minimum in $T_1M_2I_2$ (6.50 °C). The maximum temperature during the harvesting stage was found in $T_3M_1I_2$ (25.63 °C) and the minimum in $T_1M_2I_2$ (10.00°C).

Table 4: Soil temperature (°C) during different phenophase of broccoli.

Treatments	Soil Temperature							
Date of Transplanting	Transplanting		Vegetative		Heading		Harvesting	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Control	23.89	21.33	18.56	9.26	12.86	6.12	17.89	11.26
$T_1M_1I_1$	29.20	17.67	18.67	7.40	16.91	8.10	17.97	13.75
$T_1M_1I_2$	**31.73**	23.00	**22.50**	8.50	16.12	7.60	18.67	13.50
$T_1M_2I_1$	25.97	20.00	16.50	8.47	14.83	6.73	16.20	10.27
$T_1M_2I_2$	25.50	22.00	17.50	10.03	14.97	**6.50**	16.27	**10.00**
$T_2M_1I_1$	21.90	9.33	14.73	5.17	**17.00**	9.10	22.20	13.80
$T_2M_1I_2$	22.37	15.00	15.40	**5.13**	16.37	8.07	24.07	13.83
$T_2M_2I_1$	19.30	12.50	12.67	7.73	14.00	6.56	20.90	10.43
$T_2M_2I_2$	19.37	14.47	12.63	7.83	14.10	7.20	21.80	11.17
$T_3M_1I_1$	17.27	**7.83**	14.20	5.17	16.27	9.27	**25.63**	23.17
$T_3M_1I_2$	18.43	12.50	15.33	5.80	**19.13**	8.90	**26.63**	23.67
$T_3M_2I_1$	15.37	9.50	13.27	6.50	14.90	10.90	24.30	18.30
$T_3M_2I_2$	17.10	11.17	13.50	7.80	15.17	10.50	24.47	19.43

In control, during the transplanting stage, the maximum soil temperature was found to be (23.89 °C) and the minimum was (21.33 °C) while during the vegetative stage, the maximum soil temperature was (18.56 °C) and the minimum was (9.26 °C). During the heading stage, the maximum soil temperature was found to be (12.86 °C) and the minimum was (6.12 °C). The maximum temperature during the harvesting stage was found to be (17.89 °C) and the minimum was (11.26 °C). Sharma (2009) observed 28°C and 16°C as the highest and lowest soil temperatures for black mulch treatment respectively which could be due to the reduced evaporation and minimum heat loss from the soil surface.

E. Relative humidity recorded under the canopy of the crop

It is apparent from the data presented in Table 5 that during the transplanting stage, the maximum relative humidity was recorded in $T_1M_1I_2$ (61.13%) and the minimum in $T_3M_2I_2$ (29.78%). While during the vegetative stage, the maximum relative humidity was recorded in $T_3M_1I_2$ (62.1%) and the minimum in $T_2M_2I_2$ (40.5%). During the heading stage, the maximum relative humidity was recorded in $T_2M_1I_1$ (64.77%) and the minimum in $T_1M_2I_2$ (34.5%). The maximum relative humidity during the harvesting stage was found in $T_1M_1I_1$ (84.97%) and the minimum in $T_3M_2I_2$ (32.54%).

Table 5: Relative humidity (%) during different phenophase of broccoli.

Treatments	Relative Humidity							
Date of Transplanting	Transplanting		Vegetative		Heading		Harvesting	
	Morning	Evening	Morning	Evening	Morning	Evening	Morning	Evening
Control	53.23	45.75	48.00	41.23	45.89	44.82	69.87	66.23
$T_1M_1I_1$	56.1	46	56	47	54.67	45	**84.97**	73
$T_1M_1I_2$	**61.13**	50	56.47	45.6	54.07	42.4	81.77	70.8
$T_1M_2I_1$	57.73	49,00	56.33	46.4	53.67	44	83.2	75
$T_1M_2I_2$	56.2	47.5	50.47	42	46.73	**34.5**	71.67	66
$T_2M_1I_1$	52.73	43	56.93	46.32	**64.77**	53	49.67	46.57
$T_2M_1I_2$	51.47	40.3	57.47	47	63.53	55	47.43	48.45
$T_2M_2I_1$	47	35	56	45.6	64.8	53.6	54.67	47.53
$T_2M_2I_2$	43.1	34.45	49.5	**40.5**	57.33	49.1	50.29	45.17
$T_3M_1I_1$	49.07	38	61.33	50.8	51	43	48.8	36.32
$T_3M_1I_2$	46.47	37.12	**62.1**	52.36	51.5	42.45	50.67	37.5
$T_3M_2I_1$	38	31	60.6	50.1	50.17	45.22	48.17	35.8
$T_3M_2I_2$	38.67	**29.78**	55.33	47	45.93	36	40	**32.54**

In control, during the transplanting stage, the maximum relative humidity was found to be (53.23%) and the minimum was (45.75%) while during the vegetative stage, the maximum relative humidity was (48.00%) and the minimum was (41.23%). During the heading stage, the maximum relative humidity was found to be (45.89%) and the minimum was (44.82%). The maximum relative humidity during the harvesting stage was found to be (69.87%) and the minimum was (66.23%). A similar finding was observed by Tibbitts (1979) who obtained relative humidity (56.23%) due to the effect of black mulch treatment.

F. Soil moisture

It is apparent from the data presented in Table 6 that the maximum soil moisture was obtained in $T_1M_1I_1$ (72.63%) at the harvesting stage and the minimum in $T_2M_1I_1$ (20.76%) at the transplanting stage. During control, the maximum soil moisture was obtained in the heading stage (44.13%) while the minimum was in the transplanting stage (24.42%). Verma *et al.* (2018) found that soil moisture plays an important role in the growth and development of the crop. They found 53.2 percent and 15.7 percent as the highest and lower soil moisture

respectively for black mulch that could be dependent on the rainfalls.

Table 6: Soil moisture (%) during different phenophase of broccoli.

Treatments	Soil moisture			
Date of Transplanting	**Transplanting**	**Vegetative**	**Heading**	**Harvesting**
Control	24.42	41.00	44.13	35.98
$T_1M_1I_1$	23.51	58.11	63.22	**72.63**
$T_1M_1I_2$	22.48	51.13	52.28	52.10
$T_1M_2I_1$	23.50	50.02	57.54	55.16
$T_1M_2I_2$	23.31	40.00	43.68	36.24
$T_2M_1I_1$	**20.76**	63.15	70.70	64.79
$T_2M_1I_2$	20.91	54.57	64.25	57.35
$T_2M_2I_1$	22.47	54.25	70.51	64.08
$T_2M_2I_2$	25.00	43.88	46.85	39.07
$T_3M_1I_1$	29.33	56.46	71.87	66.41
$T_3M_1I_2$	30.00	31.99	48.92	41.13
$T_3M_2I_1$	29.35	43.95	56.30	55.25
$T_3M_2I_2$	28.70	35.30	41.15	38.78

G. Crop phenology

Maximum number of days was recorded in T_2 (132 days) followed by T_1 (104 days) and T_3 (94 days) at the harvesting stage. While with the application of mulch M_1, the number of days taken to reach the harvesting stage was (111days), and with no mulch treatment M_2 (109 days). The variations in crop phenology under different irrigation treatments were statistically significant at both the growth stages under I_1 (110 days) and followed by I_2 (109 days) at the harvesting stage. Table 7.

Table 7: Number of days taken by each phenophase of broccoli.

Treatment	Crop phenology			
Date of Transplanting	**Vegetative**	**Heading**	**Harvesting**	**Yield/plot**
T_1	49	72	104	8.589
T_2	65	112	132	10.440
T_3	55	71	94	6.353
SE (m) ±	**0.31**	**0.24**	**0.29**	**0.09**
C.D 0.05	**0.90**	**0.71**	**8.86**	**0.26**
M_1 (Mulching)	58	85	111	9.714
M_2 (No Mulching)	55	84	109	7.207
SE (m) ±	**0.25**	**0.20**	**0.24**	**0.07**
C.D 0.05	**0.73**	**0.58**	**0.70**	**0.21**
I_1 (Irrigation)	57	85	110	9.166
I_2 (No Irrigation)	56	84	109	7.755
SE (m) ±	**0.25**	**0.20**	**0.24**	**0.07**
C.D 0.05	**0.73**	**0.58**	**0.70**	**0.21**
Interaction (Tx M)				
T_1M_1	50	73	105	9.570
T_2M_1	66	112	132	12.355
T_3M_1	57	71	95	7.218
T_1M_2	48	71	103	7.608
T_2M_2	64	111	131	8.525
T_3M_2	53	70	92	5.487
SE (m) ±	**0.43**	**0.34**	**0.41**	**0.13**
C.D 0.05	**NS**	**NS**	**NS**	**0.37**
Interaction (Tx I)				
T_1I_1	50	72	105	9.145
T_2I_1	65	112	132	11.388
T_3I_1	55	71	95	6.965
T_1I_2	48	72	104	8.033
T_2I_2	64	111	131	9.492
T_3I_2	55	70	93	5.740
SE (m) ±	**0.43**	**0.34**	**0.41**	**0.13**
C.D 0.05	**NS**	**NS**	**NS**	**0.37**
Interaction (Mx I)				
M_1I_1	58	86	112	10.479
M_2I_1	55	84	109	7.853
M_1I_2	57	85	110	8.950
M_2I_2	54	84	108	6.560
SE (m) ±	**0.35**	**0.28**	**0.34**	**0.10**
C.D 0.05	**NS**	**NS**	**NS**	**NS**
Interaction (TxMxI)				
Control	48	69	101	5.100
$T_1M_1I_1$	51	73	106	9.990
$T_1M_1I_2$	49	72	105	9.150
$T_1M_2I_1$	48	71	103	8.300

$T_1M_2I_2$	47	71	102	6.917
$T_2M_1I_1$	67	112	132	13.293
$T_2M_1I_2$	65	112	132	11.417
$T_2M_2I_1$	64	111	131	9.483
$T_2M_2I_2$	63	111	131	7.567
$T_3M_1I_1$	57	72	96	8.153
$T_3M_1I_2$	56	71	94	6.283
$T_3M_2I_1$	53	70	93	5.777
$T_3M_2I_2$	53	69	91	5.197
SE (m) ±	**0.61**	**0.49**	**0.59**	**0.18**
C.D 0.05	**NS**	**NS**	**NS**	**0.52**

The combined effect of interaction for second transplanting (T_2) with mulch M_1 and good irrigation conditions (I_1), has taken a maximum number of days as in T_2M_1 (132 days), T_2I_1 (132 days), M_1I_1 (112 days), $T_2M_1I_1$ (132 days) and $T_2M_1I_2$ (132 days) while minimum in third transplanting (T_3), with no mulch (M_2) and rainfed (I_2) conditions i.e., T_3M_2 (92 days), T_3I_2 (93 days), M_2I_2 (108 days) and $T_3M_2I_2$ (91 days). The number of days taken to reach the harvesting stage in control was (101 days) which was significantly minimum as compared to interactions. Similar outcomes on heat requirements for attaining the different phenological stages in broccoli were also reported by Dhankhar *et al.* (2017). They observed maximum heat requirement for T_2 (date of 2nd treatment) because of the long crop harvest duration.

H. Growing degree days

It is apparent from the data presented in Table 8 that the maximum growing degree days were recorded in T_2 (940.10 °C Day hours) followed by T_1 (921.38 °C Day hours) and T_3 (569.86 °C Day hours) at the harvesting stage which resulted in a higher yield per plot in T_2 (10.44kg) followed by T_1 (8.58kg) and T_3 (6.35kg). While maximum growing degree days were obtained with the application of mulch M_1 (816.75°C Day hours) at the harvesting stage and minimum with no mulch treatment M_2 (804.14°C Day hours) during the harvesting stage which resulted in a higher yield per plot in M_1 (9.71kg) followed by M_2 (7.21kg). The variations in growing degree days under different irrigation treatments were statistically non-significant at the vegetative stage but significant at other growth stages under I_1 (816.75°C Day hours) followed by I_2 (804.14°C Day hours) at the harvesting stage which resulted in a higher yield in I_1 (9.17kg) followed by I_2 (7.76kg). A similar finding of growing degree days (970.6°C Day hours) was also observed by Dhankhar *et al.* (2017) which could be due to the long crop harvest duration.

Table 8: Growing degree days (°C Day) during different phenophase of broccoli.

Treatment	Growing degree day			Yield/plot (kg)
Date of Transplanting	**Vegetative**	**Heading**	**Harvesting**	
T_1	576.84	749.74	921.38	8.589
T_2	525.50	765.08	940.10	10.440
T_3	361.77	437.60	569.86	6.353
SE (m) ±	**4.78**	**1.15**	**2.66**	**0.09**
C.D 0.05	**14.02**	**3.37**	**7.80**	**0.26**
M_1	494.27	654.40	816.75	9.714
M_2	481.81	647.21	804.14	7.207
SE (m) ±	**3.90**	**0.94**	**2.17**	**0.07**
C.D 0.05	**11.45**	**2.75**	**6.37**	**0.21**
I_1	489.14	652.39	816.75	9.166
I_2	486.93	642.22	804.14	7.755
SE (m) ±	**3.90**	**0.94**	**2.17**	**0.07**
C.D 0.05	**NS**	**2.75**	**6.37**	**0.21**
Interaction (Tx M)				
T_1M_1	579.39	753.08	929.48	9.570
T_2M_1	532.72	769.56	947.56	12.355
T_3M_1	370.69	440.55	580.50	7.218
T_1M_2	574.29	746.40	913.27	7.608
T_2M_2	518.28	760.59	932.65	8.525
T_3M_2	352.85	434.65	559.23	5.487
SE (m) ±	**6.76**	**1.62**	**3.76**	**0.13**
C.D 0.05	**NS**	**NS**	**NS**	**0.37**
Interaction (Tx I)				
T_1I_1	575.07	750.43	924.43	9.145
T_2I_1	528.84	766.18	945.34	11.388
T_3I_1	363.53	440.55	580.48	6.965
T_1I_2	578.62	749.05	918.32	8.033
T_2I_2	522.16	763.97	934.87	9.492
T_3I_2	360.02	434.65	559.24	5.740
SE (m) ±	**6.76**	**1.62**	**3.76**	**0.13**
C.D 0.05	**NS**	**NS**	**NS**	**0.37**
Interaction (Mx I)				
M_1I_1	493.98	656.34	826.47	10.479
M_2I_1	484.31	648.43	807.04	7.853

M_1I_2	494.55	652.45	811.89	8.950
M_2I_2	479.31	645.99	796.39	6.560
SE (m) ±	**5.52**	**1.33**	**3.07**	**0.10**
C.D 0.05	**NS**	**3.89**	**NS**	**NS**
Interaction (TxMxI)				
Control	522.02	713.340	901.23	5.100
$T_1M_1I_1$	571.28	754.47	932.83	9.990
$T_1M_1I_2$	587.50	751.70	926.13	9.150
$T_1M_2I_1$	578.85	746.40	916.03	8.300
$T_1M_2I_2$	569.73	746.40	910.50	6.917
$T_2M_1I_1$	537.12	770.67	956.15	13.293
$T_2M_1I_2$	528.32	768.45	938.97	11.417
$T_2M_2I_1$	520.57	761.70	934.53	9.483
$T_2M_2I_2$	516.00	759.48	930.77	7.567
$T_3M_1I_1$	373.55	443.90	590.42	8.153
$T_3M_1I_2$	367.83	437.20	570.58	6.283
$T_3M_2I_1$	353.50	437.20	570.55	5.777
$T_3M_2I_2$	352.20	432.10	547.90	5.197
SE (m) ±	**9.56**	**2.30**	**5.31**	**0.18**
C.D 0.05	**NS**	**NS**	**NS**	**0.52**

The maximum yield per plot was obtained in the combined effect of interaction for second transplanting (T_2), with mulch (M_1) and good irrigation conditions (I_1) i.e., T_2M_1 (12.36kg), T_2I_1 (11.39kg), M_1I_1 (10.48kg) and $T_2M_1I_1$ (13.29kg), while minimum in third transplanting (T_3), with no mulch (M_2) and rainfed (I_2) conditions i.e., T_3M_2 (5.49kg), T_3I_2 (5.74), M_2I_2 (6.56kg) and $T_3M_2I_2$ (5.19kg). Also, the yield per plot obtained in the control was significantly less (5.10kg) as compared to the interactions.

I. Helio-thermal units

It is apparent from the data presented in Table 9 that the maximum helio-thermal units were recorded in T_1 (7248.74°C Day hours) followed by T_2 (6926.32°C Day hours) and T_3 (3939.68°C Day hours) at the harvesting stage which resulted in a higher yield per plot in T_2 (10.44kg) followed by T_1 (8.58kg) and T_3 (6.35kg). While maximum helio-thermal units were recorded with the application of mulch M_1 (6111.38°C Day hours) during the harvesting stage as compared to no mulch treatment M_2 (5965.11°C Day hours) during the harvesting stage which resulted in a higher yield per plot in M_1 (9.71kg) followed by M_2 (7.21kg). The helio-thermal units were maximum due to the application of irrigation i.e., in I_1 (6084.23°C Day hours) at the harvesting stage as compared to rainfed conditions I_2 (5992.26°C Day hours) at the harvesting stage which resulted in a higher yield in I_1 (9.17kg) followed by I_2 (7.76kg). Similar findings with helio-thermal units of 5866.5 and 6136.9°C Day hours were also observed by Dhankhar *et al.* (2017).

Table 9: Helio-thermal units (°C Day h) during different phenophase of broccoli.

Treatment	**Helio-thermal units**			**Yield/plot**
Date of Transplanting	**Vegetative**	**Heading**	**Harvesting**	**(kg)**
T_1	5179.51	6237.97	7248.74	8.589
T_2	4219.38	5779.50	6926.32	10.440
T_3	2427.11	2800.57	3939.68	6.353
SE (m) ±	**17.96**	**9.88**	**22.07**	**0.09**
C.D 0.05	**52.69**	**28.98**	**64.75**	**0.26**
M_1	4003.90	4909.34	6111.38	9.714
M_2	3880.10	4969.36	5965.11	7.207
SE (m) ±	**14.67**	**8.07**	**18.02**	**0.07**
C.D 0.05	**43.02**	**23.66**	**52.87**	**0.21**
I_1	3967.39	4950.80	6084.23	9.166
I_2	3916.62	4927.89	5992.26	7.755
SE (m) ±	**14.67**	**8.07**	**18.02**	**0.07**
C.D 0.05	**43.02**	**NS**	**52.87**	**0.21**
Interaction (Tx M)				
T_1M_l	5218.61	6253.28	7281.17	9.570
T_2M_1	4243.87	5829.52	6997.85	12.355
T_3M_1	2439.68	2825.28	4055.11	7.218
T_1M_2	5140.42	6222.66	7216.30	7.608
T_2M_2	4194.89	5729.49	6854.78	8.525
T_3M_2	2414.54	2775.86	3824.26	5.487
SE (m) ±	**25.40**	**13.97**	**31.21**	**0.13**
C.D 0.05	**NS**	**NS**	**91.57**	**0.37**
Interaction (Tx I)				
T_1I_1	4033.98	6246.79	7262.51	9.145
T_2I_1	3900.79	5784.99	6975.24	11.388
T_3I_1	3967.39	2820.63	4014.96	6.965
T_1I_2	3973.83	6229.15	7234.96	8.033
T_2I_2	3859.40	5774.02	6877.39	9.492
T_3I_2	3916.62	2780.51	3864.41	5.740

SE (m) ±	**25.40**	**13.97**	**31.21**	**0.13**
C.D 0.05	**NS**	**NS**	**NS**	**0.37**
Interaction (Mx I)				
M_1I_1	3900.79	4989.80	6169.63	10.479
M_2I_1	3900.79	4911.81	5998.84	7.853
M_1I_2	3973.83	4948.93	6053.13	8.950
M_2I_2	3859.40	4906.86	5931.39	6.560
SE (m) ±	**20.74**	**11.41**	**25.49**	**0.10**
C.D 0.05	**NS**	**NS**	**NS**	**NS**
Interaction (TxMxI)				
Control	5,013.31	6021.64	7101.79	5.100
$T_1M_1I_1$	5293.25	6270.91	7291.21	9.990
$T_1M_1I_2$	5,217.37	6235.66	7271.14	9.150
$T_1M_2I_1$	5143.97	6222.68	7233.81	8.300
$T_1M_2I_2$	5,063.46	6222.64	7198.79	6.917
$T_2M_1I_1$	4303.91	5840.49	7084.21	13.293
$T_2M_1I_2$	4242.20	5818.55	6911.49	11.417
$T_2M_2I_1$	4183.82	5729.49	6866.27	9.483
$T_2M_2I_2$	4147.58	5729.49	6843.29	7.567
$T_3M_1I_1$	2504.78	2857.99	4133.46	8.153
$T_3M_1I_2$	2461.91	2792.57	3976.75	6.283
$T_3M_2I_1$	2374.58	2783.27	3896.45	5.777
$T_3M_2I_2$	2367.17	2768.45	3752.08	5.197
SE (m) ±	**35.92**	**19.76**	**44.14**	**0.18**
C.D 0.05	**NS**	**NS**	**NS**	**0.52**

The maximum yield per plot was obtained in the combined effect of interaction for second transplanting (T_2), with mulch (M_1) and good irrigation conditions (I_1) i.e., T_2M_1 (12.36kg), T_2I_1 (11.39kg), M_1I_1 (10.48kg) and $T_2M_1I_1$ (13.29kg), while minimum in third transplanting (T_3), with no mulch (M_2) and rainfed (I_2) conditions i.e., T_3M_2 (5.49kg), T_3I_2 (5.74kg), M_2I_2 (6.56kg) and $T_3M_2I_2$ (5.19kg). Also, the yield per plot obtained in the control was significantly less (5.10kg) as compared to the interactions.

J. Photo-thermal units

It is apparent from the data presented in Table 10 that the maximum photo-thermal units were recorded in T_1 (10031.55°C Day hours) followed by T_2 (9926.56°C Day hours) and T_3 (5843.28°C Day hours) at the harvesting stage which resulted in a higher yield per plot in T_2 (10.44kg) followed by T_1 (8.58kg) and T_3 (6.35kg). While maximum photo-thermal units were recorded with the application of mulch M_1 (8700.23°C Day hours) during the harvesting stage as compared to no mulch treatment M_2 (8500.69°C Day hours) which resulted in a higher yield per plot in M_1 (9.71kg) followed by M_2 (7.21kg). The photo-thermal units were recorded maximum due to the application of irrigation i.e., in I_1 (8660.67°C Day hours) at the harvesting stage as compared to rainfed conditions I_2 (8540.26°C Day hours) at the transplanting stage which resulted in a higher yield per plot in I_1 (9.17kg) followed by I_2 (7.76kg). A similar finding of 10214.9 °C Day hours photo-thermal units was also observed by Dhankhar *et al.* (2017).

Table 10: Photo-thermal units (°C Day h) during different phenophase of broccoli.

Treatment	Photo-thermal units			Yield/plot (kg)
Date of Transplanting	**Vegetative**	**Heading**	**Harvesting**	
T_1	6606.78	8306.20	10031.55	8.589
T_2	7941.81	8022.13	9926.56	10.440
T_3	7132.13	4482.84	5843.28	6.353
SE (m) ±	**24.83**	**11.80**	**27.70**	**0.09**
C.D 0.05	**72.84**	**34.62**	**81.26**	**0.26**
M_1	7336.46	6976.07	8700.23	9.714
M_2	7117.36	6898.04	8500.69	7.207
SE (m) ±	**20.27**	**9.64**	**22.62**	**0.07**
C.D 0.05	**59.47**	**28.27**	**66.35**	**0.21**
I_1	7272.29	6951.35	8660.67	9.166
I_2	7181.52	6922.76	8540.26	7.755
SE (m) ±	**20.27**	**9.64**	**22.62**	**0.07**
C.D 0.05	**59.47**	**28.27**	**66.35**	**0.21**
Interaction (Tx M)				
T_1M_I	6720.99	8340.01	10113.38	9.570
T_2M_I	8031.66	8075.33	10009.39	12.355
T_3M_I	7256.72	4512.87	5977.92	7.218
T_1M_2	6492.57	8272.38	9949.72	7.608
T_2M_2	7851.97	7968.94	9843.73	8.525
T_3M_2	7007.53	4452.80	5708.63	5.487
SE (m) ±	**35.11**	**16.69**	**39.17**	**0.13**
C.D 0.05	**NS**	**NS**	**NS**	**0.37**
Interaction (Tx I)				
T_1I_1	6675.43	8313.19	10062.36	9.145

T_2I_1	7983.40	8027.99	9984.79	11.388
T_3I_1	7158.04	4512.87	5934.85	6.965
T_1I_2	6538.13	8299.20	10000.74	8.033
T_2I_2	7900.23	8016.28	9868.34	9.492
T_3I_2	7106.21	4452.81	5751.70	5.740
SE (m) ±	**35.11**	**16.69**	**39.17**	**0.13**
C.D 0.05	**NS**	**NS**	**NS**	**0.37**
Interaction (Mx I)				
M_1I_1	7395.07	6997.71	8778.74	10.479
M_2I_1	7149.51	6904.98	8542.60	7.853
M_1I_2	7277.85	6954.43	8621.72	8.950
M_2I_2	7085.20	6891.10	8458.79	6.560
SE (m) ±	**28.67**	**13.63**	**31.99**	**0.10**
C.D 0.05	**NS**	**NS**	**NS**	**NS**
Interaction (TxMxI)				
Control	6102.50	7243.33	93551.9	5.100
$T_1M_1I_1$	6810.24	8353.99	10147.22	9.990
$T_1M_1I_2$	6631.74	8326.02	10079.54	9.150
$T_1M_2I_1$	6540.61	8272.38	9977.49	8.300
$T_1M_2I_2$	6444.52	8272.38	9921.94	6.917
$T_2M_1I_1$	8075.51	8087.03	10105.00	13.293
$T_2M_1I_2$	7987.80	8063.63	9913.78	11.417
$T_2M_2I_1$	7891.29	7968.94	9864.58	9.483
$T_2M_2I_2$	7812.65	7968.94	9822.89	7.567
$T_3M_1I_1$	7299.45	4552.10	6084.00	8.153
$T_3M_1I_2$	7213.99	4473.64	5871.85	6.283
$T_3M_2I_1$	7016.63	4473.63	5785.71	5.777
$T_3M_2I_2$	6998.43	4431.97	631.54	5.197
SE (m) ±	**49.66**	**23.60**	**55.40**	**0.18**
C.D 0.05	**NS**	**NS**	**NS**	**0.52**

The maximum yield per plot was obtained in the combined effect of interaction for second transplanting (T_2), with mulch (M_1) and good irrigation conditions (I_1) i.e., T_2M_1 (12.36kg), T_2I_1 (11.39kg), M_1I_1 (10.48kg) and $T_2M_1I_1$ (13.29kg), while minimum in third transplanting (T_3), with no mulch (M_2) and rainfed (I_2) conditions i.e., T_3M_2 (5.49kg), T_3I_2 (5.74), M_2I_2 (6.56kg) and $T_3M_2I_2$ (5.19kg). Also, the yield per plot obtained in the control was significantly less (5.10kg) as compared to the interactions.

CONCLUSIONS

The present study revealed that 2nd date of sowing, mulching, and irrigation had a significant effect on the yield of broccoli (208q/ha). The crop transplanted on October 28 took a maximum of days to attain different phenological stages and accumulated the maximum number of growing days and heat units which were reduced with the subsequent delay in transplanting. The mulching and irrigation played an important role in the physiological and morphological characteristics of broccoli thus enhance the crop yield. Hence, treatment $T_2M_1I_1$ is recommended for improving morphological characteristics, yield attributes and biometric attributes, under different environmental conditions in Broccoli.

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