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Evaluation and computing study of crop phenology and agrometeorological indices i.e. GDD, HTU and other growth parameters

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Abstract
The present investigation entitled "Evaluation and computing study of crop phenology and agrometeorological indices, GDD, HTU and other growth parameters in Raipur condition." was conducted during *Rabi* season 2013-14 at Research Farm of Indira Gandhi Krishi Vishwavidyalaya, Raipur (Chhattisgarh).

The accumulated growing degree days (GDD) were also workout for phenological stages in three dates of sowing under irrigated and unirrigated conditions. It was found the growing degree days (GDD) were higher in irrigated condition as compare to unirrigated condition in all the three dates of sowing. This is because the duration of the crop under irrigated condition was higher than in unirrigated condition. The average maximum temperature under D_1 in the germination to grand growth stage is higher in the first date of sowing. However, later on that is from grand growth to bud formation the maximum temperature is higher in D_1 as compare to D_2 and D_3 both in field as well as observatory data

The average minimum temperature in the first date of sowing varied from 21.6 ^{0}C to 11.5 ^{0}C under different phenological stages based on observatory data. While in the field data it varied from 21.0 ^{0}C to 10.8 ^{0}C during different growth stages. In the second date of sowing the minimum temperature based on observatory and field data varied from 24.1 ^{0}C to 9.9 ^{0}C and 16.5 ^{0}C to 9.4 ^{0}C in different growth stages. In the third date of sowing the minimum temperature varied from 10.7 ^{0}C to 17.2 ^{0}C and 10.3 ^{0}C to 16.3^{0}C in different growth stages based on both observatory as well as field data.

Correlation coefficient between different weather parameters based on field as well as observatory data revealed that the temperatures in the field data and observatory data are highly correlated but the relative humidity between field and observatory is not well correlated. This shows higher moisture status in the field as compared to observatory.

The accumulated growing degree days (GDD) for different sowing environment conditions varied considerably from sowing to maturity. The highest growing degree days (GDD) were found from pod development to physiological maturity. As per the observatory data, the growing degree days (GDD) in the stage varied from 527 to 691 degree days under irrigated condition. Under unirrigated condition the growing degree days (GDD) varied from 456 degree days in the first date of sowing to 522 degree days in second date of sowing. While in third date of sowing the growing degree days (GDD) under unirrigated condition were 424 degree days. Thus, the GDD during pod formation stage were less under unirrigated condition than in irrigated condition. This is because of faster physiological maturity at all the dates of sowing under unirrigated condition. Similarly for 50% flowering to pod development stage also the growing degree days (GDD) were less under unirrigated condition in the first date of sowing. In other dates of sowing the growing degree days (GDD) under irrigated condition were higher than unirrigated condition.

Same pattern was observed in case of field data also. The total growing degree days (GDD) under irrigated condition based on field data varied from 4080 degree days under D_1, 3062 degree days under D_2 and 3086 degree days under D_3 conditions. In the same pattern the total degree days under unirrigated condition were from 1139 under D_1, 1246 degree days under D_2 and 1069 degree days under D_3 conditions.

The total number of helio thermal units (HTU) varied from 10466 under D_1 to 10100 under D_2 conditions. In case of D_3 the value of helio thermal units (HTU) was highest (11376). In case of unirrigated conditions the helio thermal units (HTU) values were 9164 under D_1, 9334 under D_2 and 8048 under D_3 conditions. Similarly in the third date of sowing the total helio thermal units (HTU) were 10057.

Keywords: maximum and minimum temperatures, helio thermal unit, growing degree day

1. Introduction
Plant development depends on temperature and requires a specific amount of heat to develop from one point in their lifecycle to another, such as from seeding to the harvest stage. Temperature is a key factor for the timing of biological processes and hence regulates the growth and development of plants. Crop heat unit (CHU) or thermal time or growing degree

days is a temperature response of development that differs between day and night. Growing degree days is a way of assigning a heat value to each day. Heat units are involved in several physiological processes like specific amount of heat units required for the plant at each stage from its germination to harvest of the crop and they would vary. The important processes are growth and development, growth parameters, metabolism, biomass, physiological maturity and yield. Growing degree days are used to assess the suitability of a region for production of a particular crop, determine the growth stages of crops, assess the best timing of fertilizer, herbicide and plant growth regulators application, estimate heat stress accumulation on crops, predict physiological maturity and harvest dates and ideal weather unit in constructing crop weather mode ls. (Parthasarathi *et al*., 2013) Climate and weather conditions which influence human activities and environmental resources sustainability include; rainfall, temperature (minimum, average, maximum), pressure, humidity, solar radiation, visibility, evaporation, soil temperature at various depths, wind speed and direction among others. The climate is the least manageable part of environmental resources, yet a better understanding of the climatic resources and their interaction with crops can help to increase the crop productivity.

The occurrence of different phenological events during growing season of any crop and the effect of temperature on plant growth can be inferred using accumulated heat unit or growing degree days (GDD). The duration of each growth phase is a result of crop response to external environmental factors. The concept of heat units has been applied to co-relate the phenological development of different crops to predict grain yield and physiological maturity.

2. Materials and Methods

The present study entitled "Evaluation and computing study of crop phenology and agrometeorolgical indices GDD, HTU and other growth parameters." was conducted during the *rabi* season of 2013-14. The details of experimental soil, prevailing weather conditions, materials used and techniques adopted during the course of the investigation are briefly presented in this chapter.

2.1 Location of Experimental site

The field experiment was conducted at the research farm, Indira Gandhi Krishi Vishwavidyalaya; Raipur situated in South Eastern Central part of Chhattisgarh at latitude, longitude and altitude of $21^0$16'' N, longitude $81^0$36'' E and 289.5 m above mean sea level respectively.

2.2 Climate

The climate of Chhattisgarh state is dry sub humid. Nearly 90% of the annual average rainfall occurs from June to September during south west monsoon.

During the growth period the maximum temperature ranged between 22 ^{0}C to 36.3 ^{0}C while minimum temperature ranged between 8 to 20.7 ^{0}C. The morning relative humidity varied from 59 to 100% whereas. The afternoon humidity varied from 20 to 83 % (47 SMW and 12 SMW)

Table 3.1: Cropping history of the experimental field

Year	Crop	
	Kharif	***Rabi***
2011-12	Rice	Wheat
2012-13	Rice	Wheat
2013-14	Rice	Chickpea

3.3 Experimental Detail

The details of the treatments are given below and experimental lay out is shown in Fig. 3.1.The cropping history of the experimental field is furnished in Table 3.1.

Season	**: *Rabi*-2013-14**
Crop	: chickpea (*cicer arietinum*)
Variety	: JG-130
Dates of Sowing	: Three
	: D_1 – 20 Nov. 2013
	: D_2 – 30 Nov 2013
	: D_3 – 10 Dec. 2013
Soil	: Clay loam
Seed rate	: 80 kg/ha
Fertilizer doses	: 20:40:20 kg/ha. N: P_2O_5:K_2O
Spacing	: 30 cm X 10 cm
Total number of plots	: 6
Total plot area	:120 m^2
Total experimental area	:782.0 m^2
Plot to plot distance	:0.5 m
Statistical analysis	: 't' test

3.4 Soil

The soil of the experimental site is clay loam in texture of (Alfisol group) locally known as "*Dorsa*" The soil was neutral in reaction and had low phosphorous medium nitrogen and potassium content.

3.5 Variety

JG-130: This cultivar is suitable for rainfed as well as irrigated conditions.

Plate 1: Field site with board

3.6 Field preparation
The field was ploughed twice with tractor and weeds were removed. Then it was leveled with the help of tractor driven leveler.

3.7 Fertilizer application
Fertilizer was applied to the crop as per recommended dose of nitrogen, phosphorus and potash i.e., 20:40:20 (N: P: K) Kg/ha full dose of N: P: K was applied as basal dose before sowing in rows.

3.8 Seed rate and sowing
After field preparation, the sowing was done in line at a distance of 10 X 10 cm plant to plant and 30 X 30 cm row to row distance. The sowing was done with a seed rate of 80 kg /ha.

3.9 Harvesting
The crop was harvested manually on different dates with the help of sickle from 11 March to 03 April when the crop attained full maturity. Two rows from the either side of each plot and 50 cm from other two ends were harvested separately and removed as border.
The produce of each net plot was tied into bundle and allowed to sun drying in respective plots. The harvested bundles were weighted with the help of spring balance and transported to threshing floor.

3.10 Irrigation
Only one irrigation (Excluding pre sowing irrigation) was given to the crop under irrigation treatment. Under irrigated condition first irrigation was given at 45 days after sowing.

3.11 Harvesting and Threshing
Harvesting was done for different dates of sowing under irrigated and unirrigated conditions as per maturity of the crop. The data were recorded in the 10 selected plot of 1 m^2 area.
Threshing was done after two days sun drying and then grain were cleaned and weighted for each plot in each treatment.

3.12 Observations recorded
3.12.1 Agrometeorological observations recorded
The daily weather data like maximum temperature, minimum temperature and relative humidity both morning and afternoon hours, soil temperature at 5, 10 and 20cm depths were recorded daily in field and observatory (Agrometeorological observatory, Department of Agrometeorology, IGKV, Raipur) twice in a day starting from sowing to harvest.

In the field conditions daily weather data were recorded by installing Stevenson screen in the field. Soil temperature was also recorded from soil thermometer installed in the field (Plate 2a & b).

3.13 Heat units
3.13.1 Growing degree days
Growing degree days (Heat unit) represents the sum over the growing season of crop of different between daily mean temperature and base temperature. The growing degree days was computed by following formula

$$GDD = \sum [(Tx + Tn)/2 - \text{Base temperature}]$$

Where,
Tx = Daily maximum temperature
Tn = Daily minimum temperature
For chickpea crop base temperature is taken 8^0C respectively.

3.13.2 Heliothermal Unit (HTU)
Helio thermal unit is calculated by multiplying GDD with actual sunshine hours (n).

$$HTU = GDD \times n$$

Where,
n = actual sunshine hour.

Results and Discussions
4.2 Phenological stages
The duration of different phenological stage like: sowing to germination, germination to grand growth, grand growth to bud formation, bud formation to first flowering, first flowering to 50% flowering, 50% flowering to pod development, pod development to physiological maturity for three different dates of sowing under irrigated and unirrigated conditions is shown in Table 4.3 and Plate 3a and 3b. It is seen from the table that from first flowering to 50% flowering onwards the duration under different dates of sowing in unirrigated field is less when compared to irrigated condition.

4.3 Average temperature conditions on different dates of sowing.
4.3.1 Maximum temperature.
Based on phenological observations the average maximum temperature and minimum temperature during different growth stages in different dates of sowing are shown in Table 4.4.The average maximum temperature under D_1 in the germination to grand growth stage is higher in the first date of sowing. However, later on that is from grand growth to bud

formation the maximum temperature is higher in D_3 as compare to D_2 and D_1 both in field as well as observatory. The average maximum temperature varied from 37.8 ^{0}C to 28.0^{0}C under first date of sowing. In the second date of sowing the maximum temperature varied from 34.8 to 29.2 ^{0}C, in the observatory data. In the field data it varied from 37.8 to 27.8 ^{0}C in first date of sowing and from 34.1 to 28.9 ^{0}C in the second date of sowing. In the third date of sowing the maximum temperature varied from 31.6 to 28.1 ^{0}C in observatory data while in the field data it varied from 31.1 to 27.8 ^{0}C.

4.3.2 Minimum temperature.

The minimum temperature at different growth stages based on both field and observatory data is shown in table 4.5. The minimum temperature in the first date of sowing varied from 21.6 ^{0}C to 11.5 ^{0}C under different phenologial stages based on observatory data.

Table 4.3: Phenological observations in chickpea crop for three different dates of sowing under irrigated and unirrigated conditions.

S. No.	Particular	DAS		Dates of observations		
				Irrigated	Unirrigated	
1	Dates of sowing	D_1	0	20/11/2013	0	20/11/2013
		D_2	0	30/11/2013	0	30/11/2013
		D_3	0	10/12/2013	0	10/12/2013
2	Dates of Germination	D_1	5	25/11/2013	5	25/11/2013
		D_2	7	07/12/2013	7	07/12/2013
		D_3	9	19/12/2013	9	19/12/2013
3	Dates of Grand growth	D_1	18	08/12/2013	18	08/12/2013
		D_2	23	23/12/2013	22	2212/2013
		D_3	31	10/01/2014	31	10/01/2014
4	Dates of Bud formation	D_1	44	03/01/2014	44	03/01/2014
		D_2	46	15/01/2014	47	16/01/2014
		D_3	41	20/01/2014	41	20/01/2014
5	Dates of First flowering	D_1	45	04/01/2014	46	05/01/2014
		D_2	48	17/01/2014	48	17/01/2014
		D_3	44	23/01/2014	43	22/01/2014
6	Dates of 50% flowering	D_1	59	19/01/2014	55	14/01/2014
		D_2	58	27/01/2014	53	22/01/2014
		D_3	55	02/02/2014	47	26/01/2014
7	Dates of Pod development	D_1	69	28/01/2014	69	18/01/2014
		D_2	65	03/02/2014	60	29/01/2014
		D_3	59	07/02/2014	54	02/02/2014
8	Harvest	D_1	107	07/03/2014	98	21/02/2014
		D_2	105	15/03/2014	98	08/03/2014
		D_3	103	23/03/2014	84	04/03/2014

Table 4.4: Mean maximum temperature at different phenological stages based on observatory and field data in the three different dates of sowing.

Dates of sowing	Phenological stages						
	Sowing to germination	Germination to grand growth	Grand growth to bud formation	Bud formation to first flowering	First flowering to 50% flowering	50% flowering to pod development	Pod development to physiological maturity
D_1 Observatory	37.8	29.8	28.2	28.5	28.6	28.2	28.0
D_1 Field	37.8	29.1	27.9	28.5	28.0	28.0	27.8
D_2 observatory	34.8	27.9	28.3	29.5	28.6	28.4	29.2
D_2 Field	34.1	27.6	28.0	29.4	27.7	28.1	28.9
D_3 observatory	31.6	28.4	28.5	29.0	28.1	30.2	30.2
D_3 Field	31.1	28.1	27.8	28.7	27.8	29.8	29.9

Table 4.5: Mean minimum temperatures at different phenological stages based on observatory and field data in three different dates of sowing.

Dates of sowing	Phenological stages						
	Sowing to germination	Germination to grand growth	Grand growth to bud formation	Bud formation to first flowering	First flowering to 50% flowering	50% flowering to pod development	Pod development to physiological maturity
D_1 Observatory	21.6	14.6	11.5	12.9	14.6	14.8	13.9
D_1 Field	21.0	14.0	10.8	12.0	13.5	14.2	13.4
D_2 observatory	17.3	24.1	13.3	15.3	15.4	9.9	16.2
D_2 Field	16.5	9.8	12.4	14.6	14.8	9.4	15.3
D_3 observatory	11.2	12.8	15.5	14.7	12.0	10.7	17.2
D_3 Field	10.5	11.9	14.6	14.1	11.4	10.3	16.3

While in the field data it varied from 21.0 ^{0}C to 10.8 ^{0}C during different growth stages. In the second date of sowing the minimum temperature based on observatory data varied from 24.1 ^{0}C to 9.9 ^{0}C while, in the field data it varied from 16.5 ^{0}C to 9.4 ^{0}C in different growth stages. In the third date of sowing the minimum temperature varied from 10.7 ^{0}C to 17.2^{0}C in different growth stages based on the observatory

data, while based on the field data the minimum temperature varied from 10.3 ^{0}C to 16.3 ^{0}C in different growth stages.

4.3.3 Correlation between different weather parameters based on field and observatory data.

Correlation coefficient was worked out between field and observatory data for different weather parameters and the results shown in Table 4.6. It can be seen from the table that the correlation coefficient between maximum and minimum temperatures and afternoon dry bulb temperature –II were (0.95). Higher correlation coefficient was observed for morning dry bulb temperature (0.98) followed by morning wet bulb temperature. The least correlation coefficient was observed in the relative humidity (0.58) in the afternoon hours followed by morning relative humidity (0.63). Thus, it is seen that the temperatures in the field and observatory are highly correlated but the relative humidity between field and observatory is not well correlated. This shows higher moisture status in the field as compared to observatory.

Table 4.6: Correlation coefficients between field and observatory meteorological data.

S. No.	Weather parameters	Field versus observatory
1	Maximum temperature	0.95**
2	Minimum temperature	0.95**
3	Dry bulb temperature-I	0.98**
4	Wet bulb temperature-I	0.97**
5	Dry bulb temperature-II	0.95**
6	Wet bulb temperature-II	0.80**
7	Relative humidity-I	0.63**
8	Relative humidity-II	0.58**

I =0730 AM, II =1430 AM

4.4 Heat units

4.4.1 Accumulated Growing degree days.

Based on observatory and field data the growing degree days at different phenological stages of chickpea crop under different dates of sowing in irrigated and unirrigated condition were computed and are shown in Table 4.8 and 4.9.

It can be seen that the total number of degree days under irrigated and unirrigated conditions in first date of sowing were 1435 and 1252 ^{0}C days respectively, while in the second date of sowing they were 1423 and 1299 ^{0}C days. In the third date of sowing the total degree days under irrigated and unirrigated conditions were 1447 and 1114 ^{0}C days. Thus it is observed that the total growing degree days under unirrigated conditions are less when compared to irrigated conditions. Based on the field and observatory data the growing degree days were also computed for three dates of sowing. Under the first date of sowing the total degree days under irrigated and unirrigated were 1380 and 1179 degree days while under second date of sowing the total degree days were 1362 and 1264 degree days. Under the third date of sowing, the total number of degree days under irrigated and unirrigated conditions were 1386 and 1069 ^{0}C days, respectively.

Thus under the third date of sowing the degree days are less under unirrigated condition because the maturity of the crop occurred earlier. The highest growing degree days (GDD) were found from pod development to physiological maturity. As per the observatory data, the growing degree days (GDD) for this stage varied from 527 to 691 degree days under irrigated condition. Under unirrigated condition the growing degree days (GDD) varied from 456 degree days in the first date of sowing to 522 degree days in second date of sowing. While in third date of sowing the growing degree days (GDD) under unirrigated condition were 424 degree days. Thus, the GDD during pod formation stage were less under unirrigated condition than in irrigated condition. This is because of faster physiological maturity at all the dates of sowing, Similarly for 50% flowering to pod development stage also the growing degree days (GDD) were less under unirrigated condition in the first date of sowing. In other dates of sowing the growing degree days (GDD) under irrigated condition were higher than unirrigated condition.

Same pattern was observed in case of field data also. The total growing degree days (GDD) under irrigated condition based on field data varied from 4080 degree days under D_1, 3062 degree days under D_2 and 3086 degree days under D_3 conditions. In the same pattern the total degree days under unirrigated condition ranged from 1139 under D_1, 1246 degree days under D_2 and 1069 degree days under D_3 conditions.

4.4.2 Accumulated Helio thermal units.

It is often felt that temperature alone doesn't influence the crop but the sunshine hours also influence the growth and development of crop. In view of this, the helio thermal unit (HTU) at different phenological stages was also workout using both observatory and field data (Table 4.10 & 4.11). Based on the field data the total number of helio thermal units (HTU) varied from 10466 under D_1 to 10100 under D_2 conditions. In case of D_3 the value of helio thermal units (HTU) was highest (11376). In case of unirrigated conditions the heliothermal units (HTU) values were 9164 under D_1, 9334 under D_2 and 8048 under D_3 conditions. Similarly in the third date of sowing the total helio thermal units (HTU) were 10057 under D_1 in irrigated condition, 9666 under D_2 and 10024 under D_3 condition.

Under unirrigated condition the helio thermal unit (HTU) value varied from 10227 under D_1, 8952 under D_2 and 7722 under D_3 conditions. Thus the helio thermal units (HTU) values are a better unit to assess the light and thermal requirement of a crop.

Table 4.8: Accumulated growing degree days at different phenological stages of chickpea crop under irrigated and unirrigated conditions based on observatory data.

Dates of sowing	Irrigation	Phenological stages							
		Sowing to germination	Germination to grand growth	Grand growth to bud formation	Bud formation to first flowering	First flowering to 50% flowering	50% flowering to pod development	Pod development to physiological maturity	Total
D_1	Irrigated	94.9	178.1	309.9	12.5	191.0	121.8	527.6	1435.8
	Unirrigated	94.9	178.1	309.9	26.5	117.4	59.6	446.2	1252.6
D_2	Irrigated	110.2	182.2	295.9	29.8	138.1	77.0	590.7	1423.9
	Unirrigated	110.2	169.7	323.7	14.5	72.2	87.2	522.1	1299.6
D_3	Irrigated	110.3	280.5	139.6	41.9	117.8	66.4	691.2	1447.7
	Unirrigated	110.3	280.5	139.6	28.0	53.4	78.4	424.6	1114.8

Table 4.9: Accumulated growing degree days at different phenological stages of chickpea crop under irrigated and unirrigated conditions based on weather data collected at the field.

Dates of sowing	Irrigation	Phenological stages							
		Sowing to germination	Germination to grand growth	Grand growth to bud formation	Bud formation to first flowering	First flowering to 50% flowering	50% flowering to pod development	Pod development to physiological maturity	Total
D_1	Irrigated	94.9	169.2	296.6	11.7	179.2	170.9	510.5	1380.0
	Unirrigated	94.9	169.2	269.6	24.5	111.0	55.4	429.3	1179.8
D_2	Irrigated	105.2	174.1	282.1	25.5	133.9	74.1	567.2	1362.1
	Unirrigated	105.2	162.1	308.1	11.4	70.2	83.5	505.9	1246.4
D_3	Irrigated	105.1	267.1	131.6	40.7	113.4	64.2	664.7	1386.8
	Unirrigated	105.1	267.1	131.6	27.3	51.3	75.5	411.4	1069.3

Table 4.10: Accumulated helio thermal unit at different phenological stages of chickpea crop under irrigated and unirrigated conditions based on observatory data.

Days after sowing	Irrigation	Phenological stages							Total
		Sowing to germination	Germination to grand growth	Grand growth to bud formation	Bud formation to first flowering	First flowering to 50% flowering	50% flowering to pod development	Pod development to physiological maturity	
D_1	Irrigated	699.6	1415.8	2393.6	85.8	1205.5	621.3	4045.5	10466.8
	Unirrigated	699.6	1415.8	2393.6	177.0	647.8	355.7	3474.5	9164.0
D_2	Irrigated	872.8	1445.6	1874.8	208.7	657.1	739.4	4301.8	10100.2
	Unirrigated	872.8	1333.5	2082.8	112.9	253.7	626.2	4052.9	9334.8
D_3	Irrigated	881	2072.6	1052.1	1138.9	614.1	404.2	5213.8	11376.7
	Unirrigated	955.0	1859.0	718.5	76.3	329.4	709.8	3400.1	8048.1

Table 4.11: Accumulated helio thermal unit at different phenological stages of chickpea crop under irrigated and unirrigated conditions based on weather data collected at field.

Dates of sowing	Irrigation	Phenological stage							
		Sowing to germination	Germination to grand growth	Grand growth to bud formation	Bud formation to first flowering	First flowering to 50% flowering	50% flowering to pod development	Pod development to physiological maturity	Total
D_1	Irrigated	699.6	1343.1	2287.7	82.1	1133.6	604.1	3907.5	10057.7
	Unirrigated	917.1	1625.9	2498.9	190.9	722.6	423.2	3849.0	10227.6
D_2	Irrigated	831.2	1380.5	1776.1	202.7	629.2	712.8	4133.6	9666.1
	Unirrigated	831.2	1272.9	1982.3	104.0	238.6	602.7	3920.9	8952.0
D_3	Irrigated	910.0	1764.6	757.2	107.6	893.2	581.8	5009.9	10024.3
	Unirrigated	910.0	1764.6	683.8	73.4	321.3	679.5	3289.5	7722.1

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