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Thermal indices in relation to crop phenology and yield of rice (*Oryza sativa* L.) grown in the south Gujarat region

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Abstract
Thermal indices in relation to crop phenology and yield of rice (*Oryza sativa* L.) grown in the south Gujarat region. Field experiment was conducted during *kharif* seasons of 2016 at Research and Instructional Farm of Navsari Agricultural University, Navsari. Accumulated growing degree days (GDD) for two different variety under different thermal environment varied considerably from sowing to maturity. Higher GDD, PTUE, HTUE and EDUE was observed under 18 June (D_1) in varieties GNR-3 and NAUR-1. Lowest GDD, PTUE and HTUE was observed under 28 June (D_2) in both variety. In south Gujarat region, rice is grown mostly under irrigated condition. Late sown rice crop faces high temperature during grain filling and ripening phases which is one of the most important factor which govern the crop phonological development and total biomass production along with efficient conversion of biomass into economic yield.

Keywords: GDD, PTU, HTU, Heat use efficiency (HUE) and Radiation use efficiency

Introduction
Rice (*Oryza sativa* L.) is one of the most important crop/food for more than three billion people (i.e., approximately 50% of the World's population) (Khush, 2005) [7]. Indian economy is mainly based on agriculture. Growth rate for overall GDP of India was 8.5% whereas for agriculture and allied sectors it was 10% (Anon., 2007) [2]. India is the largest growing country (8 °N to 34 °N latitude) of the rice under varying climatic conditions and it accounts for more than 40% of food grain production, providing direct employment to 70% people in rural areas. Being the staple food for more than 65% of the people, our national food security hinges on growth and stability of its production (Anon., 2006) [1]. In Gujarat, rice is cultivated on an area of 0.76 million ha with total production of 1.76 million tonnes and productivity 2189 kg ha^{-1} (Anon., 2016) [4]. The crop is mainly grown in *kharif* and in *summer* season in Navsari, Valsad, Surat, and the Dang districts of South Gujarat where perennial canal irrigation facilities are available. Among these, Navsari district occupies 87,500 ha area with production of 2, 36,600 tonnes and productivity of 2.70 t ha^{-1} (Anon., 2013) [3]. The heat unit concept assumes that a direct and linear relationship between growth and temperature is advantageous for the assessment of yield potential of a crop in different weather conditions (Kumar *et al.*, 2014) [8]. Alteration of sowing dates a directly influences growth and development of crops. Crop growth refers to an increase in crop weight, height, volume or area over a certain time scale. Development refers to the timing or progress of the crop from one phasic stage of next (Gudadhe *et al*., 2013) [6]. Quantification of these effects may help in the choice of sowing time and match phenology of crop in specific environment to achieve higher heat and radiation use efficiency. The average temperature required throughout the life period of the rice crop ranges from 21ºC to 37ºC. At the time of tillering, the crop requires high temperature for growth. The temperature requirement in reproductive stage is in the range of 26.5ºC to 29.5ºC while at the time of ripening the temperature should be in between 20ºC to 25ºC (De Datta, 1981) [5]. The occurrence of different phenological events during a growing season of crop and the effect of temperature on plant growth can be explained using accrued heat units (Sunil and Sharma, 2005) [12].

Materials and Methods
The field experiment was conducted on College Farm, N. M. College of Agriculture, Navsari Agricultural University, Navsari (Gujarat), India; during *Kharif* season of the year 2016. The Navsari Agricultural University campus is geographically located at 20° 57' N latitude and 72°

54' E longitude at an altitude of 16 m above the mean sea level. The different phonological stages like seedling emergence, tillering, panicle initiation, flowering grain filling and physiological maturity of rice cultivars were recorded by visiting the field frequently from sowing to harvesting. In the seed bed, emergence was recorded. After sowing, 5 plants were tagged with aluminium sheet in each plot to record the number of days required to attain various phenophases. The whole life cycle of the rice crop from sowing to maturity was divided into six distinct phenophases *viz*., emergence, tillering, panicle initiation, Anthesis, beginning of grain filling and physiological maturity. Data of weather parameters *viz*., maximum temperature, minimum temperature and bright sunshine hours for the period of experimentation were recorded from agrometeorological observatory of Navsari
Agricultural University which is near to experimental site. The agrometeorological indices like helio thermal unit (HTU), Photo thermal index (PTI), photo thermal unit (PTI) and energy degree unit (EDU) for completion of each phenophases and heat use efficiency were calculated by using following formulas:

Growing degree days (GDD)

$$\sum_{i=1}^{n} \frac{(T_{max} + T_{min})}{2} - T_C$$

Where, Tmax and Tmin are maximum and minimum temperatures of the day and TC is the minimum threshold temperature of the crop called as base temperature or minimum threshold temperature. The base temperature of rice crop of 10 ˚C was used for computation of GDD on daily basis (Thomas, 1957).

$$\text{Photothermal Unit (PTU)} = \sum_{i=1}^{n} \text{GDD} \times \text{N}$$

$$\text{Heliothermal Unit (HTU)} = \sum_{i=1}^{n} \text{GDD} \times \text{n}$$

$$\text{Phenothermal Index (PTI)} = \frac{\text{GDD between two phenological stages}}{\text{No. of days taken between two phenophases}}$$

Where, N = Maximum possible sunshine hours, N = Actual sunshine hours,
GDD = Growing degree days (ºC day).

$$\text{EDU} = \sum_{s}^{h} \text{GDD} \times \text{E}$$

Where E = daily accumulation of solar radiation in Langley day^{-1}

Solar radiation

Solar radiation at the surface can be estimated by using the following formula:

RS = Ra [a+b (n/N)]

Where, R = Solar radiation at surface
Ra = Radiation at the top of the atmosphere
A & b = Constant, a = 0.42 and b=0.30
n = Actual bright sunshine duration.
N = Maximum possible sunshine duration.

Results and Discussion

Growing Degree Days (GDD °C days)

The accumulated GDD of rice in different stages in different date of transplanting by various cultivars are presented in Table-1.

The thermal time expressed in terms of growing degree days (GDD) required for attaining maturity varied considerably across the two varieties, under different sowing dates. In case of *cv*. NAUR-1 the degree day accumulation from sowing to physiological maturity were found to be relatively higher and varied from 2590.5 to 2643.2 °C day in all the date of transplanting followed by *cv*. GNR-3 (2566.8 to 2564.8 °C day). These differences could probably be due to relatively longer duration of *cv*. NAUR-1 of rice cultivar. The GDD accumulation in the important stage tillering to panicle initiation for the vegetative development of the rice was observed comparatively higher in *cv*. GNR-3 (683.9 °C day) as compare to *cv*. NAUR-1. In case of grain development phase beginning of grain filling to physiological maturity relatively higher GDD was observed in *cv*. NAUR-1 (459.2 °C day). A decreasing trend in accumulated GDD for attaining all Phenological stages was observed to decrease with successive delay in sowings in all the cultivars. Crop sown on early dates accumulated higher degree-days quicker in shorter time due to relatively higher ambient temperatures coupled with longer sunshine hours. Similar decreasing trend in accumulated GDD with delayed sowing was observed. Praveen *et al*., (2013) [9] observed gradual decline in cumulative GDD with delay in transplanting.

Table 1: GDD (°C-days) required for attainment of phenophases of rice cultivars under variable weather conditions

Cultivars	Transplanting dates	Sowing to emergence	Emergence to tillering	Tillering to Panicle initiation	Panicle initiation to anthesis	Anthesis to Beginning of grain filling	Beginning of grain filling to Phy. maturity	Total
NAUR-1	18-06-2016	140.7(6)	657.5(35)	622.9(33)	640.4(34)	131.3(6)	450.4(23)	2643.2
	28-06-2016	140.5(7)	692.4(37)	674.4(36)	674.4(36)	131.9(7)	468.1(26)	2590.5
	Mean	140.6	674.9	648.6	657.4	131.3	459.2	2711.7
GNR-3	18-06-2016	121.3(5)	640.4(34)	657.5(35)	622.9(33)	92.0(5)	432.7(22)	2566.8
	28-06-2016	122.3(6)	674.4(36)	709.9(37)	657.5(35)	96.6(6)	286.1(25)	2564.8
	Mean	121.8	657.4	683.9	640.2	94.3	359.4	2557.0

Table 2: PTU (°C-days) required for attainment of phenophases of rice cultivars under variable weather conditions

Cultivars	Transplanting dates	Sowing to emergence	Emergence to tillering	Tillering to Panicle initiation	Panicle initiation to anthesis	Anthesis to Beginning of grain filling	Beginning of grain filling to Phy. maturity	Total
NAUR-1	18-06-2016	1871.3(6)	8704.4(35)	8247.0(33)	8478.0(34)	1871.3(6)	5737.0(23)	34909
	28-06-2016	1619.8(7)	6510.4(37)	6272.8(36)	6272.8(36)	1859.4(7)	3781.9(26)	26317
	Mean	1745.5	7607.4	7259.9	7376.9	1865.3	4759.4	30613
GNR-3	10/07/2012	1613.3 (5)	8478.0(34)	8704.4(35)	8247.0(33)	1613.3(5)	5506.0(22)	34162
	25/07/2012	1619.8(6)	6272.8(36)	6510.4 (37)	6049.7(35)	1619.8(6)	3544.3(25)	25616
	Mean	1616.5	7375.4	7607.4	7148.3	1616.5	4525.1	29889

Phenothermal index (PTI) (°C days hr)

The maximum value of PTI observed from sowing to emergence as compare to other phonological stage in all dates of transplanting and genotypes. It was fairly noticeable from data for higher values of PTI were recorded in 28th june date of transplanting followed by 18th june date of transplanting (table 4).

Energy degree unit (Leangle day-1)

In *cv.* NAUR-1 significantly higher value of total EDU was observed at 28th June date of translanting (1134736.0 Leangle day-1) followed by 18th June date of transplanting (10353801.1 Leangle day^{-1}). Similar trend was observed in *cv.* GNR-3. Table 5 showed that total EDU was decreased with delay in transplanting.

Thermal use efficiences

Heat use efficiencies (kg ºC day-1)

The values in table 5 revealed that in *cv.* NAUR-1 at 18th june date of transplanting showed the heat use efficiencies (1.99 kg ºC day^{-1}), but in 28th June date of transplanting slightly higher heat use efficiencies observed i.e. (2.22 kg ºC day-1). In case of *cv.* GNR-3 maximum heat use efficiency recorded in 28th June date of transplanting.

Table 3: HTU (°C-days) required for attainment of phenophases of rice cultivars under variable weather conditions

Cultivars	Transplanting dates	Sowing to emergence	Emergence to tillering	Tillering to Panicle initiation	Panicle initiation to anthesis	Anthesis to Beginning of grain filling	Beginning of grain filling to Phy. maturity	Total
NAUR-1	18-06-2016	431.9(6)	1693.43(35)	1674.42(33)	1681.42(34)	431.94 (6)	1339.45(23)	7252.43
	28-06-2016	427.19(7)	1089.7(37)	1062.7(36)	1062.7(36)	427.1(7)	715.58(26)	4784.8
	Mean	429.5	1391.5	1368.5	1372.0	429.5	1027.5	6018.5
GNR-3	10/07/2012	348.52(5)	1681.42(34)	1693.42(35)	1674.42(33)	348.52(5)	1339.4 (22)	7085.7
	25/07/2012	427.19(6)	1062.7(36)	1089.7(37)	1693.42(35)	427.19(6)	708.72(25)	5408.2
	Mean	387.8	1371.7	660.9	1683.9	387.8	1024.0	5516.1

Table 4: PTI (°C-days) required for attainment of phenophases of rice cultivars under variable weather conditions

Cultivars	Transplanting dates	Sowing to emergence	Emergence to tillering	Tillering to Panicle initiation	Panicle initiation to anthesis	Anthesis to Beginning of grain filling	Beginning of grain filling to Phy. maturity	Total
NAUR-1	18-06-2016	23.4(6)	18.7(35)	18.8(33)	18.8(34)	21.8(6)	16.58(23)	121.4
	28-06-2016	20.0(7)	18.7(37)	18.7(36)	18.7(36)	18.8(7)	18.0(26)	112.9
	Mean	21.7	18.7	18.7	18.7	20.3	18.7	116.8
GNR-3	18-06-2016	24.2(5)	18.8(34)	18.7(35)	18.8(33)	18.4(5)	19.6(22)	118.4
	28-06-2016	24.4(6)	18.7(36)	19.1(37)	18.7(35)	16.1(6)	11.4(25)	108.4
	Mean	24.3	18.7	18.9	18.7	17.2	15.5	113.3

Table 5: Energy degree unit (°C-days) required for attainment of phenophases of rice cultivars under variable weather conditions

Cultivars	Transplanting dates	Sowing to emergence	Emergence to tillering	Tillering to Panicle initiation	Panicle initiation to anthesis	Anthesis to Beginning of grain filling	Beginning of grain filling to Phy. maturity	Total
NAUR-1	18-06-2016	48975.2(6)	244007.4(35)	232090.9(33)	251522.5(34)	61881.0(6)	196903.1(23)	1035380.1
	28-06-2016	82132.5(7)	234576.6(37)	274566.0(36)	287294.4(36)	63211.3(7)	192955.1(26)	1134736.0
	Mean	65553.9	239292.0	253328.4	269408.4	62546.2	194929.1	1085058.0
GNR-3	18-06-2016	45050.0(5)	240018.6(34)	239133.0(35)	244918.4(33)	54282.5(5)	190239.9(22)	1013642.5
	28-06-2016	71522.8(6)	230232.3(36)	281580.9(37)	277862.9(35)	57267.8(6)	189215.2(25)	1107681.7
	Mean	58286.4	235125.3	260357.0	261390.7	55775.5	189727.5	1060662.1

Table 6: Heat use efficiencies of rice genotype under variable weather condition

Cultivars	Transplanting dates	HUE kg °C day^{-1}	PTUE kg °C day^{-1} hr^{-1}	HTUE kg °C day^{-1} hr^{-1}	EDUE kg Lengley^{-1} day
NAUR-1	18-06-2016	1.99	0.15	0.73	0.00509
	28-06-2016	2.22	0.22	1.20	0.00506
	Mean	2.10	0.18	0.96	0.00507
GNR-3	18-06-2016	2.00	0.16	0.72	0.00506
	28-06-2016	2.15	0.21	1.02	0.00496
	Mean	2.07	0.1	0.87	0.00501

Photothermal use efficiencies (kg ºC day^{-1} hr^{-1})

In *cv*. NAUR-1 at 18th june date of transplanting showed the photothermal use efficiencies (0.15 kg ºC day^{-1}), but in 28th june date of transplanting slightly higher photothermal use efficiencies observed *i.e*. (0.22 kg ºC day^{-1}). In case of *cv*. GNR-3 maximum photothermal use efficiency recorded in 28th June date of transplanting.

Heliothermal use efficiency (kg ºC day^{-1} hr^{-1})

In cv. NAUR-1 at 18th june date of transplanting showed the heliothermal use efficiencies (0.73 kg ºC day-1), but in 28th june date of transplanting slightly higher heliothermal use efficiencies observed i.e. (1.20 kg ºC day-1). In case of cv. GNR-3 maximum heliothermal use efficiency recorded in 28th june date of transplanting.

Energy degree use efficiency (kg ºC Lengley day^{-1})

Data tabulated in table 6 revealed that in *cv*. NAUR-1 at 18th june date of transplanting showed the energy degree use efficiency is same in both transplanting dates. (0.0050 kg ºC day^{-1}). In case of *cv*. GNR-3 maximum energy degree use efficiency recorded in 18th june date of transplanting (0.00506) followed by 18th june date of transplanting date (0.00496). These finding are in supported to the report of Rani *et al*., (2012) [10].

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