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Heat unit requirements for Phenophases of wheat genotypes as influenced by different thermal regimes: A review

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Abstract
Seasonal temperature is important climatic factor which has profound effects on the yield of *rabi* crops. Changes in seasonal temperature affect the grain yield, mainly through phonological development processes. Winter crops are especially vulnerable to high temperature during reproductive stages and differential response of temperature change (rise) to various crops has been noticed under different production environments. The occurrence of different phonological event during growing season of any crop and the effect of temperature on plant growth can be inferred using accumulated heat units or growing degree days (GDD). Temperature based agro meteorological indices such as growing degree days (GDD) and heat use efficiency (HUE) can be quite useful in predicting growth and yield of crops. Heat use efficiency (HUE), *i.e.* efficiency of utilization of heat in terms of dry matter accumulation is an important aspect, which has great practical application.

Keywords: wheat (*Triticum spp.*), GDD, HUE, temperature and yield

Introduction

Wheat (*Triticum spp.*) is the major *Rabi* crop in India and is sensitive to various biotic and abiotic stresses like weather and inter-seasonal climatic variability (in terms of changes in temperature, rainfall, radiation) soil conditions and agricultural inputs like nitrogen, water and pesticides. Three main species commonly grown in the world including India are the common wheat (*Triticum aestivum)* the Marconi or durum wheat (*T. durum*) and the emmer wheat (*T. dicoccum*), out of these species maximum area is under *T. aestivum*. In India, more than 80 percent of the total wheat area is under this species whereas the area under Marconi and emmer wheat is only 12 percent and 1 percent respectively.

In India, wheat is grown in an area of 27.75 million ha and production 80.68 million tonn with an average productivity of 2907 kg/ha which contributes about 25 percent of total food grain production of the country (Anonymous, 2010) [5]. The productivity of wheat in Chhattisgarh is very low as compared to the national average. In Chhattisgarh wheat crop is grown in 1.63 lakh ha with an average productivity of 1108 kg/ha. The main reasons for low productivity are shorter winter span and high temperature during the grain filling and maturity stages.

Solar radiation is the ultimate power source in the world and it plays an important role in terrestrial ecological systems and living organisms. The radiation received by an organism consists of direct beam, diffuse sky and reflected radiation from terrestrial objects (Campbell and Norman, 1998). The resultant net radiation is used for such natural processes as evapotranspiration, sensible heat, soil heat flux and biological processes. Different land uses may affect the absorption and reflection of solar radiation causing different values for the radiation use efficiency (RUE) of crops.

The effect of temperature on the wheat productivity can easily by seen in Central India because of high inter-annual fluctuations in the productivity due to fluctuations in seasonal temperature. The productivity of wheat is largely dependent on the magnitude of temperature change. One ^{0}C increase in temperature throughout the growing seasons will have no effect or slight increase on productivity in north India. But, an increase of 2^{0} C temperature reduced potential grain yield at most of the places (Agrawal and Sinha, 1993) [3].

In Chhattisgarh, wheat is grown mostly under irrigated conditions in rice based cropping system. The sowing of wheat is often delayed due to delay in harvesting of medium and late duration rice varieties.

Late sown wheat crop faces high temperature during grain filling and ripening phases which is one of the major causes of stunted growth and low productivity of wheat in this area. Time of sowing is one of the most important factors which govern the crop phenological development and total biomass production along with efficient conversion of biomass into economic yield.

Review of Literature

1. Wheat and environment
2. Growing degree days and
3. Yield attributes and yield

1) Wheat and environment

Growth and development of wheat depends up on the environment in which it is grown. Major environmental factors which influence growth and development of wheat are temperature, moisture, radiation and photoperiod. Udovenko (1994) [36] studied response of wheat plants to changes in the level of mineral nutrition with different thermal regimes and water supply. They reported that when temperature regime and water supply were optimum, yield and response to fertilizer application were greater under stable than under variable conditions. Noureldin *et al.* (2000) studied response of certain wheat genotypes production to heat stress using 10 cultivars were sown at two date (Nov.15th and Dec.15th). They reported that in 1997-98 and 1998-99, Gemmiza 5 had the highest grain (1.11 and 1.26 t/feddan, respectively) and biological (3.09 and 3.83 t/feddan) yields, Giza 164 had the highest straw yield (2.03 and 2.47 t/feddan), and Gemmiza 3 had the greatest 1000-grain weight (61.6 and 55.8 g). Patra and Sahu (2007) [26] conducted an experiment to use various agrometeorological indices for suitable sowing time of wheat, thermal and radiation use efficiency indices were used to identify the appropriate sowing time for wheat at Junagadh. The results revealed that under normal sowing condition the crop accumulated higher amount of heat units than late sown condition. The RUE and HUEs were also higher for earlier sowings than later sowings. Thus the study suggested that the appropriate time of sowing for wheat is 15th Nov to 25th Nov for getting higher and stable yield of wheat under South Saurashtra Agroclimatic Zone of Gujarat.

Ghodsi *et al.* (2008) [10] conducted a research using split plot experimental design based on complete randomized blocks with three replications. Moisture stress treatments (at seven levels) were assigned to main plots, including: D1 (full irrigation), D2 (no irrigation from one leaf to double ridge) stage, and in other treatments, no irrigation and preventing rainfall as: D3 (from one-leaf to floral initiation stage), D4 (from floral initiation to the commencement of stem elongation or Terminal spikelet), D5 (from commencement of stem elongation to flag leaf emergence), D6 (from flag leaf emergence to anthesis) and D7 (from anthesis to the soft dough), and four wheat cultivars, namely: Roshan, Qods, Marvdasht and Chamran, were sown in sub plots. The results of combined analysis of variance showed that the effect of moisture stress was significant. Applying D5, D6 and D7 treatments reduced the grain yield in comparison with control (D1) by 36.7, 22.8 and 45.6, respectively. Ruza and Kreita (2008) conducted a experiment using three varieties of winter wheat (Cubus, Tarso, Zentos) in 4 sowing times with a 10-day interval from the end of August till the end of September with 3 sowing rates – 300, 400, and 500 germinating seeds per m2. In total, 36 treatments were included in the experiment. The depth of sowing was 3 to 4 cm. Fertilizer treatments: The 3-year research results indicate that all the varieties of winter wheat included in the experiment showed higher (8.5 – 9.4 t ha-1) and more stable yields between years in treatments with sowing time performed the sowing rate was not the yield determinant factor. Only in late sowing (the 4th sowing time at around 29 – 30 September), when plants with none or extremely poor tillers were going to overwinter, increased sowing rate showed the tendency of yield increase.

Dubey *et al.* (2008) [9] conducted a field experiment during three consecutive years (2004-05 to 2006-07) in split plot design with four replications to assess the influence of weather parameters on wheat yield under varying sowing dates in sandy loam soil of central alluvial tract of U.P. The treatment consisted three dates of sowing Nov. 30th, Dec. 15th and Dec. 30th and three genotype namely, HD-2285, K-8804 and K-91 07. The yield was significantly influenced by different dates of sowing. The first date of sowing (D1-Nov. 30th) had produced significantly higher grain yield (4574.8 kg ha-1) over the subsequent sowing dates. Thus the reduction in grain yield of wheat was observed to the tune of 20 percent with delayed sowing by 30 days. Crop sown early (Nov. 30th) took more number of days from sowing to maturity than delayed sowing (Dec. 30th). Days taken from sowing to physiological maturity reduced with subsequent delayed sowings. Delayed sowing reduced the crop duration by 14 days. Flowering and dough phases of the wheat were found to be most sensitive to weather parameter. Lower sunshine hours and temperature range between 11.3-24.2 0C enhanced the flowering, moreover at the dough stage favourable temperature was observed between 15.3-29.0 0C for maximum production of wheat. Solanki (2009) conducted a field experiment during Result revealed that the magnitude of reduction in number of tillers/m row was more due to higher minimum temperature. The maximum heat units of 1701 degree days were recorded under 19th November sown crop with six irrigation (D2I6). The delay sowing caused reduction of 25.7 and 41.9 per cent grain yield in 4th December (D3) and 19th December (D4) sown crop,

Kumar *et al.* (2010) [19] attempted to quantify the effect of projected climate change on wheat production in non-traditional wheat areas comprising states of Gujarat, Maharashtra, Madhya Pradesh and Rajasthan that contribute about 20 per cent of national wheat production. None of the management practices like shifting in sowing date, number of irrigation and amount of nitrogen tried for adaptation options was found beneficial and in all cases there was substantial yield loss. Parya *et al*. (2010) [24] carried out a experiment with five wheat varieties (PBW 343, HD2733, HW 2045, PBW533 and K9107) on three dates of sowing (18th November, 3rd December and 18th December) in a split plot design, keeping dates of sowing in the main plot and varieties in the subplot with the objective to find out the effect of temperature change on the duration of different phenophases of wheat crop and its productivity. The phenophases (CRI, tillering, flowering and milking) were delineated and the duration of exposure of the crop to higher maximum and minimum temperature than the normal and extent of high temperature were worked out. Significantly explained through the variation in cumulative maximum as well as minimum temperatures at the flowering stage.

2) Growing degree day

Slafer *et al.* (1994) conducted a field study to test the hypothesis that wheat development rate of change of photoperiod two wheat cultivars (Condor and Thatcher). In the result there were no significant difference among treatments in the length of the period from sowing to seedling phase, ranging from 15 to 16.3 days. The rate of development from emergence to terminal spiklet initiation (TS) to increase in photoperiod in both cultivars, increasing with average photoperiod across all the treatments but there was no effect of rate of change of photoperiod independent of its average photoperiod. Slafer (1996) [33] studied the differences in phasic development rate amongst wheat cultivars in responses to photoperiod and vernalization Differences amongst wheat cultivars in the rate of reproductive development are largely dependent on differences in their sensitivity to photoperiod and vernalization. The result revealed that differences in intrinsic earliness between cultivars were modified by the temperature regime under which they were grown, i.e. the difference between cultivars (both considering the full phase to ear emergence or some sub-phases) was not a constant amount of time or thermal time at different temperatures. In addition, in some instances genotypes changed their ranking for 'intrinsic earliness' depending on the temperature regime. Rao *et al.* (1999) [28] field experiments conducted at Research Farm, HAU, Hisar during winter seasons of 1993-94 and 1994-95 with wheat and mustard and 1992-93 and 1993-94 with chickpea. Experimental results indicated highest heat use efficiency (HUE) in wheat in terms of seed yield (2.56 kg ha-1 day-1 in 1993-94 and 2.18 kg ha-1 day-1 in 1994-95) as compared to mustard and chickpea crops in that order. HUE values varied between two seasons within dates of planting in three crops. The HUE in terms of dry matter accumulation (DMA) was highest in mustard followed by chickpea and wheat and decreased when planting was delayed after recommended time of sowing for these crops.

Agrawal *et al.* (1999) [2] the phenothermal index was nearly constant with a mean value of 14.3 for both the varieties and for different dates of plantings from sowing to flowering stage of wheat crop. Both the varieties did not differ significantly in their response to the different thermal regimes. Jat *et al.* (2003) evaluated four wheat varieties *viz*., Lok-1, GW-190, GW173 and Raj. 3077 to know the phenological behaviour of wheat, under varying sowing dates and seed rates and reported that variety Lok-1 took significantly less time for initiation and completion of the various phenological stages as compared to the varieties GW-190 and Raj-3077, though it remained at par with GW-173 in this respect. Variety Lok-1 and GW-173 required significantly lower heat units for successive phenological stages as compared to GW-190 and Raj-3077. Late sowing (December 7th) significantly increased the number of days required for initiation and completion of various vegetative growth stages while significantly reduced number of days required in reproductive phase. The early sown crop (November9th) needed significantly higher heat units (1775.96 degree days) to reach maturity stage which was significantly higher by 3.06 and 1.65 per cent over November 23th and December 7th sowing, respectively. Sharma *et al.* (2003) [30, 31] conducted a field experiment at the Experimental Farm of Haryana Agricultural University, Hisar during Rabi season 1998-99 to study the phenology and photothermal indices of wheat crop under different sowing dates. The daily heat units were calculated using 5°C as base temperature for wheat. The occurrence of different phenological stages i.e. tillering jointing, flag leaf, anthesis, milking, hard dough and maturity required higher heat and photothermal unit at all stages in D1, (25th November) sown crop followed by D2 (10th December) and D3 (25th December). Among the varieties V2 (PBW 343) consumed maximum heat and photothermal units for occurence of different phenological stages followed by UP 2338, WH 542, Raj 3765 and sOnak, respectively.

Sharma *et al.* (2003) [30, 31] conducted a field experiment during rabi season 1998-99 to study the effect of weather parameters on radiation use efficiency in wheat. Five cu1tlvars VI (WH 542), V2 (PBW 343), V3 (UP 2338), V4 (Raj 3765) and Vs (Sonak) were sown on three dates Le. 25th November, 10th December and 25th December. Delay in sowing from 25th November to 10th December significantly reduced the radiation use efficiency. Efficiencies varied from 1.24 to 2.85 gm dry matter MJ•lof intercepted photo synthetically active radiation for wheat crop. Among varieties and sowing dates, Sunshine hours, vapour pressure deficit, maximum; minimum and mean temperatures of whole season were negatively associated while positive correlation existed for relative humidity with radiation use efficiency. Pandey *et al.* (2007) [22] calibrated and validated CERES-wheat model with the field experimental data generated during the years 2004-2005 and 2005-2006 for wheat (cv. GW-496) at Anand. The results revealed that grain yield as simulated by the CERES-wheat model under higher temperatures regimes showed a gradual decrease in yield, while lowering the temperatures increased the yield. However, under higher CO2 concentration the net effect was found to increase the wheat yield. When carbon dioxide (CO2) concentration was doubled, the grain yield increased up to 68 to 57 per cent under optimum and sub-optimal condition, respectively over the base yield. Mishra *et al.* (2007) [19] conducted a field experiment to analyse heat unit requirement of wheat cultivars. In the study 4 moisture level *viz*. M1 (one irrigation given at crown root intiation stage), M2 (two irrigation given at CRI and flowering stage), M3 (three irrigation given at CRI, late tillering and flowering stage) and M4 (four irrigation given at CRI+late tillering+late jointing+ear head formation stages) with the combination of three varities *viz*.-HUW-234, HD-2285 and PBW-154 as treatments. The result indicated that GDD as affected by various moisture application frequencies for three wheat varieties. PTI value decreased till jointing stage and thereafter gradually increased towards maturity. On average, the phenothermal index were found in order of M4>M3>M2>M1 in all cases from late tillering onwards.

Singh *et al.* (2008) The results also indicated that around 58 per cent of the yield variations in cotten could be expalained by LE during reproductive stage whereas in wheat almost 98 per cent of variation could be explained by the LE at vegetative stage. Pal and Murty (2009) [21] conducted a experiment during Rabi season of 2007-08 and 2008-09 at the Crop Research Centre (CRC) of G. B. Pant University of Agriculture & Technology, Pantnagar to quantify growing degree days (GDD) requirement at different phenophases of wheat with two genotypes as influenced by three sowing dates. The studies revealed that the wheat sown on 20 November, accumulated higher number of GDDs and low PTI with higher HUE, among the genotypes tried. Gill (2009) [11] the highest grain yield was correlated with longer spike growth duration, partitioning higher crop growth rate and grain spike weight ratio at anthesis phase. The results revealed that cumulative growing degree days (GDD) accumulated more during the reproductive phases as compared with the vegetative phases of wheat cultivars. The GDD is the effective selection criteria for screening thermo tolerant lines of wheat.

Kour *et al.* (2010) [16] conducted a field experiments to study the influence of sowing time on phenology and growth of the wheat cultivars and to develop the phenophases prediction model based on the agro meteorological indices. The treatment consisted of three dates of sowing and six cultivars of wheat. The results showed that the wheat sown under temperate region matured in 219 + 10 days. Early sown wheat crop took more thermal time as compared to normal and late sown. The day length and bright sunshine hours also affected the occurrence of different phenophases of wheat cultivars. Accumulated thermal time(r=0.94) was best agro meteorological indices for prediction of flowering stage in wheat, while physiological maturity was predicted well by using helio thermal unit (HTU) (r=0.95). The heat use efficiency decreased with delay in sowing. The dry matter production (g/m2) was linearly related with accumulated heat units, HTU and photo thermal indices Khan *et al.* (2010) [9] conducted a field experiment to assess the effects of thermal and radiation regimes on wheat, consisting of five dates of sowing starting from 20 November at weekly interval, was conducted. They reported accumulated global radiation and PAR during vegetative phase showed significant positive correlation, but during reproductive and grain filling phases they exhibited significant negative correlation with dry matter. Dakhore *et al.* (2011) [8] Studied wheat yield models over semi-arid regions using Radiation use efficiency (RUE) and water use efficiency (WUE). The result indicated that WUE were generally higher in vegetative and flowering stages as compared to grain filling. Thr wheat yield prediction from water use and stage specific WUE were carried out for same seasons. The better correlation found from 0.57 to 0.77 at flowering stage.

3) Yield attributes and yield

Udovenko and Volkova (1992) [37] studied response of wheat due to changes in the level of mineral nutrition and soil salinity under different thermal regimes using spring wheat cv. Oshskaya and a local Swedish cultivar. Patel *et al.* (1999) [25] field experiment was conducted during the 1994-95 and 1995-96 Rabi seasons to study the effect of different sowing dates (25 November, 5, 15 and 25 December and 5 January) on the yield attributes and yield and major nutrient uptake by 4 wheat (Triticum aestivum) cultivars, Lok 1, Swati, Mangla and GW 173 under rice-based cropping system in the eastern Madhya Pradesh in India. The study showed that sowing wheat on the first week of December (5 December) was most suitable. Thereafter, yield decreased to 46.2-67.3 kg/day with delay in sowing from 5 December to 5 January. Hussain *et al.* (2004) they reported that highly significant positive relationship between cumulative intercepted PAR and biomass production. The response of cultivars to radiation interception was slight and significant only during 1999-2000. Final grain or biomass yield was sensitive to drought timing, especially to maximum potential soil moisture deficit for the early than the later drought treatments. Pandey *et al.* (2007) [22] calibrated and validated CERES-wheat model with the field experimental data generated during the years 2004-2005 and 2005-2006 for wheat(cv. GW-496) at Anand. The results revealed that grain yield as simulated by the CERES-wheat model under higher temperatures regimes showed a gradual decrease in yield, while the lowering the temperatures increased the yield. The impact of maximum temperature was found to be more than that of minimum temperature. Increase in daily solar radiation (1 to 3MJm-2),

Khan *et al.* (2008) [9] studied to know the performance of 11 wheat genotypes (Local, SR-24, SR-25, SR-7, SR-22, SR-4, SR-20, SR-19, SR-2, SR-2, SR-23 and SR-40) under field conditions to investigate the response of different wheat genotypes to salinity stress. The study revealed that different locations and wheat genotypes had a significant ($p < 0.05$) effect on plant height, productive tillers m-2, number of grains spike-1, 1000 grain weight, grain and straw yield. The maximum plant height (84.52 cm), number of productive tillers m-2 (31.30), number of grains spike-1 (55.33), 1000 grain weight (37.67 g), grain yield (2402 kg ha-1) and straw yield (3495.89 kg ha-1), was recorded in genotype SR-40 followed by genotype SR-23 when compared with other genotypes. Singh *et al.* (2008) evaluated the effect of temperature and rainfall on historical wheat yields in south western region of Punjab. The technology trend at Bathinda indicated that over the past 25 years wheat yields have increased at the rate of 82.1 kg ha-1 year-1. The grain yield revealed positive correlation with minimum temperature but no trends were observed for other parameters. The regression models are in good agreement between the observed and predicted values of wheat yield.

Singh *et al.* (2008) [30, 31] Higher thermal units under 5 November and 20 November sowing were not found conducive for a better yield of wheat crop. Lesser value of cumulative PTI during crop period produces higher grain yield in December 5th sowing. Ali (2009) determined yield response factor of semi-dwarf winter wheat from experiment data conducted during three consecutive years (2002-03 to 2004-05). The yield response factor (Ky) varies depending on growth phases and also among seasons. On an average, the Ky for early vegetative, booting-heading, and flowering-soft dough stage were 0.27, 0.21, 0.25, and 0.17, respectively. According to the value of yield response factor, the most sensitive growth stages were in the order: CRI> booting-heading>maximum tillering> flowering-soft dough. For the alternate deficit strategies (deficit tillering +flowering –soft dough; deficit at CRI + booting-heading stages), the Ky values were 0.77 and 0.61, respectively. Kingra *et al.* (2010) studied prediction of grain yield of wheat using canopy temperature and result showed thta during the reproductive phase, all the canopy temperature based indices *viz*., canopy temperature (Tc), average canopy minus air temperature (Tc-Ta) and summation stress degree days (SDD) showed a negative and significant relationship explaining 71-87% variation in grain yield. These findings signify an ample scope of midday canopy temperature as a possible tool for monitoring plant water status and grain yield prediction.

Abdulharisa *et al.* (2011) studied impact of climate change on wheat varieties *viz*. K-9107 and HD-2733, under two different agroclimatic zones using simulation model Info Crop. Model was calibrated and validated for Patna and Ranchi centres. Sensitivity analysis indicated declining yield trend with increase in temperature. Anwar *et al.* (2011) [6] conducted a field experiment with twenty advanced lines/genotypes of wheat including two check varieties which was sown under two different sowing times throughout the Punjab province at 18 different locations with diverse environments to study their stability and adaptability. Normal sowing was done in second week of November 2007 while the delayed sowing was completed during second week of December 2007 during crop season 2007-08.

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