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MOISTURE AND NUTRIENT MANAGEMENT STRATEGIES INFLUENCE THE PHOTO-THERMAL ENVIRONMENT IN COTTON-WHEAT CROPPING SYSTEM

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ABSTRACT

Although, crop productivity is determined by several factors like photo-period, moisture and fertility, but it is primarily influenced by temperature. Increasing water scarcity due to high evapo-transpiration is a major concern for crop production. Therefore, a field experiment was planned to evaluate the response of varied irrigation and fertilization levels on agrometeorological indices of cotton-wheat cropping system at the Research Farm, Department of Soil Science, Punjab Agricultural University, Ludhiana for two consecutive years i.e. 2019-2020 and 2020-2021. Higher heat indices were resulted from longer phenophases under well fertilized and watered conditions. Cotton irrigated through sub-surface drip at 100% ET_c along with100% RDN and foliar application of nutrients i.e. 2% KNO_3 (4 times) & 1% $MgSO_4$ (2 times) exhibited higher heat indices i.e. growing degree days, helio-thermal units, photo-thermal units, relative temperature disparity and heat use efficiency over all other treatments, to reach maturity. On the other hand, wheat crop that received 100% irrigation through sub-surface drip irrigation and fertilization along with the residual effect of equivalent quantity of soil applied 2% KNO_3 and 1% $MgSO_4$, to cotton experienced higher heat indices than to other treatments.

Keywords: Agrometeorological indices, Fertigation, Growing degree days, Heat use efficiency, Temperature disparity

It is an established fact that utilization rate of solar energy, essential plant nutrients and moisture affect the crop growth and development. Availability of congenial environmental factors such as solar energy has synergistic effect on the growth and development. Among the environmental factors, temperature is the most important determinant of crop growth, development and productivity as it governs the two most important plant processes i.e. photosynthesis and respiration. Rate of which determine quantum of energy produced during active crop growth and amount of photosynthates left for accumulation as yield. Cotton requires a minimum daily air temperature of 10°C for germination, 21 to 27°C for proper growth from seedling to flowering and 27 to 32°C during the boll formation period. It generally needs more than 150 days above 10°C to produce a crop, but below 10°C (base temperature), the crop growth ceases (Wrona,1996). On the contrary, the ideal temperature range for wheat germination is 12°C to 25°C. Temperature, below & above cardinal alter plant growth and affects the yield (Hakim *et al.,* 2012) whereas, complete cessation of growth occurs below 4°C. Harsh environmental conditions along with poor management of water and nutrients adversely influence the yield of crop (Brar and Vashisht, 2020).

Crop weather relationships indicate the effect of changes in temperature and solar radiation during various growth stages on source-sink relationship and crop productivity (Bal *et al*., 2018 and Brar *et al.,* 2020). Cotton and wheat, both require certain amount of heat units to complete its developmental phases and the amount of accumulated heat units (HU) at different phenological stages, are closely associated with the productivity. Heat unit concept aids in explaining the relationship between growth and temperature for determining a crop's yield potential under various weather conditions (Kumar *et al*., 2014). Heat unit assessments in cotton are more reliable under conditions of adequate moisture supply while under water deficit conditions its usefulness diminishes. Deficit moisture reduces the number of days required to complete any phenological stage and growth indices (Ihsan *et al*., 2016).

Agrometeorological indices, viz., Growing Degree Days (GDD), Helio-thermal Units (HTU), Photo-thermal Units (PTU), Relative temperature disparity (RTD), Heat use efficiency (HUE) and Pheno-thermal index (PTI) are frequently used as indicators for evaluating crop progress (Ram *et al*., 2012), changes in phenological behavior and growth parameters (Kumar *et al.,* 2010). It can be postulated that supply of adequate nutrition and moisture tailors the plant growth for maximizing utilization of freely and abundantly available solar energy. Proper understanding of exploitation of environmental factors such as solar energy under variable irrigation

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and fertilization regimes will help in harnessing the heat energy more efficiently. The effect of weather elements under variable irrigation regimes, fertilization levels and method of nutrients application on agro meteorological indices at different phenophases is rarely reported. In view of this, we attempted to evaluate the heat units accumulation in cotton-wheat cropping system under different irrigation and fertilization regimes.

MATERIALS AND METHODS

The field experiment was conducted for two consecutive years i.e. 2019-2020 and 2020-2021 at the Research Farm, Department of Soil Science, Punjab Agricultural University, Ludhiana, Punjab. The experiment was laid out in a randomized complete block design with fifteen treatments replicated thrice. Combination of two fertilization levels viz., F_{80} :80% and F_{100} :100% of recommended nitrogen (RDN) were tied under 3 sub-surface drip irrigation regimes based on crop evapo-transpiration (ET_c) (I_{60} :60%; I_{80} :80% & I_{100} :100% ET_c) and two methods of nutrient application i.e. M_{foliar} (foliar spray of 2% KNO_3 (4 times) & 1% $MgSO_4$ (2 times)) and M_{soil} (soil application of KNO_3 @ 20 kg ha^{-1} (4 times) & $MgSO_4$ @ 5 kg ha^{-1} (2 times). These 12 treatments were compared with three controls i.e. C_1 (surface drip irrigation and 100% RDN along with foliar application of nutrients (2% KNO_3 & 1% $MgSO_4$)), C_2 (surface drip with 100% RDN with soil application of nutrients) and C_3 (flood irrigation with 100% RDN and foliar application of nutrients). Application of 2% KNO_3 & 1% $MgSO_4$) was done in cotton crop at flower and boll initiation stages and its residual effect was observed on succeeding wheat crop. Cotton and wheat crop were sown on 5th May & 8th November during 2019-2020 and 1st May & 4th November during 2020-2021, respectively. Cotton crop was sown on well prepared seed bed by keeping row to row spacing of 67.5 cm and plant to plant spacing 75 cm whereas wheat was sown keeping row to row distance of 22.5 cm. Fertilizer and irrigation was applied to both the crops according to treatment. Thinning of the cotton was done on 30 days after sowing to obtain the optimum plant population. and two blanket sprays of Ulala 50 WG (flonicamid) @ 0.2 kg ha^{-1} and one spray of Polo 50 WP @ 0.5 kg ha^{-1} (diafenthiuron) were given to crop against sucking pests.

Irrigations on the basis of crop evapo-transpiration were applied through polyethylene drip pipes placed in the soil at depth of 20cm with 30 cm. emitter spacing and 75 cm. between the laterals. Crop evapo-transpiration was calculated by multiplying reference evapo-transpiration with crop coefficient at each stage of crop growth, whenever irrigation was applied and reference evapo-transpiration was calculated from weather data using ET_o calculator based on Penman-Monteith equation. Fertigation of nitrogen in cotton was done @ 105 kg ha^{-1} in 8 splits starting from 40 days after sowing. Whereas, in case of wheat 1/5th dose of recommended nitrogen (N), phosphorus (P) and potassium (K) were applied @ 125 kg N, 62 kg P_2O_5 and 30 kg K_2O ha^{-1} in the form of urea, single super phosphate and muriate of potash, at sowing and remaining in 4 equal splits at 7 days interval.

The observations on the attainment of different phenological stages of both cotton and wheat were recorded. Growing degree days were calculated by cumulating daily mean temperature above base temperature of 10 °C for cotton (Wrona *et al.,*1996) and 4.5°C for wheat. The different agro-climatological indices at each stage were calculated as recommended by Nuttonson (1955). The experimental data for randomized complete block design was analysed as per standard statistical procedure prescribed by Cochran and Cox (1967) using SAS software. Agrometeorological indices were calculated by following equations:

$$\text{Growing degree days (°C days)} = \frac{T_{max}+T_{min}}{2} - T_b$$

where, T_{max} and T_{min} are daily maximum and minimum temperature in °C and T_b = Base temperature; Helio thermal units were calculated by:

$$\text{HTU (°C day hour)} = \text{GDD} \times \text{Actual sunshine hours}$$

For photo thermal units (PTU), the formula used is given as:

$$\text{PTU (°C day hour)} = \text{GDD} \times \text{Day length}$$

Pheno-thermal index (PTI) was calculated by following formula (Gupta *et al.,* 2017),

$$\text{PTI}\left(\frac{\text{°C days}}{\text{day}}\right) = \frac{\text{GDD consumed between two phenological phases}}{\text{Number of days taken between two phenological phases}}$$

Relative temperature disparity (RTD) was calculated, using the given formula:

$$\text{RTD} = \frac{\text{(Maximum temperature (°C) - Minimum temperature (°C)}}{\text{Maximum temperature (°C)}} +100$$

Heat use efficiency (HUE) was calculated by given formula (Aggarwal *et al.,* 2016)

$$\text{HUE}\left(\frac{\text{kg}}{\text{°C day}}\right) = \frac{\text{Grain yield}}{\text{GDD (to maturity)}}$$

RESULTS AND DISCUSSION

Accumulated growing degree days (AGDD) and helio-thermal units (AHTU)

Growing degree days, that demonstrates the relationship between plant development and mean air temperature, can be the best indicator for predicting the various pheno-phases of a crop. Helio-thermal units depict the integrated effect of varying temperature and sunshine hours on phenological development of a crop. Perusal of data on growing degree days and helio-thermal units, presented in Table 1 and 2 indicates, irrigation and moisture regimes brought about variation on accumulation of heat units accumulated for commencement of flowering, attainment of boll opening and maturity stage in cotton. A cursory look at the data in Table 1 indicates that number of heat units accumulated for commencement of flowering increased with increase in moisture and nitrogen level and effect of individual factor was enhanced with the increase in the level of the other. The highest GDD (1492, 2608 and 2926 °C days) and HTU (13831, 20867 and 23319 °C day hour) were accumulated by T_{11} which was at par with T_8 T_9, T_{10} and T_{12} while the lowest GDD (1431, 2530 and 2842 °C days) and HTU (13461, 20300 and 22588 °C day hour) by T_2. Brar and Vashisht (2020) also observed prolonged phenological stages under well watered conditions. Further, treatment T_{11} was at par with C_1 but better than C_2 and C_3 in terms of GDD accumulation up to commencement of flowering. Effect of method of application of KNO_3 and $MgSO_4$ on heat units accumulation up to flowering was not conspicuous. Further, C_1, C_2 and C_3 was at par with each other at all stages in terms of AGDD. Likewise, GDD, HTU accumulation up to flowering stage was not conspicuous, afterwards marked improvement was observed in T_{11} over all other treatments, except T_5 and T_{12}.

In wheat crop, higher GDD (640, 747 and 1621 °C days) and HTU (3071, 3470 and 9646 °C day hour) were acquired by T_{10} which was significantly better than T_1, T_2, T_3, T_4 and T_5 and at par with T_6, T_8 and T_{12} at all stages. Lowest GDD (613, 718 and 1534 °C days) and HTU (3020, 3312 and 8879 °C day hour) were attained by T_3, over other treatments. Dar *et al.*, (2018) also observed decrease in HTU with decreasing level of irrigation in wheat. Further, T_{10}, where residual effect of nutrients applied to cotton was observed, showed marked improvement over C_1 (624 and 730 °C days) and C_3 (618 and 723 °C days) in terms of GDD at jointing and booting stages. Residual effect of zinc in wheat, applied to cotton through soil was observed in cotton-wheat rotation by Paul *et al.* (2016).

Table 1. Accumulated growing degree days and helio-thermal units as influenced by varying irrigation & fertilization regimes at different stages of cotton (pooled data of 2019 and 2020)

Sr. No.	Treatment	Accumulated growing degree days (°C days)			Accumulated helio-thermal units (°C day hour)		
		Flowering	Boll opening	Maturity	Flowering	Boll opening	Maturity
T_1	$I_{60}F_{80}M_{foliar}$	1447	2547	2855	13631	20426	22733
T_2	$I_{60}F_{80}M_{soil}$	1431	2530	2842	13461	20300	22588
T_3	$I_{60}F_{100}M_{foliar}$	1468	2557	2866	13711	20480	22804
T_4	$I_{60}F_{100}M_{soil}$	1456	2539	2847	13703	20362	22614
T_5	$I_{80}F_{80}M_{foliar}$	1486	2591	2907	13810	20716	23164
T_6	$I_{80}F_{80}M_{soil}$	1467	2550	2863	13765	20450	22801
T_7	$I_{80}F_{100}M_{foliar}$	1464	2593	2915	13660	20750	23236
T_8	$I_{80}F_{100}M_{soil}$	1487	2575	2891	13830	20606	23000
T_9	$I_{100}F_{80}M_{foliar}$	1486	2596	2920	13788	20772	23255
T_{10}	$I_{100}F_{80}M_{soil}$	1478	2566	2888	13768	20543	23030
T_{11}	$I_{100}F_{100}M_{foliar}$	1492	2608	2926	13831	20867	23319
T_{12}	$I_{100}F_{100}M_{soil}$	1472	2576	2899	13682	20605	23086
C_1	C_1 (I_{100} through surface drip+ F_{100} + M_{foliar})	1473	2582	2902	13764	20600	23114
C_2	C_2 (I_{100} through surface drip + F_{100} + M_{soil})	1461	2567	2894	13683	20543	23052
C_3	C_3 (I_{100} through flooding + F_{100} through soil + M_{foliar})	1465	2558	2877	13724	20485	22911
	CD (p=0.05)	22.0	26.0	30.0	159	180	264

Accumulated photo-thermal units (APTU) and relative temperature disparity (ARTD)

The PTU and RTD accumulated by different phenophases of cotton and wheat is presented in Table 3 and 4. Well irrigated and fertilized treatments accumulated PTU and RTD values higher than those obtained under deficit irrigated condition in both cotton and wheat. T_{11} accumulated higher photo-thermal units which was at par with T_5, T_7, T_9 and T_{12} at all stages of cotton. Further, T_{11} showed improvement over C_2 and C_3. at all stages of cotton growth. The per cent increase in PTU accumulation of cotton under T_{11} was 1.63, 2.07 and 1.78% over C_3 at flowering, boll opening and maturity, respectively. While, in case of wheat, higher PTU were attained under T_{10} (6628, 7741 and 17898 °C day hour) which was statistically at par with T_6, T_8 and T_{12} at all stages of wheat. Moreover, T_{10} showed pronounced effect over C_1 (6462 and 7768 °C day hour), C_2 (6520 and 7597 °C day hour) and C_3 (6397 and 7552 °C day hour) at jointing and booting stage of wheat. These results were in agreement with Dar *et al*. (2018) who reported increase in PTU values with increase in irrigation level in wheat.

Furthermore, T_{11} (2376, 3525 and 3935) resulted in highest RTD values which was significantly better than C_2 (2355, 3481 and 3891) and C_3 (2347, 3468 and 3854) and at par with T_5, T_7 and T_9 at flowering, boll opening and maturity of cotton. However, in wheat, highest RTD (3071, 3470 and 9646) was observed with T_{10} which was statistically similar with T_6, T_8, T_{12}, C_1 and C_2 at all the stages.

Pheno-thermal index (PTI) and heat use efficiency (HUE)

Variable irrigation and fertilization regimes failed to cause any significant change in pheno-thermal index of cotton at boll opening and maturity (Fig. 1). However, significant difference was observed at flowering stage of cotton. Pheno-thermal index gradually decreased from flowering till maturity due to decline in daily heat consumption towards later stages of cotton. This could be as a result of gradual reduction of day and night temperature towards maturity (Bhuyan and Baruah, 2008). Higher pheno-thermal index in cotton was observed under T_2 (21.49 °C days day^{-1}) which was significantly superior over all treatments except T_1, T_3, T_5 and C_1 at flowering. Further, C_1 & C_2 were statistically

Table 2. **Effect of various irrigation & fertilization regimes on accumulated growing degree days and helio-thermal units at different stages of wheat (pooled data of 2019-2020 and 2020-2021)**

Sr. No.	Treatment	Accumulated growing degree days (°C days)			Accumulated helio-thermal units (°C day hour)		
		Jointing	Booting	Physiological maturity	Jointing	Booting	Physiological maturity
T_1	$I_{60}F_{100}M_{res.\ foliar}$	615	723	1555	3028	3338	9024
T_2	$I_{60}F_{100}M_{res.\ soil}$	624	731	1575	3050	3384	9187
T_3	$I_{60}F_{80}M_{res.\ foliar}$	613	718	1534	3020	3312	8879
T_4	$I_{60}F_{80}M_{res.\ soil}$	617	725	1549	3025	3365	9001
T_5	$I_{80}F_{100}M_{res.\ foliar}$	627	732	1589	3039	3393	9314
T_6	$I_{80}F_{100}M_{res.\ soil}$	635	742	1607	3053	3445	9506
T_7	$I_{80}F_{80}M_{res.\ foliar}$	618	730	1566	3028	3374	9117
T_8	$I_{80}F_{80}M_{res.\ soil}$	633	742	1601	3057	3444	9441
T_9	$I_{100}F_{100}M_{res.\ foliar}$	628	732	1592	3049	3389	9361
T_{10}	$I_{100}F_{100}M_{res.\ soil}$	640	747	1621	3071	3470	9646
T_{11}	$I_{100}F_{80}M_{res.\ foliar}$	624	731	1584	3037	3369	9267
T_{12}	$I_{100}F_{80}M_{res.\ soil}$	637	745	1615	3064	3459	9596
C_1	C_1 (I_{100} through surface drip+ F_{100} + $M_{res.\ foliar}$)	624	730	1600	3042	3388	9418
C_2	C_2 (I_{100} through surface drip + F_{100} + $M_{res.\ soil}$)	629	733	1611	3043	3400	9543
C_3	C_3 (I_{100} through flooding + F_{100} through soil + $M_{res.\ foliar}$)	618	723	1600	3014	3389	9436
	CD (p=0.05)	12.0	9.00	28.0	NS	62.0	269

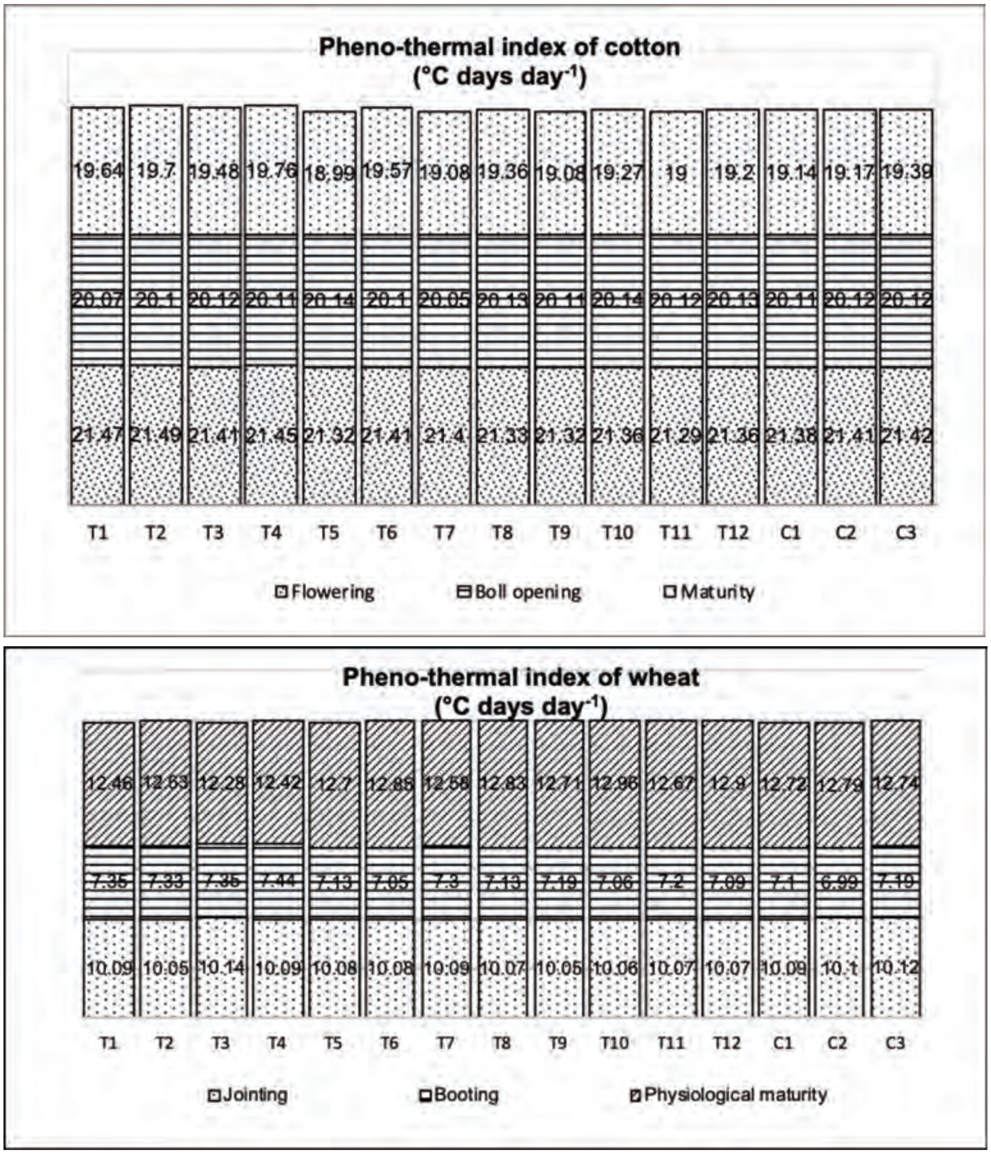

Fig. 1. Pheno-thermal index as influenced by varying irrigation & fertilization regimes at various phenophases of cotton and wheat (pooled data of 2019 and 2020)

at par with C_3. While, in wheat, PTI was significantly higher at physiological maturity than other stages (Fig. 1). However, the differences among various treatments were very minute. Kaur *et al.* (2019) also observed increase in PTI at maturity. Higher PTI was found under T_{10} which was statistically at par with T_6, T_8 and T_{12} and better than C_1, C_2 and C_3.

Further, HUE showed marked improvement in cotton but failed to cause significant change in wheat crop (Table 5). Significant variation in HUE of seed cotton was observed under T_{11} (1.16 kg ha^{-1} °C^{-1} day^{-1}) as compared to T_1, T_2, T_3, T_4 and all three controls i.e. C_1, C_2 and C_3. However, in wheat, the increment in T_{10} was very less as compared to all other treatments. Bisht *et al.* (2019) also reported increase in HUE with increasing irrigation levels in wheat. These findings were also in agreement with Dar *et al.* (2018) who reported lesser values of HUE in wheat under water deficit conditions. Amrawat *et al.* (2013) also observed increase in heat use efficiency of wheat with increase in availability of nutrients.

The observed effect of increasing level of irrigation along with different fertilization regimes on accumulation of more GDD, HTU, PTU, PTI, RTD and HUE at different phenophases, can be explained in terms of growth behavior of cotton crop. As, cotton crop has indeterminate nature of growth, higher moisture content might have resulted in prolonged crop growth. Further, absorption of nutrients from soil is limited by feed organs i.e. root hair, which starts decaying after plants enter into reproductive stage. Moreover, requirement of crop plant at initial stage is less and increases with the advancement in growth stages. Therefore, application of KNO_3 & $MgSO_4$ after flowering, was more conspicuous with the increased availability of nutrients and plant maintained its growth for longer, resulting in accumulation of higher units of GDD, HTU, PTU, PTI, RTD and HUE in cotton. As, KNO_3 contains nitrogen in relation to potassium, crop could retain its greenness for a longer period resulting in continuation of photosynthesis for longer period. Further, heat unit efficiency is calculated by dividing economic yield with GDD. It was found that, heat unit efficiency in cotton was higher under increasing level of irrigation from 60% to 100% along with increasing fertilization regimes.

Agro-climatic models for cotton

Regression analysis was conducted by fitting linear response function between yield and agro-climatic indices. All the relationships were found significant with high R^2 values.

GDD and seed cotton yield $y = -161.2+.066x$, $R^2 = 0.98$

HTU and seed cotton yield $y = -129.2+.007x$, $R^2 = 0.96$

PTU and seed cotton yield $y = -126.7+.004x$, $R^2 = 0.95$

PTI and seed cotton yield $y = 159.1-6.637x$, $R^2 = 0.91$

RTD and seed cotton yield $y = -54.01+.013x$, $R^2 = 0.87$

HUE on yield basis and seed cotton yield $y = -5.74+34.24x$, $R^2 = 0.99$

Agro-climatic models for wheat

GDD and grain yield $y = -21.24+.044x$, $R^2 = 0.87$

HTU and grain yield $y = 2.309+.005x$, $R^2 = 0.89$

PTU and grain yield $y = -3.930+.003x$, $R^2 = 0.75$

PTI and grain yield $y = -25.55+5.931x$, $R^2 = 0.79$

RTD and grain yield $y = -70.71+0.015x$, $R^2 = 0.87$

HUE on yield basis and grain yield $y = -50.72+32.0x$, $R^2 = 0.88$

Where, y is a dependent variable and x is an independent variable. These equations explain 87 to 99% variations in seed cotton yield, While, 75 to 89%

Table 3. Accumulated photo-thermal units and relative temperature disparity as influenced by varying irrigation & fertilization regimes at different stages of cotton (pooled data of 2019 and 2020)

Sr. No.	Treatment	Accumulated photo-thermal units (°C day hour)			Accumulated relative temperature disparity		
		Flowering	Boll opening	Maturity	Flowering	Boll opening	Maturity
T_1	$I_{60}F_{80}M_{foliar}$	20196	35019	38880	2321	3457	3823
T_2	$I_{60}F_{80}M_{soil}$	19950	34768	38677	2322	3435	3800
T_3	$I_{60}F_{100}M_{foliar}$	20489	35156	39027	2346	3466	3843
T_4	$I_{60}F_{100}M_{soil}$	20342	34894	38756	2332	3447	3807
T_5	$I_{80}F_{80}M_{foliar}$	20765	35624	39631	2370	3506	3907
T_6	$I_{80}F_{80}M_{soil}$	20509	35061	38995	2348	3461	3837
T_7	$I_{80}F_{100}M_{foliar}$	20432	35663	39755	2343	3508	3915
T_8	$I_{80}F_{100}M_{soil}$	20760	35403	39383	2372	3488	3877
T_9	$I_{100}F_{80}M_{foliar}$	20767	35706	39821	2369	3511	3928
T_{10}	$I_{100}F_{80}M_{soil}$	20654	35282	39367	2361	3478	3873
T_{11}	$I_{100}F_{100}M_{foliar}$	20774	35881	39905	2376	3525	3935
T_{12}	$I_{100}F_{100}M_{soil}$	20548	35506	39512	2351	3489	3891
C_1	C_1 (I_{100} through surface drip+ F_{100} + M_{foliar})	20576	35400	39561	2355	3481	3891
C_2	C_2 (I_{100} through surface drip + F_{100} + M_{soil})	20392	35284	39429	2342	3478	3882
C_3	C_3 (I_{100} through flooding + F_{100} through soil + M_{foliar})	20442	35153	39203	2347	3468	3854
	CD (p=0.05)	318	363	433	26.0	29.0	47.0

Table 4. Effect of various irrigation & fertilization on photo-thermal units and relative temperature disparity at different stages of wheat (pooled data of 2019-2020 and 2020-2021)

Sr. No.	Treatment	Accumulated photo-thermal units (°C day hour)			Accumulated relative temperature disparity		
		Jointing	Booting	Physiological maturity	Jointing	Booting	Physiological maturity
T_1	$I_{60}F_{100}M_{res.\ foliar}$	6372	7476	17080	3406	4156	7856
T_2	$I_{60}F_{100}M_{res.\ soil}$	6460	7569	17328	3466	4235	7911
T_3	$I_{60}F_{80}M_{res.\ foliar}$	6346	7424	16827	3373	4111	7800
T_4	$I_{60}F_{80}M_{res.\ soil}$	6385	7498	17008	3404	4178	7841
T_5	$I_{80}F_{100}M_{res.\ foliar}$	6487	7585	17499	3451	4242	7953
T_6	$I_{80}F_{100}M_{res.\ soil}$	6572	7686	17722	3481	4328	8009
T_7	$I_{80}F_{80}M_{res.\ foliar}$	6403	7557	17214	3416	4223	7889
T_8	$I_{80}F_{80}M_{res.\ soil}$	6549	7686	17647	3491	4319	7989
T_9	$I_{100}F_{100}M_{res.\ foliar}$	6500	7583	17536	3479	4245	7965
T_{10}	$I_{100}F_{100}M_{res.\ soil}$	6628	7741	17898	3522	4362	8053
T_{11}	$I_{100}F_{80}M_{res.\ foliar}$	6465	7575	17432	3446	4233	7938
T_{12}	$I_{100}F_{80}M_{res.\ soil}$	6599	7718	17820	3482	4339	8037
C_1	C_1 (I_{100} through surface drip+ F_{100} + $M_{res.\ foliar}$)	6462	7568	17640	3449	4235	7991
C_2	C_2 (I_{100} through surface drip + F_{100} + $M_{res.\ soil}$)	6520	7597	17778	3462	4258	8029
C_3	C_3 (I_{100} through flooding + F_{100} through soil + $M_{res.\ foliar}$)	6397	7552	17638	3409	4258	7991
	CD (p=0.05)	118	92.0	341	74.0	80.0	85.0

Table 5. Heat unit efficiency on seed cotton and wheat grain yield basis as influenced by varying irrigation & fertilization regimes (pooled data of 2019 and 2020)

Sr. No.	Treatment	Heat use efficiency (kg ha^{-1} $°C^{-1}$ day^{-1})	
		Seed cotton yield	Wheat grain yield
T_1	$I_{60}F_{80}M_{foliar}$	1.00	3.08
T_2	$I_{60}F_{80}M_{soil}$	0.99	3.10
T_3	$I_{60}F_{100}M_{foliar}$	1.03	3.06
T_4	$I_{60}F_{100}M_{soil}$	0.99	3.13
T_5	$I_{80}F_{80}M_{foliar}$	1.11	3.12
T_6	$I_{80}F_{80}M_{soil}$	1.02	3.13
T_7	$I_{80}F_{100}M_{foliar}$	1.12	3.16
T_8	$I_{80}F_{100}M_{soil}$	1.07	3.13
T_9	$I_{100}F_{80}M_{foliar}$	1.15	3.18
T_{10}	$I_{100}F_{80}M_{soil}$	1.06	3.19
T_{11}	$I_{100}F_{100}M_{foliar}$	1.16	3.17
T_{12}	$I_{100}F_{100}M_{soil}$	1.09	3.18
C_1	C_1 (I_{100} through surface drip+ F_{100} + M_{foliar})	1.10	3.13
C_2	C_2 (I_{100} through surface drip + F_{100} + M_{soil})	1.08	3.14
C_3	C_3 (I_{100} through flooding + F_{100} through soil + M_{foliar})	1.02	3.04
	CD (p=0.05)	0.05	NS

variation in wheat grain yield.

Based on the study, it may be concluded that the knowledge of agrometeorological indices and their relationship with yield is crucial for improving crop productivity and improving management practices. Both cotton and wheat used more heat units for attaining different phenological stages till maturity, with gradual increase in irrigation from 60% ET_c to 100% ET_c along with fertilization regimes. GDD, HTU, PTU and RTD were higher under $I_{100}F_{100}M_{foliar}$ (T_{11}), with progressively increase in availability of water and nutrients throughout the crop growing season. Increase in heat use efficiency was also found with increasing irrigation scheduling from 60% to 100% ET_c along with 100% RDN and foliar application of nutrients. This indicates that judicious use of production inputs such as moisture and fertilizer can improve utilization of solar energy for crop productivity enhancement.

Authors' contribution

Conceptualization of research work and designing of experiments (AS,PKS); Execution of field/lab experiments and data collection (TK,PKK); Analysis of data and interpretation (TK,PKS); Preparation of manuscript (TK,PKK).

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LITERATURE CITED

Aggarwal N, Singh N and Singh S P 2016. Heat utilization and radiation interception in transplanted rice (*Oryza sativa*) in relation to seedling stage. *J Agrometeorol* **18**: 93-96.

Amrawat T, Solanki N S, Sharma S K, Jajoria D K and Dotaniya M L 2013. Phenology growth and yield of wheat in relation to agro-meteorological indices under different sowing dates. *African J Agric Res* **8:** 6366-74.

Bal S K, Mukherjee J, Choudhury B U and Dhawan A K (eds) 2018. Advances in Crop Environment Interaction, Springer Nature Singapore Pte Ltd. 450p.

Bisht H, Singh D K, Singh S, Mishra A K, Sarangi A, Prajapati V K, Singh M and Krishnan P 2019. Heat unit requirement of wheat (*Triticum aestivum* L.) under different thermal and moisture regimes. *J Agrometeorol* **21**: 36-41.

Brar H S, Kumar D and Singh P 2020. Dataset of source-sink manipulation through growth retardant for enhancing productivity and profitability of cotton in north-west, India. *Data in Brief* 31: 105914. doi:10.1016/j. dib.2020.105914.

Brar H S and Vashist K K 2020. Drip irrigation and nitrogen fertilization alter phenological development and yield of spring maize (*Zea mays* L.) under semi- arid conditions. *J Plant Nutr* **43**: 1757-67.

Cochran W G and Cox G M (1967) Experimental Designs. Johns Wiley Publishers, New York.

Dar E A, Brar A S and Yousuf A 2018. Growing degree days and heat use efficiency of wheat as influenced by thermal and moisture regimes. *J Agrometeorol* **20**: 168-70.

Gupta M, Sharma C, Sharma R, Gupta V and Khushu M K 2017. Effect of sowing time on productivity and thermal utilization of mustard (*Brassica juncea*) under sub-tropical irrigated conditions of Jammu. *J Agrometeorol* **19**: 137-41.

Hakim M A, Hossain A, Teixeira da Silva J A, Zvolinsky V P and Khan M M 2012. Yield, protein and starch content of 20 wheat (*Triticum aestivum* L.) genotypes exposed to high temperature under late sowing conditions. *J Sci Res* **4**: 477-489.

Ihsan M Z, El-Nakhlawy F S, Ismail S M, Fahad Sand Daur I 2016. Wheat phenological development and growth studies as affected by drought and late season high temperature stress under arid environment. *Front Plant Sci* **7**: 1-14.

Kaur J, Ram H and Pal Singh S 2019. Productivity, phenology and heat accumulation of wheat as influenced by nitrogen management using green seeker. *J Crop Weed* **15**: 24-28.

Kumar R, Ramesh K, Singh R D and Prasad R 2010. Modulation of wild marigold phenophasestowards the varying temperature regimes - "A field study". *J Agrometeorol* **12**: 234-240.

Kumar S N, Aggarwal P K, Rani D S, Saxena R, Chauhan N and Jain S 2014. Vulnerability of wheat production to climate change in India. *Climate Res* **59**: 173-87.

Neog P, Bhuyan J and Baruah N 2008. Thermal indices in relation to crop phenology and seed yield of soybean (*Glycine max* L.). *J Agrometeorol* **10**: 388-92.

Nuttonson M Y 1955. *Wheat climatic relationship and use of phenology in ascertaining the thermal and photothermal requirements of wheat.* The American Institute of Crop Eclogy,Washington D.C., 388p.

Paul T, Rana D S, Chaudhary A K, Das T K and Rajpoot S K 2016. Crop establishment methods and Zn nutrition in *Bt*-cotton: Direct effects on system productivity,economic-efficiency and water-productivity in *Bt* cotton- wheat cropping system and their residual effects on yield and Zn biofortification in wheat. *Indian J Agric Sci* **86**: 1406-12.

Ram H, Singh G, Mavi G S and Sofia V S 2012. Accumulated heat unit requirement and yield of irrigated wheat (*Triticum aestivum* L.) varieties under different crop growing environment in central Punjab. *J Agrometeorol* **14**: 147-153.

Wrona A F, Banks J C, Hake K, Lege K, Patterson M B, Roberts C E, Snipes and Supak J 1996. Achieving a clean finish. *Cotton Physiol* **7**: 25-30.