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Estimating wheat productivity for north western plain zone of India in relation to spatial-thermal variation

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ABSTRACT

The study aimed at quantifying the interaction of exposure of wheat to high thermal stress for a specific duration during the reproductive stage with yield over north western plain zones of India. Thermal stress duration of at least of continuous five days, where average daily temperature positively depart by ≥ 2 ^{0}C above long term normal were correlated with annual wheat yield, for two phenological stages, viz. late vegetative and reproductive, under the most ideal location, i.e. Ludhiana, and were extended to estimate yield in other locations through introduction of a thermal response factor. In the reproductive stage a 10 per cent reduction from the average yield was expected in 10 days of thermal stress for Hisar, 13 days for Karnal and 15 days for Kanpur if exposed to average stress temperature departure of above normal (4.20, 3.63 and 3.54 ^{0}C, respectively). Findings suggested that the locations with relatively cooler thermal regimes experience proportionately higher yield loss compared to relatively warmer places for same amount of thermal stress exposure. Besides, achievable wheat production in India may be limited by 1.170 to 2.392 million tonnes every year, if climate change scenarios are taken in to consideration. This simple procedure may be useful in estimating wheat yield in relation to spatially variable atmospheric thermal regime in spite of complexities and uncertainties involved in actual farm productions.

Key words: Climate change, response factor, thermal stress, variability, wheat

Production of rice, wheat and maize in the past few decades have followed declining trend in many parts of Asia, including India, due to many reasons including increase in water stress, arising partly from increasing temperature, increasing frequency of El Niño events and reduction in the number of rainy days. Agriculture, in general, faces serious threats from climatic aberrations under climate change apart from ever deteriorating soil fertility, erosion and other related issues (Aggarwal *et al.*, 2000). The North West Plain Zone (NWPZ), consisting of Punjab, Haryana, western Uttar Pradesh and Rajasthan, is the most productive wheat belt in India contributing 70-75 per cent of total annual wheat production in India. In spite of assured irrigation and other management supports, a large variability in wheat yield has been observed across this region, where, the average yield is 4.2 t ha^{-1} at Punjab, 3.9 t ha^{-1} at Haryana and 2.7 t ha^{-1} at Uttar Pradesh. Again, the growth of yield show a negative trend by (–) 1.9 and (–) 0.9 per cent in Punjab and Haryana, respectively, during 2001-2006 (Sant Kumar, 2009).

Degradation of soil fertility with continuous rotation of rice-wheat in NWPZ, problems of drainage and soil salinity, delayed sowing due to late harvesting of the preceding crop, poor crop stand, weeds and diseases are some of the major abiotic and biotic factors inflicting wheat yield loss by 0.10 to 0.23 t ha^{-1} in rice-wheat and cotton-wheat systems across the NWPZ (DWR, 2002) apart from the impact of climatic variability with in climate change scenario. In recent years, prevalence of high thermal regime during winter has become a major concern as it is expected to cause adverse affects in wheat. Rise of minimum temperature by an average of 1.5 ^{0}C at many places of Indo-Gangatic plains has been reported (Sinha *et al*., 1998). At Ludhiana, the minimum and average temperatures found increasing significantly at the rates of 0.06 and 0.03 ^{0}C year^{-1}, respectively, and during the last 32 years the minimum temperature did increase by 1.9 ^{0}C (Pathak and Wassmann, 2009). The yield loss of wheat in India, due to rising temperature, has been projected as 4-5 million tonnes per year with every degree rise of temperature through out the growing period even after considering the benefits of carbon fertilization (Aggarwal, 2007). In North Indian wheat belt, a simulation study has observed significant impact of the average temperature on potential yield of wheat where an increase of temperature by 2 ^{0}C has reduced potential yield in many places (Aggarwal and Sinha, 1993).

Temperature has a differential effect on vegetative and reproductive phases of wheat growth. The sensitivity to high temperature during vegetative phase is expressed as a decreased duration of vegetative stage and reduced leaf area and growth (Shpiler and Blum, 1986), a reduction in total number of leaves and spike-bearing tillers (Midmore *et al.*, 1984). The reproductive stage is critical in setting the extent to which the grain yield potential is realized. While a decrease in minimum temperature increases the crop duration and yield, an increase in minimum temperature increases night respiration contributing toward a decline in yield (Matthews *et al.*, 1995). The main effect of heat stress after floral initiation is observed on number of kernels. The number of kernels per unit area decreases at a rate of 4 per cent for each degree increase in average temperature during the 30 days preceding anthesis (Fischer, 1985).

The information on interaction of intensity and duration of thermal stress and wheat yield is limited and important to understand the process to stabilize productivity. This present study is aimed at quantifying the interaction of intensity and exposure to thermal stress for a specific duration, during wheat reproductive stage with yield. Here, it is aimed to specifically quantify the spatial impact of high temperature on the wheat productivity to assist strategic planning.

MATERIALS AND METHODS

The study area

Four major wheat growing locations were selected for the study, *viz.*, Ludhiana (Punjab), Hisar and Karnal (Haryana) and Kanpur (Uttar Pradesh) where wheat is normally sown almost simultaneously around mid-November and the crop duration extends up to 150 days between 46^{th} and 15^{th} standard meteorological weeks. The locations are part of fertile Indo-Gangetic plains with assured irrigation and hence, the uncertainties associated with rainfall are not a major limiting factor in wheat production in these areas (Table 1). Data pertaining to district level annual wheat area and yield for different locations were collected from Centre for Monitoring Indian Economy (CMIE), New Delhi, India from 1971-1972 to 2004-2005. Daily climatic data for the wheat growing period was collected from the Agrometeorological Data Bank maintained at Central Research Institute for Dryland Agriculture, Hyderabad for the same periods. Among the places, Ludhiana represents the highest productivity level of wheat with lowest average maximum temperature (24.9 ^{0}C) between 46^{th} to 15^{th} SMWs. Though minimum temperature does not indicate any particular trend, the difference in maximum temperature between Ludhiana and Kanpur is 3 ^{0}C and impact of it was reflected on the yield difference of about 1500 kg ha^{-1}. The average yield found decreased by about 497 kg ha^{-1} with every unit increase of average temperature in a range of 17.5 ^{0}C at Ludhiana to 20.4 ^{0}C at Kanpur during the wheat season. Ludhiana also receives highest rainfall (142.6 mm) during the wheat season due to intense western disturbance activities.

Phenological stages of wheat

As sowing and harvesting of wheat for different locations are done almost in the same time, the phenological developments for commonly grown wheat varieties in the region, more or less, coincides (Table 2). Late vegetative (from 1^{st} January to start of heading) and reproductive (from start of heading to reaching of dough stage) were the two stages to which the analysis was confined.

Selection of temperature stressed periods

In this study, following findings of Aggarwal and Sinha (1993), thermal stress was defined as the total duration of at least continuous 5 days, where average daily temperature positively departed by ≥ 2 ^{0}C above long term normal which could cause certain amount of yield loss in wheat. Positive departure of temperature had been considered in place of their absolute values assuming that impact due to high maximum or minimum temperature, on yield, would be identical. For this purpose, climatic and yield data from 1984-1985 onward only was considered owing to fact that majority of wheat area in NWPZ was brought under irrigation from that period.

The maximum and minimum temperatures for (a) 1^{st} January to 18^{th} February and (b) 19^{th} February to 18^{th} March, corresponding to late vegetative and reproductive stage, respectively, were screened out on yearly basis to identify the stress durations. If both maximum and minimum temperatures showed similar trend of thermal stress in any year, in that case, the one with comparatively higher departure and longer duration was taken in to consideration. One or two days of break within a long spell of above normal high temperature was considered part of the total stress period assuming such short period might not nullify the negative impacts already set in motion.

Development of thermal stress-yield relationships and response factor

Ludhiana represented most ideal condition for wheat among all the locations because of low temperature regime and highest productivity, and hence thermal stress-yield relationships were developed for both late vegetative and reproductive growth stages for it. The relationships were extended to other locations through introduction of a 'response factor' (RF), which took care of the spatial wheat yield variability due to combined effect of temperature stress (T) and corresponding spell of the stress period (D). The response factor (RF) was expressed as the ratio between the difference in average wheat yield between Ludhiana and a given location to the average yield at Ludhiana due

Table 1: Average climatic condition during wheat season (46th to 15th SMW), acreage and yield of wheat from 1971-1972 to 2005-2006 at different locations in this study

Parameters	Locations			
	Ludhiana	Karnal*	Hisar	Kanpur
Latitude (N)/ Longitude (E)	30.9/75.8	29.4/77.0	29.1/75.7	26.4/80.3
Average max. temperature (°C)	24.9	25.4	26.7	27.9
Average min. temperature (°C)	10.1	10.8	9.5	12.8
Average temperature (°C)	17.5	18.1	18.1	20.3
Average rainfall (mm)	142.6	125.8	63.5	60.4
Rate of change of max. temperature (°C $annum^{-1}$)	0.02	-0.009	-0.007	0.026
Rate of change of min. temperature (°C $annum^{-1}$)	0.07	0.004	0.002	-0.027
Net area under wheat (000 ha)	260	187	210	186
Irrigated area under wheat (000 ha)	260	181	201	153
Yield (kg ha^{-1})**	4325	3831	3829	2830

* Data ranged from 1972-1973 to 2004-2005; ** Averaged from 1984-1985 to 2004-2005

to combined effect of thermal stress (T x D). The RF was a unit less parameter. For all other locations yearly wheat yield estimate were made through incorporation of the RF in the original equations and comparison with the actual yield were done to assess their spatial suitability. The spatial applicability of the procedure to estimate wheat yield was validated following standard statistical procedures, viz., Kolmogorov-Smirnov test of normality of errors and root mean square error (RMSE).

RESULTS AND DISCUSSION

Trend of temperature

Temperature exhibited a mixed trend with respect to both location and phenological stages (Table 3). At the late vegetative stage, between 1st January and 18th February, an annual rate of increase of minimum temperature by 0.02 ^{0}C was observed at Ludhiana. But in other locations both the maximum and minimum temperatures showed a decreasing trend. The rate of decrease of maximum temperature was more noticeable and ranging from 0.09 ^{0}C per annum at Kanpur to 0.15 ^{0}C per annum at Hisar. Same trend of decreasing temperature was also observed between 28th February and 8th March corresponding to the anthesis to milking stage in all the locations. Increase of maximum temperature was observed in two most important phases of reproductive stage i.e. from heading to anthesis and milking to dough. Kanpur experienced an annual rise of maximum temperature of 0.12 ^{0}C between 19th and 27th February. The rate of increase of maximum temperature, between 9th and 18th March, was highest at Ludhiana with 0.10 ^{0}C per annum. Rise of minimum temperature is of concern during heading to anthesis stage at Ludhiana, where it was increasing at the rate of 0.08 ^{0}C per annum. In rest of the locations minimum temperature showed a general decreasing trend.

Temperature stress periods and yield

Average daily positive temperature departure, from long term normal, in both the stages in various locations ranged between 2.74 and 4.20 ^{0}C (Table 4). Range of stress duration was more at reproductive stage (9.94 to 12.4 days) than at late vegetative stage (12.9 to 14.7 days). Out of 21 years, (1984-1985 to 2004-2005), Wheat at Ludhiana experienced thermal stress in total 17 years in each of the phenological stages. At Karnal, lowest stress period of 12.9 days duration was observed with an average temperature departure of 2.74 ^{0}C in the late vegetative stage. Highest average temperature departure of 4.20 ^{0}C was observed at Hisar with an average 11.9 days exposure at the reproductive stage. Wheat at the reproductive stages was exposed to lowest duration of stress period at Ludhiana followed by Hisar, Kanpur and Karnal. The study to evaluate combined effect of positive temperature departure and stress duration (T x D) on yield did reveal that the effect was comparatively more pronounced in the late vegetative stage (44.15 ^{0}C-days) than at the reproductive stage (42.20 ^{0}C-days). The (T x D) magnitudes of 35.35, 47.78 and 46.28 might have caused average negative yield difference of 493, 496 and 1355 kg ha^{-1} at Karnal, Hisar and Kanpur, respectively, when compared with Ludhiana.

The yield and thermal stress data between 1984-1985 and 2003-2004 (late vegetative) and 1984-1985 and 2004-2005 (reproductive stage) for Ludhiana were used to quantify 'yield-temperature departure-stress duration' relationships.

Table 2: Phenological stages of wheat with their period of occurrence

Phenological stages	Between Dates	Between Julian Days	Between SMW's	Days required
Vegetative				
Emergence to CRI	15th November – 4th December	319-338	46-49	20
CRI to Heading	5th December - 18th February	339-49	49-8	75
Reproductive				
Heading to Anthesis	19th February – 27th February	50-58	8-9	9
Anthesis to Milking	28th February – 8th March	59-68	9-10	9
Milking to Dough	9th March – 18th March	69-78	10-11	10
Dough to Physiological Maturity	19th March – 15th April	79-106	12-15	28
Total Duration	15th November – 15th April	319-106	46-15	151

SMW represents Standard Meteorological Week; CRI stands for Crown Root Initiation

Table 3: Rate of change of temperature at various phenological stages for different locations between 1971-1972 and 2005-2006

Phenological stages	Rate of change of maximum/minimum temperature (^0C annum^{-1})			
	Ludhiana	Karnal	Hisar	Kanpur
Late Vegetative				
1st January to Heading (1st January – 18th February)	-0.11/0.02	-0.13/-0.03	-0.15/-0.05	-0.09/-0.15
Reproductive				
Heading to Anthesis (19th February – 27th February)	0.03/0.08	0.04/-0.01	0.04/0.03	0.12/-0.01
Anthesis to Milking (28th February – 8th March)	-0.10/-0.04	-0.08/-0.05	-0.13/-0.07	-0.01/-0.10
Milking to Dough (9th March – 18th March)	0.10/-0.02	0.01/-0.06	0.01/-0.15	0.002/-0.10

Normal date of sowing: 15th November

Highest yield of wheat was recorded in three consecutive years, viz., 2000-2001 (5066 kg ha^{-1}), 2001-2002 (5170 kg ha^{-1}) and 2002-2003 (5074 kg ha^{-1}), where no thermal stress periods was detected in any of the stages. In the late vegetative stage the average stress temperature departure was ranging from 2.01 (1985-1986) to 5.70 ^{0}C (1991-1992) and the duration was from 33 days (1984-1985) to no stress in three years between 2000-2001 and 2002-2003. Similarly, in the reproductive stage, in 1984-1985 highest temperature departure (4.57 ^{0}C) and stress duration (23 days) were observed. Wheat growth in 1984-1985 was subjected to altogether 56 days of thermal stress in both the thermally sensitive phenological stages and recorded the lowest yield of 3350 kg ha^{-1}. The multiple regression equations to estimate wheat yield based on thermal stress for Ludhiana are given as below:

(a) Late vegetative stage (1st January to 18th February)

$$Y = 4910.506 - (41.438X_1) - (41.411X_2) \text{ ——— } (1)$$

($R^2 = 0.574^{**}$, d. f. = 18)

(b) Reproductive stage (19th February to 18th March)

$$Y = 5045.532 - (117.026\ X_1) - (43.919X_2) \text{ ——— } (2)$$

($R^2 = 0.626^{**}$, d. f. = 18)

In both the relationships, Y is the estimated yield (kg ha^{-1}), X_1 (^{0}C) is the temperature departure above average by ≥ 2 ^{0}C for any continuous duration X_2 (days, ≥ 5). The factors X_1 and X_2 were found to influence yield by equal magnitude at the late vegetative stage but at the reproductive stage the influence of X_1 had magnified by almost three folds over the

Table 4: Average positive temperature departure of > 2 ^{0}C, above long term normal, and their durations during late vegetative and reproductive stages of wheat at different locations between 1984-1985 and 2004-2005

Locations	Late vegetative stage			Reproductive stage			Yield (kg ha^{-1})	Difference in yield compared to Ludhiana due to effect of (T x D) (kg ha^{-1})
	Average temperature departure (^{0}C) (T)	Average stress duration (days) (D)	Combined effect of temperature and duration (^{0}C-days) (T x D)	Average temperature departure (^{0}C) (T)	Average stress duration (days) (D)	Combined effect of temperature and duration (T x D)		
Ludhiana	3.63 (17)	13.0	47.19	3.24 (17)	9.94	32.21	4325	---
Hisar	3.25 (10)	14.7	47.78	4.20 (12)	11.9	49.98	3829	-496
Karnal	2.74 (18)	12.9	35.35	3.53 (16)	12.4	43.77	3832	-493
Kanpur	3.17 (17)	14.6	46.28	3.54 (14)	12.1	42.83	2970	-1355

Values in parentheses represent the total number of years where average temperature departure exceeds by 2 ^{0}C in at least 5 continuous days between 1984-85 and 2004-05.

Table 5: Response factors derived as a function of combined effect of temperature departure (T) and stress duration (D) at late vegetative and reproductive stages of wheat

Combined effect of (T x D) (^{0}C-days)	Response factor	
	Late vegetative stage	Reproductive stage
1.0	0.004	0.004
10	0.041	0.043
20	0.082	0.086
30	0.123	0.128
40	0.164	0.171
50	0.205	0.214
60	0.245	0.257
70	0.286	0.300
80	0.327	0.342
90	0.368	0.385
100	0.409	0.428
Standard equations	Y = 0.0041x	Y = 0.0043x

Y represents Response factor, x represents magnitude of (T x D)

second factor. Both the relationships were highly significant (at **1% probability level) statistically.

Response factor and wheat yield estimation

The changes in average yield of wheat due to unit change in combined effect of thermal stress (T x D) were 17.7 and 18.5 kg ha^{-1} for late vegetative and reproductive stages, respectively (Table 4). Response factors were calculated for different magnitudes of (T x D) (Table 5). The response factor, in general, during the reproductive stage was comparatively higher in magnitude than the late vegetative stage.

Table 6: Kolmogorov-Smirnov test of normality of errors (obtained by subtracting estimated yield values from observed values) and RMSE determined for estimated wheat yields.

Locations	Crop stage	Statistic	P (P<0.05)	RMSE (kg ha^{-1})
Hisar	Late Vegetative	0.162	0.200	285.9
	Reproductive	0.185	0.145	448.7
Karnal	Late Vegetative	0.138	0.200	228.1
	Reproductive	0.222	0.107	412.8
Kanpur	Late Vegetative	0.190	0.103	401.6
	Reproductive	0.243	0.049	268.4

Wheat yield was estimated for Hisar, Karnal and Kanpur by introducing the response factor in to the original equations. For that purpose, the original yield estimate, for any given location and year, obtained from the equations was multiplied with the response factor and the resultant value was deducted from the original yield estimate. The findings of the Kolmogorov-Smirnov test analysis suggest that the errors (difference between observed and estimated yield) were normally distributed. This has confirmed the suitability of the equations, which were originally trained for Ludhiana, and can effectively be used to estimate wheat yield in other areas of NWPZ with inclusion of thermal stress based response factor. The low RMSE values also support the methodology that was developed (Table 6).

Following reverse calculation procedure computations was made for the minimum stress exposure requirement to

Table 7: Minimum exposure to thermal stress required to have 10 per cent yield reduction from the average observed yield at different locations.

Locations	Average observed yield for the stressed years (kg ha^{-1})	Average stress temperature experienced (°C)	Estimated stress exposure required to have 10 per cent yield reduction compared to average observed values (days)
Late vegetative stage			
Hisar	3806	3.25	14
Karnal	3652	2.74	17
Kanpur	2889	3.17	17
Reproductive stage			
Hisar	3792	4.20	10
Karnal	3650	3.53	13
Kanpur	2716	3.54	15

Table 8: Impact on wheat production and productivity due to change in thermal regime: *Scenario A*: Current condition of thermal stress would prevail in future; *Scenario B*: The exposure to thermal stress will increase by average 5 days (current + 5) in future

Scenario A: Current condition of thermal stress would prevail in future						
Locations	Average stress temperature currently experienced (°C)	Average stress duration currently experienced (days)	Average present yield (kg ha^{-1})	Estimated yield with current set of thermal stress (kg ha^{-1})	Yield limitation (kg ha^{-1})	Relative Yield limitation (%)
Ludhiana	3.24	9.94	4325	3797	-528	-12.21
Hisar	4.20	11.90	3829	3353	-476	-12.43
Karnal	3.53	12.40	3831	3486	-345	-9.01
Kanpur	3.54	12.10	2830	Not affected		
Average					-450	-11.22
Current loss of total wheat production in India due to exposure to thermal stress in reproductive stage: 11,70,000 kg ≈ 1.170 million tonnes (Assuming, wheat area sown in India = 26 million ha)						

Scenario B: The exposure to thermal stress would increase by average 5 days (current + 5) in future						
Locations	Average stress temperature currently experienced (°C)	Projected stress duration (days)	Average present yield (kg ha^{-1})	Estimated yield with projected set of thermal stress (kg ha^{-1})	Yield limitation (kg ha^{-1})	Relative yield limitation (%)
Ludhiana	3.24	14.94	4325	3326	-999	-23.10
Hisar	4.20	16.90	3829	2866	-963	-25.15
Karnal	3.53	17.40	3831	3033	-798	-20.83
Kanpur	3.54	17.10	2830	Not affected		
Average					-920	-23.03
Projected loss of total wheat production in India due to exposure to thermal stress in reproductive stage: 23,92,000 kg ≈ 2.392 million tonnes (Assuming, wheat area sown in India = 26 million ha)						

have a 10 per cent yield reduction from the average observed yield for the stressed years, for which yield estimation was done (Table 7). The duration was ranging from 14 days in Hisar to 17 days each in Karnal and Kanpur in the late vegetative stage. In the reproductive stage same amount of yield reduction could be seen in 10 days at Hisar, 13 days at Karnal and 15 days at Kanpur. This implies that reproductive stage is more sensitive to exposure to high thermal stress than late vegetative stage and identical magnitude of stress exposure might cause yield reduction at a higher proportion in locations with relatively cooler thermal regimes.

Following the same principle suggested here, a general impact on wheat production and productivity in India due to change in thermal regime has been explored using two different kinds of scenario. In 'Scenario A' it was assumed that the current condition of thermal stress would prevail and in 'Scenario B' the exposure to thermal stress would be increased by average 5 days (current + 5) in future. Aggarwal (2007) projected average loss of wheat production in India would be 4-5 million tonnes with every degree increase in temperature in its entire growth period. In our projection, we would present the impact in terms of 'limitation to achieve the potential yield due to rise in temperature' rather than reduction of yield from the current position (Table 8).

Projected increase in temperature as suggested by Inter Governmental Panel on Climate Change (IPCC), at the end of 21^{st} century, is likely to be in the range of 2 to 4.5 ^{0}C with a best estimate of about 3 ^{0}C, and is very unlikely to be less than 1.5 ^{0}C (IPCC, 2007). From this analysis it was seen that wheat, in its reproductive stage, already started experiencing the elevated temperature of around 3 ^{0}C at different locations with varied exposure. At this present condition (Scenario A), achieving the potential yield has been limited in a larger proportion in locations with cooler thermal regime than comparatively warmer locations. This way, the total wheat production in India at the current level is limited by 1.170 million tonnes every year due to exposure to stress temperature in the reproductive stage.

Considering 'Scenario B', the gap between actual average yield and achievable potential yield might increase further. The gap may increase from current -11.22 per cent in 'Scenario A' to -23.03 per cent in 'Scenario B' leading to average yield gap of 2.392 million tonnes every year. In both the scenarios the average area sown under wheat has been considered as 26 million ha and this is based on the average wheat area sown in India between 2002-2003 and 2006-2007. Besides, the places already exposed to high degree of thermal stress, eg. Kanpur, may likely to respond in a lesser magnitude in terms of change in wheat production and productivity.

CONCLUSION

High temperature stress is of major concern for wheat production in entire NWPZ of India. Among different locations, Ludhiana represents best environmental condition for wheat production. But positive growth rate of both maximum and minimum temperatures at an alarming rate of 0.02 and 0.07 ^{0}C per annum, respectively, may cause decrease in productivity in the coming years. This might be due to affect of high temperature on either sub-normal or abnormal physiological mechanism of fruit setting and its development. Heat stress starting from anthesis mainly affects assimilate availability, translocation of photosynthates to the grain starch synthesis and its deposition on the developing grain. This may lead to lower kernel weight. Acevedo *et al.* (1991) reported an average reduction of 4 per cent in grain weight per degree increase in average temperature during grain filling. The 'heading to anthesis' (19 to 27 February) stage is of primary concern as of now, as it coincides with important grain filling period and subjected to maximum risk of temperature stress in most of the locations. Hastened senescence, on the other hand, reduces assimilate supply to the grain. This is how climate sets the limit to the productivity of crops.

Spatial and temporal variations in climate directly affect the economic and environmental performances of agricultural systems in a region. Quantification of the spatial impact of climate on crop productivity could effectively assist the strategic planning of crop layout at a regional level. Assessment of the potential value of seasonal climate forecasts spatially helps to understand to what extent climate risk can be managed and whether responsive management strategies to be developed? A better understanding of how regional wheat productivity is influenced by the spatial variation of climate and how much value, seasonal forecasts can potentially add to management practices and these could contribute to future planning and development of cropping and management strategies. However, the complex interactions between agricultural systems make it difficult to assess the impact of individual factors (Enli *et al*., 2009).

The approach that now formulated from this study is an empirical one but essence of generalization has been imparted through introduction of thermal stress based response factor to the original equations for extending their applicability to other areas instead of developing individual set of equations for each location. As the method is not process based the influence of stress on yield at the late vegetative stage cannot be brought forward to the reproductive stage. Still, the method has the potentiality to be used as a handy yield estimation tool, where the observed yield is likely to fall close to the probabilistic yield values obtained from two sets of relationship.

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