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Effects of dates of sowing on phenology, thermal and radiation regimes, and yield of wheat*

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ABSTRACT

To assess the effects of thermal and radiation regimes on wheat, a field experiment consisting of five dates of sowing starting from 20 November at weekly interval, was conducted. The crop sown on 20 November needed 113 days to attain maturity and with delay in sowing dates, maturity durations decreased upto 91 days in 18 December sown crop. The highest thermal and radiation regimes of 2095^{o}C day for GDD, 15515^{o}C day h for HTU, 31880^{o}C day h for PTU and 2140 mmol m^{-2} for PAR were associated with maximum yield from crop sown on 20 November. 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. Accumulated GDD during vegetative, entire growth period and grain filling period registered significant positive correlation with grain yield. Accumulated HTU, PTU, global radiation and PAR, prevailing during reproductive and grain filling phases, showed significant negative association with grain yield. Because of higher values of HUE, HTUE, PTUE, RAUE and PARUE, in terms of grain yield, amounting to 0.1614 g m^{-2} GDD, 0.0219 g m^{-2} HTU, 0.0104 g m^{-2} PTU, 0.2220 g MJ^{-1} and 0.1599 g $mmol^{-1}$, respectively, the 20 November sown crop was adjudged as the optimum time of sowing. R^2 of regression models was significant at 1% level, accounting for 97 to 99% variation in total grain yield.

Key words : GDD, PAR, phenology, wheat, yield and yield attributes

The average productivity of wheat in the state of West Bengal is lower than the average yield of India. Climatic factors responsible for lower productivity of wheat in West Bengal are short and mild winter, higher temperature and soil moisture regimes during seedling phase accelerating infestation of *Sclerotium rolfsii* and cut worms causing poor stand establishment of crops sown early, and higher temperatures during vegetative and ripening phases depressing tillering, accelerating heading and adversely affecting grain yield. So, higher productivity of wheat when grown, with adequate monetary inputs, is dependent upon adjustment with optimum thermal and radiation environment. The concept of thermal and radiation use efficiency has been used by several workers to compare the performance of different varieties, or of serial dates of sowing in different environments. Although such works have been done elsewhere (Rajput *et al*., 1987; Rao *et al*., 1999; Aggarwal *et al*., 1999), it has not hitherto been reported from West Bengal. Hence, the present investigation was undertaken to determine the optimum time of sowing of wheat based on the concept of thermal and radiation use efficiency.

MATERIALS AND METHODS

Field experiment with wheat was conducted during the winter season of 2008-09 in the Instructional Farm of the Bidhan Chandra Krishi Viswavidyalaya located at Mohanpur (Latitude : 22°56´N, Longitude : 88°32´E; Altitude : 9.75 m a. m. s. l.) in rice-based cropping system. Experimental treatments consisted of five dates of sowing of wheat viz., 20 November, 27 November, four December, 11 December and 18 December, designed in randomized block with four replications. All the crops were grown with package of practices recommended for the place. The variety grown was 'UP-262'. Phenological events like emergence, crown root initiation (CRI), panicle initiation (PI), heading, 1st anthesis, 50% anthesis, 100% anthesis and physiological maturity (PM) were recorded by visiting the field at two days interval. Daily weather data comprising maximum and minimum temperatures, sunshine hours, global radiation (GR) and photosynthetically active radiation (PAR) were collected from nearby automatic weather station situated in the same farm. PAR values, which were originally recorded in µmol m^{-2} s^{-1}, were converted into mmol m^{-2} for the sake of convenience in presentation. Growing degree day (GDD), calculated from mean temperature above base temperature of 5^{o}C, photo thermal unit (PTU), product of GDD and maximum possible sun shine hours and helio thermal unit (HTU), product of GDD and actual measured sun shine hours by Campbell-Stokes sunshine recorder, were calculated following the methods given by Sastry and Chakravarty

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(1982) and Sahu *et al.* (2007). Heat use efficiency (HUE), which is a measure of amount of dry matter or grain yield produced per unit of GDD was determined. On the contrary, photo thermal use efficiency (PTUE) and helio thermal use (HTUE) which are measures of dry matter or grain yield per unit of PTU or HTU were worked out as per procedures reported by Sahu *et al.* (2007). Radiation use efficiency (RUE) and photosynthetically active radiation (PARUE) which are regarded as amount of dry matter or grain yield per unit of global radiation or PAR utilized were computed following the procedure adopted by Rosenthal and Gerik (1991). HUE, HTUE, PTUE, RUE and PARUE in terms of both total dry matter at harvest and grain yield have been expressed in g m^{-2} GDD^{-1}, g m^{-2}HTU, g m^{-2} PTU, g MJ^{-1} and g $mmol^{-1}$, respectively.

RESULTS AND DISCUSSION

Crop phenology

Days taken to complete vegetative (sowing to panicle initiation), and sowing to anthesis increased with delay in sowing, whereas durations during grain filling phase (anthesis to maturity) and entire growth phase (sowing to maturity) decreased with delay in sowing (Table 1). Days to panicle initiation, anthesis and physiological maturity from sowing varied from 26 to 33, 49 to 65 and 99 to 113 days, respectively. On an average, duration was maximum at grain filling phase, followed by vegetative and reproductive phases.

Thermal indices as influenced by dates of sowing

The highest GDD (Table 1) value for completion of maturity from sowing was required by crop sown on 20 November, whereas the lowest was needed by the crop sown on 18 December. Total GDD requirements for entire growth phase, which decreased with delayed sowing dates, were 2095, 2047, 1985, 1953 and 1899°C day for the crops sown on 20 November, 27 November, 4 December, 11 December and 18 December, respectively. Similar variation was also observed in grain filling period, where GDD requirements varied from 1129 °C day in 18 December sown crop to 1322°C day in 20 November sown crop. Miller (2000) observed that GDD to reach maturity decreased by 60° days with delayed sowing.

The HTU requirements for entire growth phase and grain filling period were found to decrease as the sowing dates delayed. The crop sown on 20 November needed HTU of 15515°C day h, as against 14255°C day h for crop sown on 18 December for the entire growth phase (Table 1).

In case of vegetative phase, PTU requirements (Table 1) for crops sown on different dates decreased as sowing dates delayed upto 11 December crop, while the crop sown beyond 11 December required more PTU, due to longer day length. However, PTU requirements for completion of maturity from sowing were found to decline consistently as the sowing date delays.

Radiation regimes as influenced by dates of sowing

The global radiation (Table 1) during sowing to anthesis was found to increase, while during anthesis to physiological maturity, it decreased. During entire growth phase, solar radiation receipt at the crop surface varied from 1471 MJ m^{-2} in 4 December sown crop to 1497 MJ m^{-2} in 18 December sown crop. Solar radiation receipts over different dates of sowing ranged from 237 to 363, 110 to 217 and 948 to 1098 MJ/m^2, during vegetative, reproductive and grain filling phases, respectively.

The PAR receipts decreased with delay in sowing during entire growth and grain filling phases. In case of entire growth phase, it varied from 1931 mmol/m^2 in 18 December sown crop to 2140 mmol m^{-2} in 20 November sown crop, while during grain filling period, it ranged from 1092 mmol m^{-2} in 18 December sown crop to 1352 mmol/m^{-2} in 20 November sown crop (Table 1).

Correlation with dry matter

Acc. GDD (Table 2) during 50% anthesis to physiological maturity and from sowing to maturity registered significant positive correlation with dry matter, whereas GDD during crown root initiation to first anthesis showed significant negative correlation with dry matter. Acc. HTU during 100% anthesis to physiological maturity, panicle initiation to 100% anthesis and sowing to physiological maturity had exhibited significant positive correlation with dry matter. To the contrary, HTU during panicle initiation to 50% anthesis and 50% anthesis to maturity had significant negative association with dry matter production. Acc. PTU during emergence to crown root initiation, emergence to panicle initiation and from sowing to maturity had significant positive association with dry matter at harvest. In contrast, PTU values during panicle initiation to 50% anthesis and 50% anthesis to physiological maturity had significant negative association with dry matter.

Acc. global radiation (Table 2) during 100% anthesis to maturity, vegetative phase, and panicle initiation to 100% anthesis registered significant positive correlation with total dry matter, whereas during reproductive and grain filling phases it exhibited significant negative correlation with dry matter. Acc. PAR during emergence to crown root initiation and sowing to maturity showed significant positive correlation with dry matter, whereas during reproductive and

Table 1: Duration and accumulated thermal and radiation regimes at different phenophases

Dates of sowing	Phenophases				
	Vegetative (sowing-PI)	Reproductive (PI-anthesis)	Grain filling (anthesis-PM)	Entire phase (sowing-PM)	Sowing-anthesis
			Duration (days)		
20 Nov.	26	18	69	113	65
27 Nov.	27	18	65	110	64
4 Dec.	28	20	58	106	58
11 Dec.	31	19	53	103	54
18 Dec.	33	17	49	99	49
			GDD (^{o}C day)		
20 Nov.	563	210	1322	2095	1322
27 Nov.	515	255	1277	2047	1277
4 Dec.	504	275	1206	1985	1206
11 Dec.	521	219	1213	1953	1213
18 Dec.	534	236	1129	1899	1129
			HTU (^{o}C day h)		
20 Nov.	3997	1040	10478	15515	10478
27 Nov.	3159	1542	10409	15110	10409
4 Dec.	2797	1493	10189	14479	10189
11 Dec.	2601	1498	10173	14272	10173
18 Dec.	2855	1958	9442	14255	9442
			PTU (^{o}C day h)		
20 Nov.	8106	2597	21177	31880	21177
27 Nov.	7287	3381	21050	31718	21050
4 Dec.	6854	3532	20666	31052	20666
11 Dec.	6747	2778	21339	30864	21339
18 Dec.	6820	3122	20719	30661	20719
			Global radiation (MJ m^{-2})		
20 Nov.	268	110	1098	1476	1098
27 Nov.	237	181	1067	1485	1067
4 Dec.	242	217	1012	1471	1012
11 Dec.	298	179	1008	1485	1008
18 Dec.	363	186	948	1497	948
			PAR (mmol m^{-2})		
20 Nov.	570	218	1352	2140	1352
27 Nov.	503	265	1315	2083	1315
4 Dec.	487	275	1215	1977	1215
11 Dec.	500	250	1181	1931	1181
18 Dec.	546	275	1092	1913	1092

grain filling phases it had significant negative correlation with dry matter.

Correlation with grain yield

Acc. GDD during vegetative, entire growth and grain filling periods registered significant positive correlation with grain yield, whereas acc. GDD during crown root initiation to first anthesis showed significant negative association with grain yield (Table 2). Acc. HTU during entire growth period had significant positive association, whereas during reproductive and grain filling phases it had exhibited significant negative association with grain yield. PTU also showed similar types of association with grain yield (Table 2).

Acc. global radiation during vegetative phase registered significant positive correlation, whereas during reproductive and grain filling phases it had shown significant negative association with grain yield. Acc. PAR during entire growth period had significant positive association, whereas during reproductive and grain filling phases, it exhibited significant negative association with grain yield (Table 2).

Table 2: Correlation coefficients of agrometeorological parameters during different phenophases with total dry matter (g m^{-2}) at harvest and grain yield (kg ha^{-1})

Phenophases	GDD	HTU	PTU	GR	PAR
			Total dry matter		
1. Em-CRI	0.85	0.83	0.88*	0.70	0.89*
2. CRI-PI	-0.85	-0.38	-0.45	-0.89*	-0.86
3. PI-FAN	-0.53	-0.99**	-0.81	-0.82	-0.97**
4. FAN-50AN	0.63	-0.97**	-0.81	-0.61	-0.22
5. 50AN-100AN	-0.36	-0.65	-0.71	-0.52	-0.04
6. 100AN-PM	0.88*	0.92*	0.81	0.90*	0.93*
7. Em-PI	0.25	0.55	0.88*	0.90*	-0.37
8. Em-FAN	-0.35	-0.61	0.42	-0.96**	-0.78
9. CRI-FAN	-0.91*	-0.86	-0.79	-0.98**	-0.94*
10. PI-50AN	-0.51	-0.99**	-0.98**	-0.97**	-0.93*
11. 50AN-PM	0.95**	-0.97**	-0.88*	-0.89*	-0.91*
12. FAN-100AN	-0.26	-0.93*	-0.82	-0.78	-0.48
13. PI-100AN	-0.54	0.96**	0.82	0.94*	0.96**
14. Sow-PM	0.99**	0.95**	0.94*	-0.40	0.96**
			Grain yield		
1. Em-CRI	0.87*	0.76	0.89*	0.58	0.80
2. CRI-PI	-0.90*	-0.53	-0.57	-0.95**	-0.94*
3. PI-FAN	-0.39	-0.99**	-0.76	-0.76	-0.95**
4. FAN-50AN	0.50	-0.91*	-0.86	-0.62	-0.01
5. 50AN-100AN	-0.51	-0.76	-0.80	-0.60	-0.22
6. 100AN-PM	0.95**	0.97**	0.90*	0.96**	0.97**
7. Em-PI	0.12	0.37	0.80	0.96**	-0.55
8. Em-FAN	-0.30	-0.75	0.34	-0.99**	-0.88**
9. CRI-FAN	-0.95**	-0.94*	-0.88*	-0.99**	-0.98**
10. PI-50AN	-0.38	-0.98**	-0.99**	-0.92*	-0.84
11. 50AN-PM	0.99**	-0.99**	-0.94*	-0.88*	-0.91*
12. FAN-100AN	-0.44	-0.95**	-0.92*	-0.87*	-0.53
13. PI-100AN	-0.62	0.99**	0.92*	0.99**	0.98**
14. Sow-PM	0.99**	0.91*	0.96**	-0.43	0.94*

Sow–Sowing, Em–Emergence, CRI–Crown root initiation, PI–Panicle initiation, FAN–First anthesis, 50AN–50% anthesis, 100AN–100% anthesis, PM–Physiological maturity, GR–Global radiation.
*,**Significant at P=0.05 and P=0.01 level, respectively.

Table 3: Thermal and radiation use efficiency in terms of total dry matter (g m^{-2}) at harvest and grain yield (g m^{-2})

Dates of sowing	HUE (gm^{-2} GDD^{-1})	HTUE (g m^{-2} HTU^{-1})	PTUE (g m^{-2} PTU^{-1})	RUE (g MJ^{-1})	PARUE (g $mmol^{-1}$)
			Total dry matter		
20 Nov.	0.582	0.088	0.041	0.811	0.572
27 Nov.	0.511	0.077	0.035	0.696	0.508
4 Dec.	0.492	0.076	0.036	0.653	0.493
11 Dec.	0.445	0.068	0.031	0.568	0.447
18 Dec.	0.406	0.060	0.029	0.502	0.400
Mean	0.487	0.074	0.034	0.646	0.484
			Grain yield		
20 Nov.	0.1614	0.0219	0.0104	0.2220	0.1599
27 Nov.	0.1551	0.0208	0.0098	0.2065	0.1538
4 Dec.	0.1423	0.0194	0.0091	0.1909	0.1427
11 Dec.	0.1241	0.0167	0.0080	0.1690	0.1222
18 Dec.	0.1091	0.0148	0.0069	0.1425	0.1094
Mean	0.1384	0.0187	0.0088	0.1862	0.1376

Table 4: Regression equations for prediction of grain yield (kg ha^{-1}) and dry matter production (g m^{-2}) at harvest

Parameters	Regression equations	R^2	S. E. ±
Model 1: Grain yield (kg ha^{-1})	Y=7444.118-3.959SGR P8-5.266?GDD P9	0.99**	35.0
Model 2: Grain yield (kg ha^{-1})	Y=3397.36-5.608SGDD P9 + 0.0026?PAR P13	0.97**	77.6
Model 3: Grain yield (kg ha^{-1})	Y=-7444.4-0.0054SPAR P6 + 14.672?GDD P11	0.99**	29.2
Model 4: Total dry matter (g m^{-2})	Y=-336.923-0.67SGDD P6 + 0.0019PAR P13	0.88*	54.7

P6–100% anthesis to PM, P8–Emergence to 1st anthesis, P9–CRI to 1st anthesis, P11–50% anthesis to PM, P13–PI to 100% anthesis, GR–Global radiation.
*,**Significant at P=0.05 and P=0.01 level, respectively.

Thermal and radiation use efficiency in terms of dry matter

The values of HUE, HTUE and PTUE in terms of dry matter production at harvest were highest in 20 November sown crop, whereas the lowest occurred in 18 December sown crop. The highest HUE, HTUE and PTUE values recorded in 20 November sown crop were 0.582 g m^{-2} GDD^{-1}, 0.088 g m^{-2} HTU^{-1} and 0.041 g m^{-2} PTU^{-1}, and in 18 December sown crop, they were 0.406 g m^{-2} GDD^{-1}, 0.060 g m^{-2} HTU^{-1} and 0.029 g m^{-2} PTU^{-1}, respectively. Radiation use efficiency (RUE) and PAR use efficiency (PARUE), which were also highest in 20 November sown crop, were 0.811 g MJ^{-1} and 0.572 g $mmol^{-1}$, respectively. The lowest RUE and PARUE values, registered by 18 December sown crop, were 0.502 g MJ^{-1} and 0.400 g $mmol^{-1}$, respectively (Table 3).

Thermal and radiation use rfficiency in terms of grain yield

Thermal and radiation use efficiency in terms of grain yield (Table 3) were highest in 20 November sown crop and lowest values were recorded in crop sown on 18 December. As the sowing date delayed, values of thermal and radiation efficiency were found to decrease. In case of 20 November sown crop, values of HUE, HTUE, PTUE, RAUE and PARUE were 0.1614 g $m^{-2}GDD^{-1}$, 0.0219 g m^{-2} HTU^{-1}, 0.0104 g m^{-2} PTU^{-1}, 0.2220 g MJ^{-1} and 0.1599 g $mmol^{-1}$, respectively. On the other hand, values of HUE, HTUE, PTUE, RAUE and PARUE as recorded by the crop sown on 18 December were 0.1091 g $m^{-2}GDD^{-1}$, 0.0148 g m^{-2} HTU^{-1}, 0.0069 g m^{-2} PTU^{-1}, 0.1425 g MJ^{-1} and 0.1094 g $mmol^{-1}$, respectively. Similar HUE values in wheat were also reported earlier from Jabalpur (Aggarwal *et al*., 1999).

Weather-based models for prediction of dry matter and grain yield

Weather variables showing strong and significant correlation with dry matter and grain yield have been utilized for development of regression models (Table 4) which revealed that R^2 values of models accounted for 97 to 99% of total variation in grain yield. First model is able to predict yield by first anthesis, 2nd model by 100% anthesis and 3rd model by maturity. The R^2 of the model for total dry matter could explain 88% of the total variation in dry matter.

REFERENCES

Aggarwal, K. K., Shaker, U., Upadhyay, A. P., Gupta, V. K. and Shanker, U. (1999). Accumulated heat unit requirements for different phenophases of wheat (*Triticum aestivum*) cultivars as influenced by sowing dates at Jabalpur. *J. Agromet.,* 1 : 173-76.

Miller, P. R. (2000). Effect of varying seeding date on crop development, yield and yield components in canaries. *Can. J. Pl. Sci,.* 80 : 83-86.

Rajput, R. P., Deshmuk, M. R. and Paradkar, V. K. (1987). Accumulated heat units and phenology relationship in wheat as influenced by planting dates under late sown condition. *J. Agron. Crop Sci.,* 159 : 234-48.

Rao, V. U. M., Singh, D. and Singh, R. (1999). Heat use efficiency of winter crops in Haryana. *J. Agromet.* 1 : 143-48.

Rosenthal, W. D. and Gerik, T. J. (1991). Radiation use efficiency among cotton cultivars. *Agron. J.*, 83 : 655-58.

Sahu, D. D., Chopada, M. C. and Patoliya, B. M. (2007). Determination of sowing time for chickpea varieties in south Saurashtra, India. *J. Agromet.,* 9 : 68-73.

Sastry, P. S. N. and Chakravarty, N. V. K. (1982). Energy summation indices for wheat crop in India. *Agric. Meteorol.,* 27 : 45-48.