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Physiological responses of sowing windows and irrigation regimes using weather model and spatial data of wheat in North Western Himalayas

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Abstract
A field experiment was conducted during *Rabi* 2018-19 and 2019-20 at CSK HPKV, Palampur to study the physiological response of wheat at different dates of sowing under various irrigation regimes methods in mid-hills of Himachal Pradesh. Sowing of wheat on different dates recorded significant physiological responses. Crop sown on 25th October reported significantly higher value of growth indices while lowest values were found in 10th December sown crop. Irrigation regimes also have significant effect on these parameters which directly contribute to crop yield. Initially growth rates were significantly higher in the treatments having three irrigations remaining at par with two irrigations. But in later stages, regimes of irrigation as per the recommendation of modified Penman-Monteith method and spatial data have recorded significantly higher growth rates remaining statistically similar with three irrigations. It means regimes of irrigation as per recommendation not only saves water but also increases the growth parameters of crop.

Keywords: Date of sowing, irrigation regimes, weather model, penman monteith method, spatial data

Introduction

One of the most pressing environmental issues of the twenty-first century is water scarcity which results from changing climatic scenarios. Irrigation is used on less than a quarter of the cropping area, but it supports roughly half of the world's food production. Agricultural production accounts for roughly 67 percent of global water consumption, with irrigation accounting for 87% of total consumption (Shiklomanov, 1997) [19]. Water shortages in developing countries, particularly in India, are becoming increasingly limiting, where there are growing water demands from various sectors. Agriculture uses the most water in India (81 percent), so efficient and judicious water management in agriculture should be a top priority (Surendran *et al*. 2015) [20]. Presently the net cultivated area in India is 141.4 million hectare of which 68.2 million hectare has irrigation facility (Anonymous, 2017) [2, 3]. In 2020, the irrigation water requirement is expected to rise by 7 to 8%, and in 2050, it could rise by 14 to 15% (Chatterjee *et al*. 2012) [7]. The increased water demand in agriculture and other sectors and decreasing trend of water reserves in past few decades necessitate the sagacious use of this limited natural resource.

Wheat (*Triticum aestivum* L.) is the most important food crop, after rice, in India and accounts for about 49% of food grain production among winter cereals. The crop was cultivated on an area of 30.60 million hectares during 2017-180 with the total production of 98.38 million tonnes and average productivity of 3216 kg/ha (Anonymous 2017) [2, 3]. Wheat is also the most important food crop of Himachal Pradesh where during 2017-18 it was calculated on area of 371.06 thousand hectares with the total production of 667.62 thousand tonnes with average yield of 1530 kg/ha (Anonymous 2017-18) [4]. Wheat is a long-day crop that is sensitive to temperature besides being responsive to irrigation application. The temperature has a significant impact on its growth and productivity. Wheat sowing time is one of the most important determinants of crop phenological development and efficient biomass conversion into economic yield (Kumar and Kumar, 2014) [10]. Normal sowing has the best growth duration, which allows for more biomass accumulation than late sowing, resulting in higher grain and biological yield. In the case of delayed sowing, the wheat crop is exposed to sub-optimal temperatures during established phases and supra-optimal temperatures during reproductive phases, resulting in forced maturity and a decrease in yield (Sattar *et al*., 2010) [8].

Time of sowing also affects the other management which include mainly water management. Wheat requires 400-650 mm of water for optimum yield, depending on climate, growing period, and soil. For irrigated wheat crop five to six irrigations are required at 20-21 days' intervals. The time and amount of irrigation water play an important role in the production of wheat crop in the arid, semi-arid and rainfed areas. However, excess and deficit irrigation directly have adverse impacts on the crop yield. The stages like crown root initiation (CRI) (21-25 days after sowing), tillering (40-45 DAS), jointing (60-65 DAS), flowering (80-85 DAS), milking (105-110 DAS) and dough (120-125 DAS) are the critical growth stages. The highest wheat yields may be obtained from following four irrigations: CRI, booting, flowering and milking stages. Out of all stages, CRI is the most important stage for irrigation. Irrigation requirements varies from soil to soil, in sandy loam soil 6-8 irrigations may be required whereas in heavy clay soil 3-4 irrigations are considered to be sufficient for the crop growth (Ranjan *et al*. 2018; Kumar, 2009) [16]. However, the maximum yield loss is associated with reduced number of grains per spike observed due to water stress at tillering stage. Judicious water scheduling maximizes irrigation efficiency by saving energy and water use. Effective scheduling plan aim to provide sufficient water to plants while minimizing losses due to deep percolation or runoff (Mandal and Roy, 2012) [14]. Crop water can also be estimated by evaluating evapotranspiration (ET) which plays an essential role for detecting plant water status and scheduling irrigation (Amazirh *et al*., 2017) [1]. It is based on the Penman-Monteith equation which include all the parameters that manage the energy exchange between vegetation and atmosphere. Modified Penman–Monteith equation can be used to identify the when to irrigate based on the computation of reference and crop evapotranspiration with dual crop coefficients and allow the saving of irrigation water (Laghari *et al*., 2008). Now –a day, with appropriate temporal and spatial resolutions, the operational use of dense time series of remote sensing (RS)-based multispectral imagery at high spatial resolution can monitor crop biophysical parameters related to crop ET and crop water use throughout the growing season. Irrigation management is one of the most visible and direct applications of these approaches in agriculture (Calera *et al*., 2017) [6].

Considering the above facts, the present study was carried out to study the impact of different sowing dates as well as irrigation levels on the different growth indices so as to identify the most suitable planting date as well as irrigation schedule so as to achieve higher wheat productivity.

Materials and Methods

The research was carried out at the research farm of Department of Agronomy, CSK HP Krishi Vishwavidyalaya, Palampur during *Rabi* 2018-19 and 2019-20. The experimental farm is located at 32˚4´ N latitude, 76˚3´ E longitude and 1224 meters' altitude of North Western Himalayas. The area represents the mid-hills sub-humid zone of Himachal Pradesh and is characterized by a wet temperate climate. The area receives a high rainfall that ranges between 1500-2500 mm per annum, of which 80 percent is received during monsoon months from June to September. The soil of the experimental field was silty clay loam in texture and acidic in reaction. The soil was rated as medium in organic carbon, available nitrogen, available phosphorus and available potassium. The experiment consisted of three date of sowing (25 October, 20 November, 10 December) and five irrigation schedules [Rainfed (I_1), Two irrigation (I_2), Three irrigation (I_3), Irrigation scheduling based on Penman Monteith modified method (I_4) Irrigation scheduling based on spatial reference ET of grid(I_5)] which was tested in split plot design with date of sowing in main plot and irrigation schedules in sub plot. The crop was raised using recommended package of practices. The recommended dose of nutrients (120:60:30) were applied through urea (46% N), SSP (16% P_2O_5), and MOP (60% K_2O) with half dose of nitrogen and full dose of phosphorus and potassium applied as basal dose while remaining nitrogen applied in two split at CRI and tillering stage.

Plant observations such as Leaf area, dry matter accumulation per square meter were recorded at 30, 60, 90 and 120 DAS. From the values of observations recorded, the values of CGR, LAR and NAR were calculated by using formulae given by Radford (1967) [15] while RGR was calculated by using Blackman (1919)'s formula.

The data pertaining to each of the characters of the experimental crops were tabulated and finally analyzed statistically. Analysis of variance for split plot design were worked out as per the standard procedure described by Gomez and Gomez (1984). For parameters where the effects exhibited significance at 5 per cent probability level, critical difference (CD) were calculated.

Results and Discussion

A perusal of data (Table 1) showed significant difference in crop growth rate (CGR) of wheat during 2018-19 and 2019-20. From the period between 30 and 60 DAS significantly higher CGR during both the years was recorded from the crop sown on 25th October while lowest value of CGR was recorded when the crop was on 10th December. Similar trend was observed with respect to CGR between 60 to 90 DAS and 90 to 120 DAS with 25th October sowing recorded higher CGR though this date was at par with 20th November sowing between 60 and 90 DAS while the delayed sowing on 10th December recorded significantly lower CGR values at both the stages.

Among irrigation schedules significantly higher values of CGR between 30 and 60 DAS during both the years was recorded when the crop was provided with three irrigations though this treatment was at par with the crop raised with two irrigations during first year of study (2018-19). Significantly lower values of CGR between 30 and 60 DAS during both the years was recorded when no irrigation was applied to the crop. For the period between 60 and 90 DAS significantly higher CGR in 2018-19 was recorded when the crop was irrigated at stage as suggested by modified Penman-Monteith method while during 2019-20 significantly higher CGR was recorded when the irrigation was scheduled on the basis of special reference ET though both these treatments were at par during both the years. Scheduling irrigation as per the recommendation of modified Penman-Monteith method during 2018-19 and application of three irrigations also gave higher CGR between 90 and 120 DAS. Significantly lowest values of CGR during both the years at all the stages was recorded when the crop raised without any irrigation

Data on relative growth rate (RGR) have been shown in Table 1. At 30-60 DAS, data revealed that significantly higher value of RGR was recorded in wheat sown on 10th December which was remaining at par with crop sown on 20th November during 2018-19. From the period between 60 and 90 DAS, significantly higher value of RGR was recorded during 2018-19 of crop sown on 10th December. But during the same growth period in 2019-20, the value of RGR was at par with the crop sown on 10th December and 20th November and it was significant over 25th October sown crop. The RGR between 90 and 120 DAS was significantly highest in wheat sown on 10th December during 2018-19 and 2019-20. Among irrigation schedules, between 30 and 60 DAS, the growth rates where irrigation was scheduled having two and three irrigations were at par with each other and significant over others during both the seasons. Between 60 and 90 DAS, the RGR was significantly higher in modifiedPenman-Monteith weather model being at par with irrigation scheduling by using spatial data during 2018-19. It was significantly higher in the treatment where irrigation was scheduled by usingspatial data being at par with as suggested by modified Penman Monteith and rainfed conditions during 2019-20. Between the period 90 and 120 DAS, the results of RGR were similar among all the treatments except rainfed conditions which recorded significantly lowest value of RGR.

A perusal of data (Table 2) showed significant difference in Net Assimilation rate (NAR) during both seasons of wheat. Among date of sowings, the NAR between 30 and 60 DAS was significantly highest in crop sown on 20th November during 2018-19 while it was highest in delayed sown wheat on 10thDecember during 2019-20. However, between 60 and 90 DAS, it was significantly highest in third sowing both the seasons. Significantly highest value of NAR was recorded in wheat sown on 25th October between 90 and 120 DAS during both years. Among irrigation schedules, between 30 and 60 DAS, significantly higher value of NAR was recorded where the irrigation was provided with two irrigations which was remaining at par where no irrigation was applied during first year of study while in subsequent year, it was significantly higher in the treatment in which three irrigations were applied which recorded similar assimilation rates where two irrigations and no irrigation was applied. Rainfed dependent treatment recorded significantly higher value of NAR between 60 and 90 DAS during both year of study over others whereas NAR was not found to be significant between the period 90 and 120 DAS.

Data presented in Table 2 revealed significant differences in LAR during both seasons. Among date of sowings, between 30 and 60 DAS significantly higher values of LAR was recorded in wheat sown on 10th December during first year of study but it was at par with crop sown on 20th November during 2019-20. Between 60 and 90 DAS, the significantly highest values of LAR were recorded in 25th October sowing crop during both years. Between 90 and 120 DAS, significantly higher LAR was recorded in late sowing i.e. 10th December crop being at par with 20th November sown crop during 2018-19, however it was significantly highest in crop when sowing was done on 10th December in the subsequent year. Among irrigation schedules, LAR was found to be significantly highest in the treatment where irrigation was scheduled by using modifiedPenman Monteith between 30 and 60 DAS during both the years. Between 60 and 90 DAS, irrigation application as suggested by modified Penman Monteith recorded significantly higher LAR being at paras suggested by spatial data during 2018-19 and where three irrigations were applied during 2019-20. Treatment where no irrigation was applied recorded significantly higher values of LAR between 90 and 120 DAS during both years but in later it values were at par when irrigation was applied as suggested by spatial data.

Different sowing dates significantly influenced the grain yield of wheat crop during both the years of investigation. Delayed sowing of wheat from 25th October to 10th December reduced the grain yield of wheat. Sowing of wheat on 25th October produced significantly higher grain yield as compared to sowing on 20th November and 10th December. Sowing of wheat on 25th October recorded the maximum grain yield of 4432 and 4275 kg ha^{-1} during 2018-19 and 2019-20, respectively, which was significantly superior over rest of the sowing dates during 2018-19 but was at par with the yield produced when crop was sown on 20th November in 2019-20. However, the lowest grain yield was recorded when the crop sown on 10th December (3006 and 3148 kg ha^{-1}) during 2018-19 and 2019-20, respectively. The sowing of wheat crop on 25th October has increased the grain yield by 47.4 and 35.8 per cent as compared to the crop sown on 10 December during both the years of investigation respectively. Data further indicated that the scheduling of irrigation significantly influenced grain yield of wheat crop. The maximum grain yield 4158 and 4109 kg ha^{-1} was obtained with the Penman monteith and three irrigation scheduling in 2018-19 and 2019-20 respectively, which was statistically superior in 2019-20 but at par with two and three irrigations during 2018-19 year of investigation. The lowest grains yield 3111 and 3441 kg $ha^{-1}$was recorded under rainfed conditions during 2018-19 and 2019-20 respectively.

Growth indices *viz*., CGR, RGR, NAR and LAR at 30-60, 60-90 and 90-120 DAS were significantly increased under different dates of sowing and various irrigation schedules and thereby significant results of grain yield were observed. However, irrespective of dates of sowing and irrigation levels, dry matter and leaf area index increased, as the crop progresses up to 120 DAS. Leaf area index is the efficiency of photosynthetic process and depends on the extent of photosynthetic surface (Fang and Liang, 2014). Leaf area index in the vegetative phase of wheat which determines the quantum of intercepted photosynthetically active radiation, which is a yield determining factor. Hence, the higher photosynthetic activity per unit area and more dry matter production led to increase in growth indices *viz*. CGR, RGR, NAR and LAR which ultimately enhanced the grain yield of wheat. These results are in conformity with the findings of (Saren *et al*., 2004, Kumar *et al*., 2012, Vishuddha *et al*., 2014 and Kumar *et al*., 2015) [17, 10, 22] who also reported the maximum values of growth indices during experimentation. Yusuf *et al*. (2019) [22] also observed that 5th November sown crop recorded significantly grain yield (5432 kg ha^{-1}) compared to rest of the sowing dates. Kumar *et al*. (2017) [10] who studied the interaction effects of different sowing dates and irrigation schedule on yield attributes of wheat and revealed that among different sowing dates and irrigation schedules, the maximum number of spikelet per spike, grains per spike and grain yield was recorded with sowing of wheat on 25th Nov and 4 irrigations respectively.

Table 1: Effect of sowing windows and irrigation regimes on Crop growth rate and Relative growth rate

Treatment	Crop growth rate(g m^{-2} day^{-1})						Relative growth rate (mg g^{-1} day^{-1})					
	(30-60 DAS)		(60-90 DAS)		(90-120 DAS)		(30-60 DAS)		(60-90 DAS)		(90-120 DAS)	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Sowing dates												
25 October (S_1)	3.181	2.909	6.141	5.872	13.763	14.179	48.3	44.7	30.3	30.5	28.2	29.8
20 November (S_2)	2.528	2.803	6.242	5.857	12.586	12.914	49.9	53.0	35.8	32.7	28.1	28.8
10 December (S_3)	2.056	2.448	5.708	4.840	11.493	11.961	50.6	56.8	38.8	32.1	28.9	30.8
S.Em+	0.006	0.006	0.070	0.036	0.088	0.127	0.2	0.2	0.2	0.1	0.2	0.2
CD (P=0.05)	0.022	0.023	0.275	0.143	0.347	0.499	0.7	0.6	1.0	0.5	0.6	0.7
Irrigation regimes based on weather models												
Rainfed (I_1)	2.237	2.513	5.399	5.348	10.579	10.434	47.1	50.4	35.3	32.5	27.3	26.6
Two irrigation (I_2)	2.918	2.878	5.698	5.390	12.693	13.529	52.4	52.9	31.4	30.2	28.5	30.6
Three irrigation (I_3)	2.942	2.997	5.963	5.599	13.323	13.971	51.6	53.4	32.0	30.3	28.8	30.5
Penman monteith method (I_4)	2.466	2.643	6.668	5.618	13.618	13.603	48.9	50.6	38.1	32.6	28.9	30.7
Spatial ET (I_5)	2.377	2.570	6.424	5.659	12.856	13.554	48.0	50.2	37.9	33.2	28.5	30.7
S.Em+	0.033	0.024	0.086	0.080	0.212	0.212	0.5	0.4	0.4	0.4	0.4	0.4
CD (P=0.05)	0.095	0.071	0.252	0.235	0.618	0.617	1.4	1.2	1.2	1.1	1.1	1.1

Table 2: Effect of sowing windows and irrigation regimes on Net assimilation rate, Leaf area ratio and grain yield

Treatment	Net assimilation rate (mg cm^{-2} day^{-1})						Leaf area ratio (cm^{2}g^{-1})						Grain yield (kg/ha)	
	(30-60 DAS)		(60-90 DAS)		(90-120 DAS)		(30-60 DAS)		(60-90 DAS)		(90-120 DAS)			
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Sowing dates														
25 October (S_1)	39.0	38.2	137.4	138.4	1061.9	986.7	1.245	1.174	0.223	0.223	0.028	0.032	4432	4275
20 November (S_2)	40.2	41.0	174.3	162.3	812.5	625.9	1.253	1.297	0.208	0.206	0.036	0.047	4048	4079
10 December (S_3)	32.6	43.9	308.0	205.5	714.1	418.4	1.566	1.299	0.132	0.166	0.041	0.076	3006	3148
S.Em+	0.2	0.1	5.2	2.4	61.3	14.1	0.011	0.005	0.004	0.003	0.002	0.001	53	59
CD (P=0.05)	0.8	0.2	20.5	9.3	240.8	55.3	0.043	0.021	0.014	0.013	0.006	0.003	208	231
Irrigation regimes based on weather models														
Rainfed (I_1)	40.2	42.9	276.5	225.6	711.3	701.1	1.181	1.174	0.150	0.154	0.041	0.057	3111	3441
Two irrigation (I_2)	41.3	43.0	188.9	159.5	878.5	686.4	1.279	1.229	0.179	0.194	0.033	0.050	3922	3916
Three irrigation (I_3)	36.9	43.6	179.7	142.1	910.9	715.0	1.415	1.224	0.188	0.216	0.033	0.047	4140	4109
Penman monteith method (I_4)	32.5	37.4	186.6	142.7	916.8	659.4	1.527	1.351	0.218	0.231	0.034	0.050	4158	3905
Spatial ET (I_5)	35.4	38.4	201.2	173.9	896.5	623.2	1.372	1.306	0.204	0.197	0.034	0.054	3812	3798
S.Em+	0.6	0.6	10.7	5.3	67.3	39.7	0.021	0.012	0.006	0.005	0.002	0.002	102	65
CD (P=0.05)	1.6	1.7	31.2	15.4	NS	NS	0.062	0.034	0.018	0.016	0.006	0.006	298	188

Conclusions

From the overall appraisal of the study, it can be concluded that timely sowing of crop has significant effect on the CGR, RGR, NAR and LAR of wheat which later on impacted significantly to the grain yield. It is a climate factor which significantly affects these parameters. Irrigation scheduling also have significant effect on these parameters which directly contribute to crop yield. During the stage of maximum growth *i.e.* 90-120 DAS, the irrigation scheduling based on Penman Monteith weather model have increased the growth rate. Saving of water could be approached by scheduling the crop as per recommendation and this approach also contributes in enhancing the growth parameters.

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