Journal of Agrometeorology

ISSN : 0972-1665 (print), 2583-2980 (online)
Vol. No. 26 (3) : 300-304 (September - 2024)
https://doi.org/10.54386/jam.v26i3.2560
https://journal.agrimetassociation.org/index.php/jam

Research Paper

Exploring the nexus of grain production and climate variability under nitrogen and hydrothermal regimes using CERES-wheat model

ANUREET KAUR[1], KARAMJIT SINGH SEKHON[1], RAJ KUMAR PAL[2*], SUDHIR THAMAN[3], ANURAG MALIK[1], SAMANPREET KAUR[3] and SONY BORA[2]

[1]Punjab Agricultural University, Regional Research Station, Bathinda, Punjab, India
[2]Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana, Punjab, India
[3]Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana, Punjab, India
**Corresponding author: rkpal1985@pau.edu*

ABSTRACT

Field experiment was conducted at Punjab Agricultural University, Bathinda from 2017-18 to 2019-20 to evaluate the growth and yield of wheat under varying sowing dates (Nov. 15, Nov. 30 & Dec 15), irrigation regimes (IW: CPE = 0.6, 0.8, & 1.0), and nitrogen levels 80% RDN, 100% RDN & 120% RDN). Timely sowing (15 November) resulted in significantly highest grain yield (5090 kg ha^{-1}) and delay in sowing caused reduction in yield by 2.83 % and 9.91 % in crop sown on 30 November and 15 December respectively. Yield and yield attributes were found to increase with increase in irrigation and nitrogen levels. The highest yield was achieved with 15 November sowing, IW: CPE ratio 1.0 and 120% RDN. The sensitivity of the validated CERES-wheat model to increase in temperature by 0.7, 1.2, 1.5 ^{0}C and CO$_2$ concentration by 435, 460, 500 ppm, as projected for years 2030, 2040 and 2050 respectively, revealed reduction in the wheat yield. The combination of 15 November sown crop, irrigation at IW:CPE ratio 1.0, and recommended dose of nitrogen showed resilience against increasing CO$_2$ concentration and temperature rise.

Keywords: Grain yield, Yield attributes, Sensitivity analysis, CERES Model, Climate change. CO$_2$ concentration

Wheat (*Triticum aestivum* L.) is extensively grown *rabi* cereal crop in India as well as worldwide. Due to the volatility of seasonal weather in India, wheat output is highly unpredictable. Owing to climate change, shifting in time of sowing, efficient irrigation and nitrogen management practices are imperative to cope up with the changing scenario. One of the most important aspects of plant phenological growth and conversion of available biomass into economic yields is sowing time (Kaur and Pannu 2008). Furthermore, major factors affecting both growth and yield are the availability of adequate and balanced water as well as nutrients in soils. As irrigation frequency increases, crop yield increases. Nitrogen content in wheat crop yields production is very important in determining yield potential. Among the numerous soil constituents, nitrogen is the most important for increasing wheat output. Nitrogen is important for the growth of shoots, buds, leaves, roots, and bolls, while phosphorus is required for early root development, photosynthesis, and other processes (Kaur *et al.*, 2010).

The Decision Support System for Agrotechnology Transfer (DSSAT) is a global modeling platform that encompasses crop models for more than 40 different crops. The models have been used extensively throughout the world for a variety of reasons from on-farm and precision management to regional climate change effect studies (Singh, 2023; Dar *et al.,* 2023). As we navigate the challenges posed by climate change, optimizing sowing dates, irrigation regimes and nitrogen applications become imperative for sustaining and enhancing agricultural productivity in the face of evolving environmental conditions. Such insights provide valuable guidance for informed decision-making in agricultural practices to ensure food security in changing climate. Keeping this in view, the sensitivity of grain yield delves into the effects of elevated CO$_2$ concentrations, air temperatures, and their combined effects across various sowing dates, irrigation regimes and nitrogen levels.

Article info - DOI: *https://doi.org/10.54386/jam.v26i3.2560*
Received: 02 April 2024; Accepted: 30 May 2024 ; Published online : 01 September 2024

MATERIALS AND METHODS

Experimental details

Field experiments were undertaken at Punjab Agricultural University's Regional Research Station, Bathinda (30°58'N, 74°18'E) to evaluate the impact of different irrigation and nitrogen levels on wheat growth and yield during three consecutive seasons of *rabi* 2017-18, 2018-19 and 2019-20. Bathinda has the semi-arid climate with an average annual rainfall of 450 mm. The experimental soil was sandy loam in texture. The crop was sown with three sowing environments as on November 15 (D1), November 30 (D2) and December 15 (D3) along with three irrigation levels *viz.* I_1 (IW:CPE=0.6), I_2 (IW:CPE=0.8) and I_3 (IW:CPE=1.0) and three nitrogen levels *i.e.* N_1 = <20% of Recommended, N_2 = Recommended and N_3 = >20% of Recommended.The studies were carried out in a split plot design with three replications.

Calibration and validation of CERES-wheat model

The CERES-wheat model was used to simulate the effects of different irrigation and nitrogen levels on growth and yield metrics. In view of that, field data were recorded from the research trials, conducted in three consecutive seasons of 2017-18 to 2019-20 for the wheat genotype PBW - 3086. Weather parameters were recorded during study period from agro-meteorological observatory of the University that is about 20 m away from experimental site. However, experimental data from rabi 2019-20 was utilised to validate the crop model in Punjab's South-Western region. The model was calibrated for the wheat variety PBW-3086 produced in a specific location using seven factors. Within the model, these coefficients are scalar values that are transformed to physiological values (Table 1).

Sensitivity analysis

Sensitivity of grain yield to CO_2 concentration, air temperature and their combination was carried out taking simulated grain yield of crop growing year 2019-2020 using CERES wheat. The decadal projected values till 2050 for CO_2 concentration and air temperature as given by IPCC, Global Climate Projections (IPCC, 2021) are 435ppm, 460ppm, 500ppm and 0.7, 1.2, 1.5 respectively. These values have been used in the study for sensitivity analysis.

Table 1: Genetic coefficients derived for the wheat genotype PBW-3086

Parameters	HD 3086
Vernalisation coefficient (P1V)	5
Photoperiodism coefficient (P1D)	92
Grain filling duration coefficient (P5)	698
Kernel number coefficient (G1)	30
Kernel weight coefficient (G2)	31
Tiller weight coefficient (G3)	2.7
Phyllochron interval (PHINT)	95

RESULTS AND DISCUSSION

Yield and yield attributes

The grain yield and yield attributes of wheat was significantly higher in 15 November (D_1) sown crop followed by 30 November (D_2) and lowest in 15 December (D_3) sown wheat. The quantum of decrease noticed in D_2 and D_3 than D_1 was 2.83 % and 9.91 % respectively. While comparing irrigation regimes, significant increase in grain number per spike and 1000 grain weight was noticed in IW: CPE ratio 1.0 (I_3) and lowest in 0.6 ratio (I_1) (Table 2). Accessibility of well distributed moisture at various stages of growth owing to irrigation may have improved the plant growth (Kaur *et al.,* 2017). The straw yield was also significantly highest in I_3 than I_2 and I_1 treatments. The nitrogen level >20 % of recommended (N_3) recorded higher grain number per spike and 1000 grain weight than recommended level of nitrogen (N_2). The significantly lowest values of all yield attributes, grain and straw yield was observed in nitrogen level <20% of recommended (N_1) mainly because of low dose of nitrogen N_1.

Evaluation of CERES-wheat crop model

Phenology: The pooled comparison between observed and simulated phenology as well as yield attributes as influenced by sowing time, irrigation and nitrogen levels for three years (2017-20) have been illustrated in Fig. 1. The pooled analysis of three years revealed that the value of simulated emergence ranged from 3 – 5 days while, observed emergence varied from 6-11 days. The negative mean biased error (MBE) value (-3.79) showed that the model had underestimated the days taken to emergence. Moreover, lesser value of RMSE (3.96) and higher R^2 (0.61) indicated close proximity between simulated and observed emergence (Fig. 1).

Similarly, the value of simulated days to anthesis were found in the range from 82 to 99, while, observed days to anthesis varied from 87 to 99. The R^2 and RMSE values between simulated and observed days taken to anthesis were 0.42 and 6.63 respectively. The negative mean biased error (MBE) value (-3.80) showed that the model had underestimated the days taken to anthesis. Higher deviation indicated that the model failed to estimate the days taken to attain anthesis. Similarly, higher RMSE values (6.63) also indicated larger difference in simulated anthesis over observed anthesis (Fig. 1).

In case of physiological maturity, model output indicated deviation from 120 – 142 as against observed values 118-143 days. The results indicated better performance of the model having lesser RMSE value (4.76) and higher R^2 value (0.76). Also, the MBE value (-1.46) indicated underestimation of the days taken to maturity by the model (Fig. 1). Moreover, the value of nRMSE also indicated lesser deviations between observed and simulated anthesis and physiological maturity which were 0.005 and 0.001 indicating better performance of the model. As usual, among the phenology, emergence indicated higher value of nRMSE and showed more deviation over observed value. Similarly, in respect to wheat grain yield nRMSE value was also found close to observed grain yield (0.004) which depicted better model performance. nRMSE value closer to zero indicates better model applicability and presentation.

Table 2: Effect of various sowing dates, irrigation regimes and nitrogen levels on yield and yield attributes of wheat (Pooled 2017-2020)

Treatment	Grains per spike (no.)	1000 grain weight	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Date of sowing				
D1 (Nov. 15)	43.9	42.9	5090	6170
D2 (Nov. 30)	42.6	41.7	4945	5990
D3 (Dec. 15)	37.6	38.5	4609	5670
CD (P=0.05)	1.71	1.20	157	129
Irrigation regimes				
I1 (IW: CPE 0.6)	38.1	39.0	4581	5641
I2 (IW: CPE 0.8)	41.5	40.9	4894	5946
I3 (IW: CPE 1.0)	44.5	43.2	5170	6243
CD (P=0.05)	1.19	1.06	130	79.0
Nitrogen levels				
N1 (<20% of RDN)	38.3	38.5	4590	5716
N2 (RDN)	42.5	41.9	4969	6037
N3 (>20% of RDN)	43.3	42.7	5081	6089
CD (P=0.05)	1.07	1.36	133	89.0

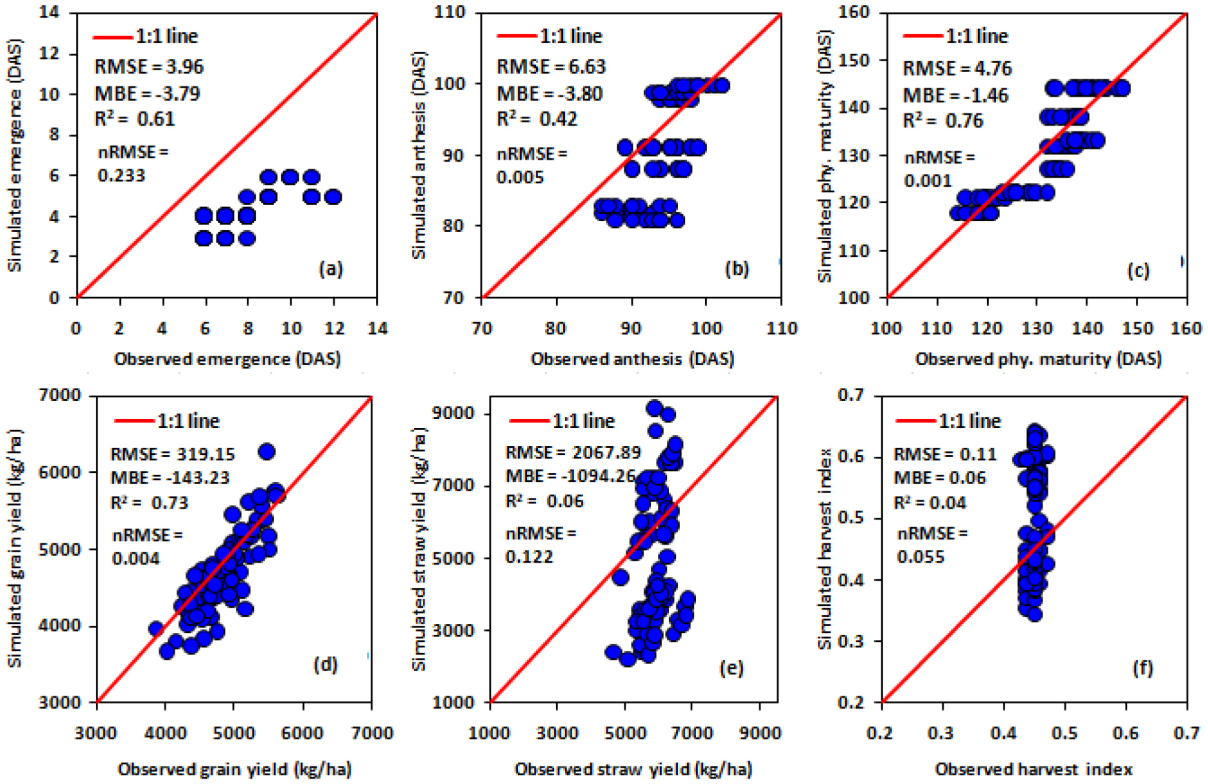

Fig. 1: Comparison between observed and simulated phenology and yield attributes of wheat (a) emergence, (b) anthesis (c) physiological maturity (d) grain yield, (e) straw yield and (f) harvest index.

Yield and its attributes: Grain yield, being the ultimate result of many yield attributing parameters, revealed that, among sowing dates, irrigation and nitrogen levels, observed grain yield ranged from 4074–5624 kg ha^{-1}, while, simulated grain yield varied from 3882–5896 kg ha^{-1} during three crop growing years. Lesser RMSE (319.15) and R^2 values (0.73) revealed close proximity and better performance of the model. The MBE value indicated that the model had underestimated the yield. The findings of Patel *et al.,* (2010) revealed similar results for middle Gujarat region. Whereas, Singh *et al.,* (2017) found overestimation of simulated yield in agro-climatic regions of Bihar. Meleha *et al.,* (2020) found that planting dates had a substantial impact on grain yields and some attributed yields, with early sowing (20 November) being preferable to late sowing (20 December) (Fig.1).

Table 3: Percent change in grain yield for different treatments under different projected values for CO_2 and air temperature

Treatments	CO_2 concentration (ppm)			Increment in air temperature (°C)			Combination of CO_2 (ppm) & temperature (°C)		
	435	460	500	0.7	1.2	1.5	435+0.7	460+1.2	500+1.5
Date of Sowing									
D1 (Nov. 15)	-0.67	0.73	2.65	-1.25	-2.43	-4.93	-0.41	0.38	-1.99
D2 (Nov. 30)	1.77	4.08	7.97	-3.69	-8.15	-9.18	-1.97	-4.41	-2.09
D3 (Dec. 15)	1.80	4.10	7.85	-3.85	-7.44	-11.29	-2.11	-3.58	-4.25
Irrigation regimes									
I1 (IW:CPE 0.6)	1.58	3.72	7.10	-3.10	-8.03	-10.88	-1.65	-4.59	-4.58
I2 (IW:CPE 0.8)	-0.02	2.08	5.41	-4.18	-6.54	-8.60	-2.62	-3.11	-3.25
I3 (IW:CPE 1.0)	1.25	3.00	5.79	-1.43	-3.44	-5.83	-0.20	0.05	-0.54
Nitrogen application									
N1 (<20% RDN)	-0.13	1.97	5.35	-4.26	-7.38	-9.57	-2.76	-3.17	-4.06
N2 (RDN)	1.51	3.53	6.62	-2.06	-4.63	-7.42	-0.63	-1.49	-1.44
N3 (>20% RDN)	1.31	3.18	6.21	-2.45	-5.87	-8.16	-1.13	-2.79	-2.76

The value of simulated straw yield was found in the range from 3383 to 6387 kg ha^{-1}, while, observed straw yield was varied from 4989 to 6507 kg ha^{-1}. The RMSE and R^2 value were 2067.89 and 0.06 respectively. The value of harvest index was found in the range between 0.44 to 0.46 and 0.45 to 0.55 as observed and simulated values, respectively in all the treatments. The value of RMSE and R^2 values observed were 0.11 and 0.04 respectively. Model output showed overestimation in harvest index (MBE= 0.06). The values indicated poor performance of model in estimating straw yield as well as harvest index (Fig. 1). The studies of Patel *et al.,* (2017) for Varanasi region revealed good predictive capacity of CERES-wheat model. They observed R^2 value of 0.96 between observed and simulated grain yield.

Sensitivity to CO_2 concentration

The grain yield across all the treatments exhibited an increase with increase in CO_2 concentration over successive decades. In 2020, the recorded CO_2 concentration was 414.2 ppm, with projections estimating concentrations of 435ppm, 460ppm, 500ppm for 2030, 2040 and 2050 respectively. Notable, the decadal percent change in grain yield showed increments of 0.67%, 0.73% and 2.65% corresponding to CO_2 concentration increase of 20.8ppm, 45.8ppm and 85.8ppm for the 15 November sown crop in the years 2030, 2040 and 2050. For the 30 November sown crop, there was a more pronounced change in yield, with percentages being 1.77%, 4.08% and 7.97% aligning with the same CO_2 concentration increments. Similarly, the 20 December sown crop demonstrated yield changes by 1.80%, 4.10% and 7.85% for the respective years, indicating a greater percent change for later sowing dates. The table further illustrates that the highest percent changes were observed for 30 November and 15 December sown crops, followed by the 15 November sown crop (Table 3). Considering different irrigation regimes, the most significant percent changes over the decades were observed in I_1 followed by I_3 and I_2. While, in case of Nitrogen applications, the greatest percent change was evident in N_2 followed by N_3 and N_1 (Table 3). Consequently, the optimal combination for maximizing yield under changing CO_2 conditions appears to be the 30 November sown crop in conjugation with I_3 and N_2.

Sensitivity to air temperature

Contrary to the positive correlation with CO_2 concentrations, the grain yield across all the treatments exhibited a decrease with escalating air temperatures over the decades. Notable, the 15 December sown crop experienced the most substantial percent change in yield, registering declines of 3.85 %, 7.44% and 11.29% in the years 2030, 2040 and 2050 respectively, corresponding to the temperature increases of 0.7 °C, 1.2 °C and 1.5 °C. This trend was more pronounced compared to the 30 November and 15November sown crops. Analyzing the impact of different irrigation regimes, the percent change with higher magnitude over the decades was observed in the case of I_1 followed by I_2 and I_3. Similarly, regarding nitrogen application, the maximum percent deviation in yield was evident in N_1 followed by N_3 and N_2 (Table 3). Under the scenario of increasing air temperature, the 15th November sown crop along with I_3 and N_2 is anticipated to demonstrate the least decrease in the grain yield. This recommendation aligns with overarching observation that different crop management practices, such as sowing dates, irrigation regimes, and nitrogen application, play a crucial role in mitigating the adverse effects of rising temperatures on grain yield.

Sensitivity to combination of CO_2 concentration and air temperature

In contrast to the positive impact of elevated CO_2 concentrations alone, the grain yield across all the treatments exhibited a decrease with the combined increase in CO_2 and air temperature. Notably, the 15 December sown crop recorded the most substantial percent decrease in yield, with reductions of 2.11%, 3.58% and 4.25% in the years 2030, 2040 and 2050, respectively under the influence of both elevated and air temperatures. This trend was more pronounced compared to 30 November and 15 November sown crops, indicating a heightened vulnerability of later sowing dates. Analyzing the irrigation regimes, the percent change with higher magnitude was observed in the case of I_1 followed by I_2 and I_3. Similarly, for nitrogen applications, the greatest deviation was noted in N_1, followed by N_3 and then N_2 (Table 3). This underscores the multifaceted impact of both elevated CO_2 and rising temperatures, where crop management strategies become crucial in mitigating yield losses.

Given these observations, under the scenario of increasing CO_2 concentration and air temperature, the 15 November sown crop, when combined with I_3 and N_2, emerges as the potential strategy to minimize the decrease in grain yield. This recommendation aligns with the nuanced understanding that specific combinations of sowing dates, irrigation regimes and nitrogen levels can play a pivotal role in addressing the complex challenges posed by the combined effects of elevated CO_2 and temperatures on crop productivity.

CONCLUSION

Results revealed that the delayed sowing of wheat caused reduction in the yield. Wheat yield increased with increase in irrigation frequency and nitrogen levels. The CERES-wheat model showed underestimation among the phenology and yield attributes but good association with grain yield. The elevated CO_2 concentrations alone were associated with an increase in grain yield, while rising air temperatures exhibited a consistent decrease in yield across all treatments. The 15 November sown crop, when paired with irrigation at IW:CPE=1.0 and recommended dose of nitrogen, demonstrated resilience in the face of increasing CO_2 concentration and air temperature, resulting in the minimum observed decrease in grain yield.

ACKNOWLEDGEMENTS

The research supported by the Punjab Agricultural University, Ludhiana, Punjab and AICRP (IWM) is duly acknowledged.

Funding: No funding was taken from any organization. It was supported by Punjab Agricultural University, Ludhiana.

Data availability: Crop data were collected from field experiment conducted at PAU Regional Research Station, Bathinda from 2017-2020 while weather information were obtained from PAU Agrometeorological Observatory located at Bathinda.

Conflict of Interest Statement: The authors declare that there is no conflict of interest.

Authors contribution: **A. Kaur**: Data collection and manuscript writing; **K. S. Sekhon**: Conceptual ideas and supervision of the work; **R. K. Pal**: Data analysis and manuscript writing; **S. Thaman**: Contributed to implementation of the research; **A. Malik**: Graphical formatting of the work; **S. Kaur**: Contributed to the design of work and supervision; **S. Bora**: Comprehensive analysis and manuscript writing

REFERENCES

Dar, Eajaz Ahmad, Gerrit Hoogenboom and Zahoor Ahmad Shah. (2023). Meta analysis on the evaluation and application of DSSAT in South Asia and China: Recent studies and the way forward. *J. Agrometeorol.,* 25(2): 185-204. https://doi.org/10.54386/jam.v25i2.2081

IPCC. (2021). Climate change 2021: the physical science basis [M]// Lee J Y, Marotzke J, Bala G, *et al.,* FFuture global climate: scenario-42 based projections and near-term information. Cambridge: Cambridge University Press, 1-195

Kaur, A. and Pannu, R. K. (2008). Effect of sowing time and nitrogen schedules on phenology, yield and thermal-use efficiency of wheat (Triticum aestivum). *Indian J. Agric. Sci., 78*(4): 366-369.

Kaur, A., Pannu, R. K. and Buttar, G. S. (2010). Quality of wheat (Triticum aestivum) as influenced by sowing dates and nitrogen scheduling. *Indian J. Agric. Sci.,* 80(9). 781-785

Kaur, A., Thaman, S., Sidhu, A. S., Sekhon, K. S. and Buttar, G. S. (2017). Effect of variable irrigation supply based diversification of Bt cotton (Gossypium hirsutum)-wheat (Triticum aestivum) system on productivity, profitability, soil fertility and water expense efficiency. *Indian J. Agron.,* 62(4): 431-437.

Meleha, A. M., Hassan, A. F., El-Bialy, M. A. and El-Mansoury, M. A. (2020). Effect of planting dates and planting methods on water relations of wheat. *Int. J. Agron.,* 2020: 1-11.

Patel, H. R., Patel, G. G., Shroff, J. C., Pandey, V., Shekh, A. M., Vadodaria, R. P. and Bhatt, B. K. (2010). Calibration and validation of CERES-wheat model for wheat in middle Gujarat region. *J. Agrometeorol.,* 12(1): 114-117**.** https://doi.org/10.54386/jam.v12i1.1286.

Patel, C., Nema, A. K., Singh, R. S., Yadav, M. K., Singh, S. K. and Singh, M. (2017). Evaluation of DSSAT-CERES model for irrigation scheduling of wheat crop in Varanasi region of Uttar Pradesh. *J. Agrometeorol., 19*(2): 120-124. https://doi.org/10.54386/jam.v19i2.683.

Singh, P. K., Singh, K. K., Singh, P., Balasubramanian, R., Baxla, A. K., Kumar, B., Gupta, A., Rathore, L. S. and Kalra, N. (2017). Forecasting of wheat yield in various agro-climatic regions of Bihar by using CERES-Wheat model. *J. Agrometeorol., 19*(4): 346-349. https://doi.org/10.54386/jam.v19i4.604**.**

Singh, Piara. (2023). Crop models for assessing impact and adaptation options under climate change. *J. Agrometeorol.,* 25(1): 18–33. https://doi.org/10.54386/jam.v25i1.1969.