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Impact assessment of climatic variability on wheat and pearl millet productivity using CERES models in arid zone of Haryana*

KARAMBIR SHARMA, O.P. BISHNOI, RAM NIWAS and M.L. KHICHAR

Department of Agricultural Meteorology

CCS Haryana Agricultural University, Hisar-125 004 (Haryana), India

ABSTRACT

An investigation was conducted at Department of Agricultural Meteorology, CCS Haryana Agricultural University Hisar using meteorological data of 60 years (1941-2000) to study the climatic variability and trends in maximum and minimum temperature and rainfall. CERES models were used to determine the impact of future trend scenarios on productivity of wheat and pearl millet in arid zone of Haryana. Annual maximum and minimum temperature showed a decreasing trend during the past 60 years (-0.31^{0}C year^{-1}), but in last 30 years have shown an increasing trend (.0087^{0}C year^{-1}). Minimum temperature (annual and seasonal) showed both cooling and warming trend for a long period of 60 years, whereas maximum temperature showed a cooling trend during the same period. On the other hand, rainfall was observed with high coefficient of variability in post-monsoon and monsoon seasons. CERES models were calibrated for crop varieties, wheat (HD 2160) and pearl millet (HHB 67) and then validation was done with use of experimental data of wheat and pearl millet. CERES-Wheat model predicted yield with a variation of -7.3 to 15.3%, whereas CERES-Millet with a variation of -10.9 to 11.3% of the actual yield under different cooling and warming scenarios. Crop results indicated that warm temperature scenarios caused an adverse effect on growth and yield of wheat by hastening the physiological maturity. It was observed that flowering and maturity of wheat and pearl millet crops were advanced and delayed from normal with rise and fall of temperature upto 2^{0}C, respectively.

Key words : CERES model, climatic variability, pearl millet, temperature, wheat, yield

Climate change due to anthropogenic pollution of the atmosphere in the 21st century became a higher profile issue then ever before. Fears, uncertainties and confusion regarding necessary adjustments in environmental and economic policy in order to reduce emissions of green house gases and aerosols have intensified. These confusion and debates are particularly compelling in the arena of global climatic change and its relation to agriculture because agricultural activities relate to and interact to so many different aspects of climatic change issue (Rosenweig and Hillel, 1998). Agricultural activities contribute significantly to the production of greenhouse gases, such as methane and nitrous oxide. Agricultural enterprise is a human managed system with a fundamental biophysical base, and this complexity makes the task of discerning effects of climatic change. As a biophysical system dependent on climatic resources, agriculture can be affected through changes in crop yields and production levels. Climate change models predict in general an increase in temperature and variations in precipitation and radiation levels which are likely to influence the crop production. Several studies with crop growth models have predicted alteration in mean crop yields as a result of the changed crop environment (Rao *et al*., 2008). Agriculture will be adversely affected by an increase or decrease amount of rainfall and shifting of time of rainfall. Ramakrishna *et al.* (2002) reported that a 2°C rise in temperature was estimated to reduce the production of pearl millet by 10-15% in Rajasthan. The increase in mean air temperature over last 100 years (1850-1899 to 2001-2005) was 0.76°C which will affect the agricultural production. The fourth assessment report of Intergovernmental Panel on Climate Change (2007) concluded that there was high confidence that recent regional changes in temperature have had discernible impacts on many physical and biological systems.

Wheat and pearl millet are the most important cereal crops of arid zone of Haryana. Potential yields of these crops are likely to vary under the influence of changing climatic scenarios of the future. The proposed study has been undertaken with the objectives to study the climatic variability and trends in rainfall and temperature and impact of climatic changes on productivity of pearl millet and wheat with the use of CERES models.

MATERIALS AND METHODS

The arid zone of Haryana representing the location of Hisar is characterized by tropical to sub-tropical climate with mild to cold climate during the winter season and hot dry to

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sub-humid climate during summer and rainy seasons. Daily and monthly weather data on different parameters for Hisar were collected for the period of 1941-2000 to study the climatic variability and trends in determining normal values of weather variables for the location. Standard deviation and coefficient of variations were computed at annual, seasonal and monthly period levels for maximum, minimum temperature and rainfall. The long term trends were determined at seasonal and annual periods by using linear trend analysis. The linear trend value, represented by the slope of a simple least square regression line with time, was determined as suggested by Wigley and Jones (1981).

In the present investigation, the CERES-Wheat version 3.5 (Ritchie and Otter, 1985) and CERES-Millet version 3.5 (Ritchie *et al*., 1990) models were used to simulate the crop growth and yield of wheat and pearl millet. These models were calibrated for wheat and pearl millet crops using input data on soil, crop and management practices as per package of practices recommended by CCS Haryana Agricultural University, Hisar. First these models were validated with field experimental data and then used for studying the different scenarios. The daily weather variables maximum and minimum temperature, solar radiation and rainfall were used in weather input file. The field data on growth and development of wheat crop of season 1999 and 2000 were taken from annual research report of wheat. The growth and development data of pearl millet were observed in the field experiment conducted at Department of Soil Science, CCS Haryana Agricultural University, Hisar during the years 1999 and 2000.

RESULTS AND DISCUSSION

Climatic variability

Variability in climatic parameters i. e. maximum and minimum temperature and rainfall for 60 years were computed. The standard deviation and coefficient of variation of maximum and minimum air temperature, and rainfall over annual and seasonal levels are presented in Table 1. Standard deviation values for maximum temperature were 0.7, 0.6 and 0.8ºC for the period of 1941-1970, 1971-2000 and 1941-2000, respectively. Coefficient of variation was highest of the order of 2.7% during the period of 60 years i. e. 1941-2000 and was lowest of 2.1% for the period of 30 years (1971-2000). Standard deviation values during the summer, monsoon, post-monsoon and winter seasons were 1.5, 1.0, 1.3 and 1.5ºC, respectively. Coefficient of variability was highest 2.6% in the winter but was lowest in the south-west monsoon season at 7.1%. These results tally confirms the results reported by Bukan Lal (1993).

Standard deviation values for minimum temperature were of the order of 0.5, 0.6 and 0.8°C for the periods of 1941-1970, 1971-2000 and 1941-2000, respectively. Coefficients of variation were 3.1, 4.4 and 5.5% for the aforesaid periods, respectively. Standard deviation was highest in the summer season, whereas lowest in the winter season. Coefficients of variation were 7.4, 4.0, 11.1 and 18.1% during summer, monsoon, post-monsoon and winter seasons, respectively. Annual standard deviation was highest around 162.4 mm and was lowest (145.1 mm) for the period of 1971-2000 and 1941-1970, respectively. Coefficients of variation were 32.9, 35.7 and 32.3% for the periods 1941-1970, 1971-2000 and 1941-2000, respectively. Standard deviation values during summer, monsoon, post-monsoon and winter seasons were 12.2, 35.7, 11.2 and 10.9 mm, respectively. Coefficient of variation was highest around 47.8% during post-monsoon period, whereas it was lowest (10%) during south-west monsoon season. Analysis of long period change over more than 100 years of the monsoon season (June-September) rainfall for India taken as one unit was 85 cm, with a coefficient of variability of 10% based on area weighing of uniform network of 306 plain stations by Parthasarathy *et al*. (1993).

Trend in maximum temperature

Annual maximum air temperature trend was studied in three phases i. e. 1st is the trend of first half of 60 years (1941-70), 2nd is the trend of 2nd half of 60 years and 3rd is the overall 60 years. Trend of 1st half 30 years from 1941-70 was found to decrease by 0.04ºC and 2nd half by 0.008ºC with an overall trend during 60 years decrease by 0.031ºC. Mean of 1st half was found more in comparison to 2nd half. Seasonal trend of maximum temperature was found to decrease by 0.04ºC in summer, 0.01ºC in south-west monsoon, 0.02ºC in post-monsoon and 0.05ºC in winter seasons. Decreasing trend was more significant in winter season and least significant in south-west monsoon season (Table 2).The decreasing trend per year in maximum air temperature was noticed particularly in winter months. This cooling effect was due to increase in cropping intensity and irrigation facility in the region. During second half period, an increasing trend was recorded in maximum temperature and this warming trend was due to increase in CO2 concentration due to industrialization and deforestation. Hingane *et al*. (1985) analysed seasonal and annual surface air temperature for 90 years during the past century for 73 stations and reported a significant warming effect of about 0.40C in 100 years.

Trend in minimum temperature

A warming of 0.003º, 0.002º and 0.03ºC per year was found in the annual minimum temperature during 1941-1970, 1971-2000 and 1941-2000, respectively. The highest per year change of -0.06ºC for the period 1941-2000 in minimum

Table 1: Mean, standard deviation (SD) and coefficient of variations (CV) of maximum, minimum temperature and rainfall of arid zone of Haryana

Period	Maximum temperature			Minimum temperature			Rainfall (mm)		
	Mean (^{0}C)	SD (^{0}C)	CV (%)	Mean (^{0}C)	SD (^{0}C)	CV (%)	Mean (^{0}C)	SD (^{0}C)	CV (%)
Annual									
1949-2070	31.3	0.7	2.2	15.8	0.5	3.1	440.8	145.1	32.9
1971-2000	30.3	0.6	2.1	14.6	0.6	4.4	454.8	162.4	35.7
1941-2000	30.8	0.8	2.7	15.4	0.8	5.5	473.8	152.9	32.3
Seasonal									
Summer season (March-May)	35.7	1.5	4.2	18.5	1.4	7.4	35.3	12.2	34.6
SW-Monsoon (June- Sept.)	36.8	1.0	2.6	25.6	1.0	4.0	356.7	35.7	10.0
Post-monsoon (Oct.-Dec.)	28.5	1.3	4.6	10.9	1.2	11.1	23.4	11.2	47.8
Winter season (Jan.-Feb.)	22.3	1.5	6.7	6.4	1.2	18.1	58.4	10.9	18.7

temperature was recorded in summer season, whereas the lowest in post-monsoon season by -0.01ºC during this period (Table 2). Both cooling and warming trends were observed during 1st and 2nd half periods under study.

Trend in rainfall

Rainfall trend has been calculated on annually and seasonal periods. Rainfall increased by 1.2 mm per year for a period of 30 years (1941-1970) and decreased by 0.34 mm per year for the second half 30 years (1971-2000). An increasing trend by 0.45 mm per year was indicated for the period of 60 years (1941-2000). Seasonal trend in rainfall was found to increase in summer and winter seasons by 0.61 and 0.17 mm year^{-1} over the period of 60 years (1941-2000) but showed a decrease in rainfall trend in south-west monsoon and post-monsoon periods by 0.23 and 0.10 mm per year over the same period. Increasing rainfall trend was found in summer and winter months with highest value of the order of 0.54 mm per year (Table 2).

Effect of temperature

The simulated phenology and grain yield by CERES models in wheat and pearl millet crops under different cooling and warming scenarios of temperature are presented in Table 3. The increase in the temperature of 0.1 0.3, 0.5, 1.0 and 2.0ºC advanced the maturity of wheat by 0, 1, 2, 4 and 7 days, whereas decrease in the temperature of 0.1, 0.3, 0.5, 1.0 and 2.0ºC delayed the maturity by 0, 1, 2, 4 and 10 days from normal, respectively. Pearl millet maturity remained unaffected with increase or decrease in temperature of 0.1 and 0.30C from normal values. With further increase or decrease in temperature by 0.5, 1.0 and 2.00C from normal values maturity was advanced and delayed by 1, 3, 5 and 2, 3, 6 days from normal, respectively.

Grain yield of wheat decreased by 0.5, 0.9, 1.4, 6.4 and 7.3% and increased by 1.8, 3.1, 4.8, 8.8 and 15.2% from their normal values of 5061 kg ha^{-1} (Table 3) with the changes in temperature of ±0.1, ±0.3, ±0.5, ±1.0 and ±2.0ºC above and below the normal values, respectively. Pearl millet grain yield decreased by 1.2, 2.3, 3.3, 7.6 and 11.3% and increased 1.7, 2.6, 3.1, 4.9 and 10.9% from normal of 2617 kg ha^{-1} with temperature change levels of ±0.1, ±0.3, ±0.5, ±1.0 and ±2.0ºC above and below the normal, respectively. These results are supported by the results reported by Mathauda and Mavi (1994). Mahi *et al*. (1991) reported that wheat yield declined by 5% when temperature was increased by 10C under Punjab conditions.

Effect of rainfall

The 30% increase in rainfall advanced the flowering and maturity of wheat by 1 day, whereas the decrease of rainfall by 30% from normal, flowering and maturity was delayed by 4 and 2 days from normal values. Flowering of pearl millet crop was not affected with the increase of rainfall by 30%, whereas maturity of the crop was delayed by two days from normal value with the decrease of rainfall by 30%.

Grain yield increased from 2.0 to 15.6% and decreased

Table 2: Trends in maximum, minimum temperature and rainfall (1941-2000) of arid zone of Haryana

Period	Mean (0C)	Mean of the 1st half of the total years (°C/year)	Slope of the 1st half of the total years (°C/year)	Mean of the 2nd half of the total years (°C/year)	Slope of the 2nd half of the total years (°C/year)	Trends/year (1941-2000) (°C/year)
Maximum temperature						
Summer season (March-May)	35.7	36.2	-0.07	35.1	.0006	-0.04
Monsoon season (June-Sept.)	36.8	37.1	-0.03	36.5	0.03	-0.01
Post-monsoon season (Oct.-Dec.)	28.5	28.7	-0.04	28.3	-0.018	-0.02
Winter season (Jan.-Feb.	22.3	23.2	-0.006	21.4	-0.034	-0.05
Annual			-0.0395		-0.0076	-0.0305
Minimum temperature						
Summer season (March-May)	18.5	19.0	-0.017	17.1	-0.015	-0.06
Monsoon season (June-Sept.)	25.6	26.1	0.008	25.1	0.031	-0.03
Post monsoon season (Oct.-Dec.)	10.9	11.1	0.012	10.6	-0.03	-0.01
Winter season (Jan.-Feb.	6.4	6.9	0.018	5.8	0.056	-0.02
Annual			0.0034		0.0021	-0.0302
Rainfall						
Summer season (March-May)	35.3	23.1	0.41	58.2	-0.28	0.61
Monsoon season (June-Sept.)	356.7	358.9	-0.05	356.2	0.04	-0.23
Post monsoon season (Oct.-Dec.)	23.4	31.0	-0.22	25.8	0.12	-0.10
Winter season (Jan.-Feb.	58.4	18.7	-0.13	36.0	0.26	0.17
Annual			1.2256		-0.3377	0.4541

from 2.5 to 13.7% from normal yields of wheat with the increase and decrease of rainfall from 5 to 30% (Table 3). Grain yield of pearl millet also showed a similar trend with the increasing or decreasing of amount of rainfall. Pearl millet grain yield increased from 6.4 to 18.8% and decreased from 4.5 to 17.5% from normal yield values with the increase or decrease of rainfall from 5 to 30% from its normal value. Similar results were reported by Parry and Carter (1988).

CONCLUSION

Annual maximum and minimum temperature showed a decreasing trend during the period of 60 years (-0.310C year^{-1}), but in last 30 years showed an increasing trend (.00870C year^{-1}). An increasing trend of 0.45 mm per year in annual rainfall was observed for the period of 1941-2000. CERES-Wheat model predicted yield with a variation of -7.3 to 15.2% under different temperature scenarios (±0.1, ±0.3, ±0.5, ±1.0 and ±2.0ºC), whereas CERES-Millet under same scenarios predicted a variation of -10.9 to 11.3% of the actual yield of pear millet. The results indicated that warm temperature scenarios caused an adverse effect on yield of wheat and pearl millet by hastening the physiological maturity.

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Table 3: Effect of climate change scenarios on phenology and grain yield of wheat and pearl millet in arid zone of Haryana

Climate change scenario	Wheat			Pearl millet		
	Flowering (days)	Maturity (days)	Grain yield (kg ha^{-1})	Flowering (days)	Maturity (days)	Grain yield (kg ha^{-1})
Normal (DAS)	98	142	5061	43	72	2617
Temperature scenario (^{0}C)						
-2.0	10	10	15.2	4	6	10.9
-1.0	4	4	8.8	2	4	4.9
-0.5	2	2	4.8	1	1	3.1
-0.3	1	1	3.1	0	0	2.6
-0.1	0	0	1.8	0	0	1.7
0.1	0	0	-0.5	0	0	-1.2
0.3	-1	-1	-0.9	0	0	-2.3
0.5	-2	-2	-1.4	-1	-1	-3.3
1.0	-3	-4	-6.4	-2	-2	-7.6
2.0	-6	-7	-7.3	-3	-3	-11.3
Rainfall scenario (%)						
-30	3	2	-13.7	2	1	-17.5
-20	1	1	-9.3	1	1	-12.2
-10	0	0	-4.1	1	0	-7.3
-5	0	0	-2.5	0	0	-4.5
5	0	0	2.0	0	0	6.4
10	0	0	3.6	0	0	10.2
20	-1	0	8.6	-1	0	13.1
30	-1	-1	15.6	-1	-1	18.8

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