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Research Article

Simulating maize yield study at enhanced level of temperature using CERES maize model DSSAT.4.7

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Abstract

Climate variability has been and continues to be the principal source of fluctuations in global food production in countries of the developing world and is of serious concern. Process-based models use simplified functions to express the interactions between crop growth and the major environmental factors that affect crops (i.e., climate, soils, and management) and many have been used in climate impact assessments. Mean yearly maximum and minimum temperature both shows an increasing trend for last 30 years. Climatic scenario from A1B scenario 2011-2090 extracted from PRECIS run shows that overall maximum and minimum temperature increase by 5.39 °C (±1.76) and 5.08 °C (±1.37). Decrease in yield with increase in temperature adopted the following order, Maximum (max.)+Minimum (min.) > Max. > Min. Maximum decrement of 16.86 q/ha in the yield was recorded when the both max. and min. temperature were increased by 4°C as compared to normal temperature accounts to about 38.7%. Max. temperature lead to staggering in the irrigation water productivity, however a consistent increase in the irrigation water productivity was realised with an increase in minimum temperature. Dry matter productivity of 50 kg DM /ha/mm [ET] was observed with the increase of 1°C in both Max. and Min. temperatures and the lowest value of (16.7 kg DM /ha/mm[ET]) was recorded when the crop is supposed to grow at enhanced level maximum temperature by +4 °C both maximum and minimum temperature. Increase in both the max and minimum temperature by +10°C lead to maximum irrigation water productivity of 22.4 (kg[yield]/ha/mm [irrig]) and the lowest irrigation water productivity of 16.7 (kg[yield]/ha/mm [irrig]) was registered when both max. as well as min. temp. was raised by +4°C minimum temperature.

Keywords: DSSAT; ceres maize model; enhanced temperature; dry matter- ET productivity

1. Introduction

Climate variability has significant influence on the production of crops owing to occurrence of extreme events as result of climate change (Field, 2012). It is projected that climate change would lead to global warming, which will influence the duration as well as yield of the crops.

Thus assessment of variability in climate would help in providing an important insight in decision making regarding the management of agricultural crops (Abbas *et al*., 2017).

Maize (*Zea mays* L.) is an important cereal crop cultivated throughout the world as staple food, being processed in different products serves an important source of income for vast majority of the people in developing countries. It is also used as one of the important sources of carbohydrates for human consumption and as feed for livestock (Undie *et al*., 2012). Globally maize occupies an area of 161.82 million hectares with the production of 844.36 million tonnes (FAO, 2017) and productivity of 5.22 tonnes ha^{-1}. Jammu & Kashmir which is located in the extreme North west of India is the traditional maize growing region of the country and is major crop of the Union Territory in terms of acreage with the production of 0.48 m tonne (D.E.S, 2015-16). In J&K, it is sown as *kharif* season crop with about 85 % of the area as rainfed and is as such prone to the vagaries of rainfall distribution. The average productivity of maize in J&K has nearly doubled in the past two decades, which can be attributed to horizontal area expansion under high yielding varieties. However, the genetic potential of the improved varieties is at least three times the present productivity of the union territory of J&K.

Maize crop is highly sensitive to the environmental variability. Lobel *et al.,* (2011) observed a decrease in grain yield by 1% with the elevation in temperature above 30°C under normal growing condition and 1.7% under drought stressed condition in maize. Thus to augment the productivity of maize for the uplifting small farm holders in the state it becomes imperative to manage the crop in changing environment.

Simulation models have been providing an important means to help in decision making to mitigate the risk associated with changing environment and to provide the stability for sustained production level. For long term climatic scenarios these models have been widely used to determine the impact of climate variability on crop production (Bassu *et al.,* 2014). A validated model with known genetic constants for varieties can be powerful tool for studying the performance of varieties in contrasting environments, soil types, diverse cultural practices and management inputs (Boote, 1999). Technological packages including optimum planting time, irrigation, plant population, suitable varieties and plant geometry can be designed using models. The CERES – maize model has been extensively tested under tropical conditions of Hawaii, Indonesia and Philippines (Singh, 1985) USA and Europe, Kenya (Keating *et al.,* 1991) and India (Rajireddy, 1991; Sheikh and Rao, 1996). The DSSAT v 4.5 CERES-Maize Crop Simulation Model which was tested over a wide range of environments (Tsuji et al., 1994; Hoogenboom *et al.,* 1999) has been successfully used in some parts of our country for management decisions and technology evaluation. Thus an attempt was made to predict the maize yield, water productivity and crop water use efficiency under the mentioned environmental modifications using DSSAT v 4.7 CERES simulation model.

2. Materials and methods

Study with respect to effect of enhanced levels of temperature on maize water productivity in the temperate region of Jammu and Kashmir using CERES maize model DSSAT 4.7 already calibrated and validated by Lone *et al.,* (2019) was carried out at Section of Agro-meteorology at main Campus of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar which is situated 16 Km away from city centre that lies between 34.08° N latitude and 74.83° E longitude at an altitude of 1587 meters above the mean sea level.

3. Results and discussion

3.1 Yield

Model simulation indicated that there was decrease in yield with the increase in temperature. This decrease in yield with increase in temperature adopted the following order, Max. +Min. > Max. > Min. Maximum decrement of 16.86 qt ha^{-1} in the yield was recorded when the both Max and Min. temperature increased by 4°C as compared to normal temperature accounts to about 38.7% (Table 4). This decrease in yield with the increase in temperature can be attributed to decrease in duration of the crop. Our results are in agreement with (Ali and Amin, 2006; Rahman *et al.,* 2018) who observed that at elevated temperature crop growth and development is accelerated leading to the shortening of life cycle which in turn causes the reduction in yield.

Table 1. Environmental modifications taken under study

Soil depth (cm)	Lower (m^3)	Upper (m^3)	SAT SW (m^3)	EXTR SW (m^3)	INIT SW (m^3)	Root (cm)	Bulk density (g/cm^3)	pH	NO_3 (ugN g-1)	NH_4 (ugN g-1)	OC (%)
0- 5	0.204	0.34	0.392	0.136	0.322	1	1.45	6.9	11.2	1.2	2.19
5-15	0.204	0.34	0.392	0.136	0.322	1	1.45	6.9	11.2	1.2	2.19
15- 25	0.209	0.345	0.39	0.136	0.322	0.75	1.45	7.2	11.2	1.2	1.21
25- 35	0.209	0.345	0.39	0.136	0.322	0.5	1.45	7.2	11.2	1.2	1.21
35- 50	0.198	0.335	0.39	0.137	0.281	0.35	1.49	8	11.2	1.2	0.53
50- 65	0.185	0.323	0.395	0.138	0.257	0.2	1.58	8.2	11.2	1.2	0.2
65- 80	0.185	0.323	0.395	0.138	0.244	0.15	1.58	8.2	11.2	1.2	0.2
80- 99	0.201	0.328	0.408	0.127	0.239	0.1	1.54	8.1	11.2	1.2	0.1
99-122	0.198	0.325	0.41	0.127	0.325	0.05	1.58	8.2	0.01	0.01	0.09

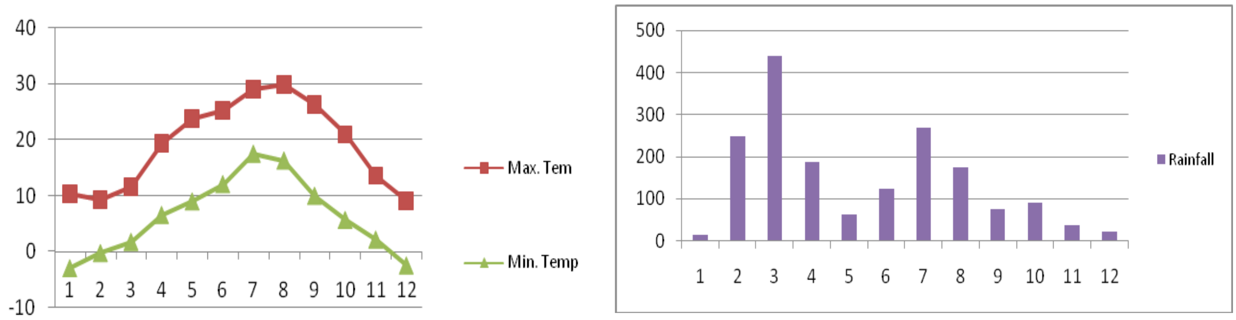

Fig 1: Mean monthly maximum, minimum temperature and rainfall of weather data used in DSSAT

Table 2: Environmental modifications taken under study

Environmental modifications tested
Normal
(Max+1)
(Max+2)
(Max+3)
(Max+4)
(Min+1)
(Min+2)
(Min+3)
(Max & Min+1)
(Max & Min+2)
(Max & Min+3)
(Max & Min+4)

Detailed soil profile data (Table 1) and weather information (Fig. 1) from Srinagar location was used according to the minimum data sets required for simulation in CERES–maize model as suggested by Jones and Kiniry (1986). CERES–maize model is a module within the DSSAT cropping system model (CSM). The DSSAT CSM can facilitate the evaluation of the effects of different weather parameters at enhanced or decreased level on crop yields, growth rates, water productivity, irrigation productivity and nutrient losses etc

At the same time, it also predicted the temporal changes in crop growth, nutrient uptake, water use, final yield as well as other plant traits, and outputs. Study carried out by Muslim *et al.,* (2015) shows that overall maximum and minimum temperature will increase by 5.39°C (±1.76) and 5.08°C (±1.37)). In our study we used Model (CERES maize) which has been already calibrated and validated in many studies under temperate conditions of Kashmir. Genetic coefficients calibrated and validated by Lone *et al.,* (2019) for same location were used to carry out the simulation studies (Table 2.) and environmental modifications taken under study are given in table 3.

Table 3: Already calibrated Genetic coefficients used in study

Coefficient	Unit	Definition	Value
P1	˚C day	Thermal time from seedling emergence to juvenile phase	280
P2	Days	Extent to which development is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 h).	0.30
P5	˚C days	Thermal time from silking to physiological maturity	789
G2	Number	Maximum possible number of kernels per plant.	650
G3	mg/day	Kernel filling rate during the linear grain filling stage and under optimum conditions	6.03
PHINT	˚C day	Phyllochron interval; the interval in thermal time between successive leaf tip appearances	48

3.2 Water productivity

In this study, it was observed that an increase in max. temperature staggered the irrigation water use efficiency and dry matter produced per unit of ET. However a consistent increase in the yield per unit of irrigation water was realised with an increase in minimum temperature (Fig.2-a). Increase in the both maximum and minimum temperature by +1⁰C lead to maximum irrigation water use efficiency of 22.4 (kg[yield]/ha/mm[irrig]), thereafter consistent decrease in irrigation water productivity was observed with lowest value of 16.7 (kg[yield]/ha/mm[irrig]) recorded when both max. as well as min. temp. was raised by +4⁰C minimum temperature. With regard to dry matter production per unit of ET data reflected that maximum value of 25.9 (kg[DM]/ha/mm[ET] was registered, when both Max.+ Min .temperature were raised by 1°C and lowest value of 16.7 (kg[DM]/ha/mm[ET] when crop will be supposed to grow at enhanced level maximum temperature by +4°C alone. (Fig.2-b).

3.3 Evaporation, transpiration, evapo-transpiration, crop water use efficiency

In general cumulative seasonal, evaporation, transpiration and evapo-transpiration were observed to follow a decreasing trend (Fig. 3). Simulation curve reflected that any deviation in terms of increase in temp. in max, min or both lead to decrease in total seasonal evaporation, transpiration and evapo-transpiration, from normal observed temperature. Soil evaporation was observed to decrease with increase in temperature. Though the effect was more noticeable with increase in maximum temperature. For every 1°C rise in both max. and minimum temperature a sharp decline in soil evaporation was realised, with percentage decrease of 21.7 % and 39.7 % when both Min.& Max temperature were increased by 1°C and 4°C, respectively over normal temperature. Maximum seasonal transpiration of 471 mm was observed at normal temperature and the lowest (416 mm) was observed when both max. a minimum temp. were increased by + 4 oC . Although the gradual decrease in transpiration was observed with the rise in max. temp. However, an increase in minimum temperature reflected in sharp decline. Furthermore, decline was more intense when both max. and min. temperature were increased with the decline of 13.22 %. Lowest total season evapo-transpiration, of 484 mm was recorded when temperature was elevated by 4°C (Max. & Min.) with the deviation of 16.94 % from the existing normal temperature. This decrease in transpiration with the increase in temperature can be attributed to limited stomatal conductance as a mechanism to halt the transpiration losses. Further the decrease in evaporation, transpiration and evapotranspiration can be attributed to reduction in the duration of the crop.

Crop water use efficiency (yield/ET (kg yield/ha mm[ET])) reflected a decline with increase in temperature, though the decline was steep with elevation in max. temperature and gradual , when min. and max.+ min temperature were raised and the lowest value registered with the deviation of + 4^{o}C in max. + min. temperature (Fig. 4-a). Increase in minimum temperature also followed the same trend, however drastic decrease in yield-ET productivity (kg[yield]/ha/mm[ET]) was observed at enhanced temperature of both maximum and minimum temperature by +4^{o}C. This decrease in crop water use efficiency with elevation in temperature can be attributed to suboptimal level of photosynthesis owing to low stomatal conductance and higher maintenance respiration needs (Rezaei et al., 2015).

4. Nitrogen Uptake

With regard to nutrient uptake in grain a highest value of 74 kg/ha was registered with normal temp and the lowest

Table 4: Simulated yield and other data recorded

Treatment	Harvest weight at maturity	Total season evapotranspiration, Simulation-harvest (mm)	Total season transpiration (mm)	Total season soil evaporation (mm)
Normal	4357	566	471	95
(Max+1)	4261	550	462	88
(Max+2)	3843	541	458	82
(Max+3)	3547	539	460	79
(Max+4)	3213	530	452	77
(Min+1)	4110	547	458	89
(Min+2)	3858	536	452	84
(Min+3)	3590	525	444	82
(Max & Min+1)	4141	522	439	83
(Max & Min+2)	3250	509	431	78
(Max & Min+3)	3041	497	423	75
(Max & Min+4)	2671	484	416	68

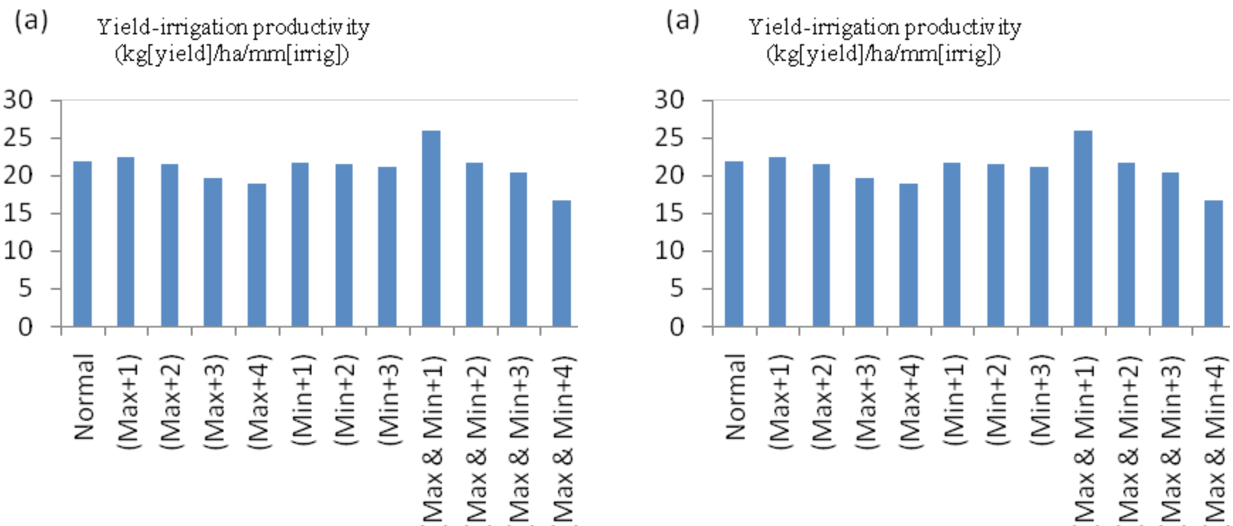

Figure 2a and b: Simulation of yield irrigation water productivity and drymatter/unit of ET

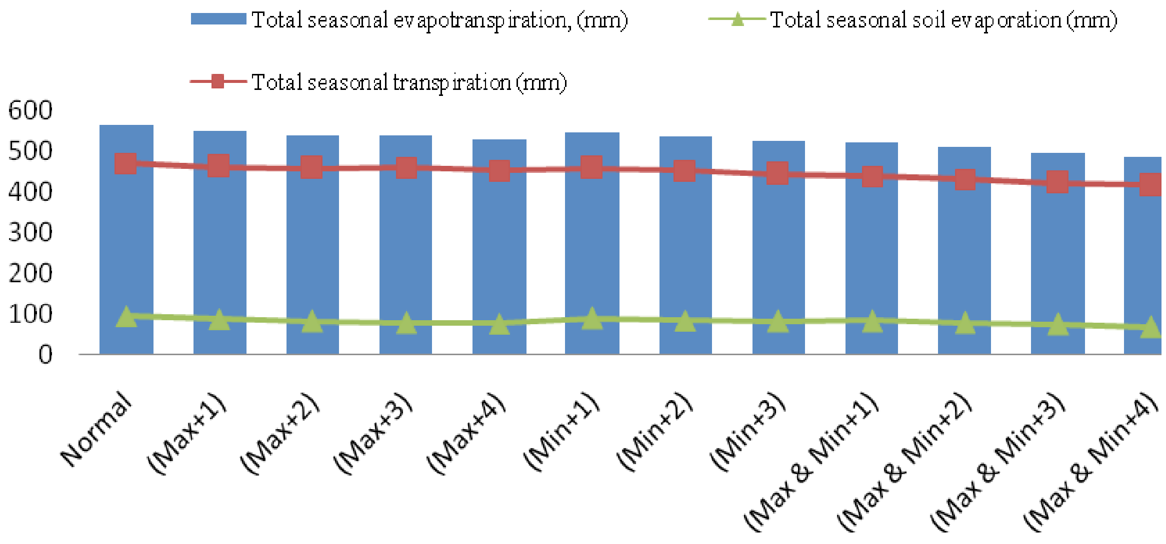

Figure 3: Simulated seasonal cumulative evaporation, transpiration and evapotranspiration

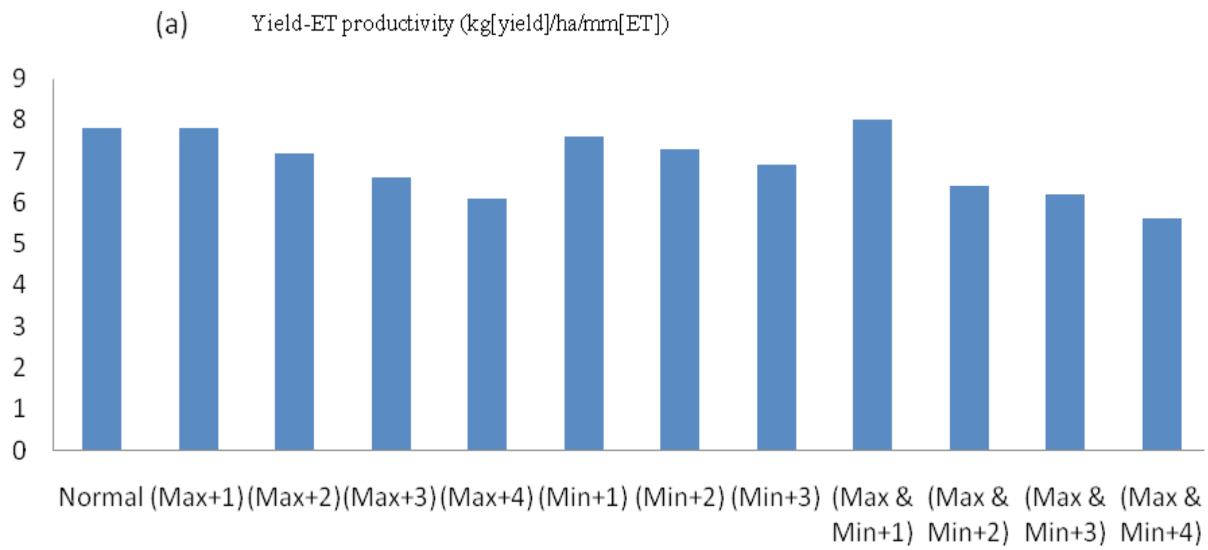

Figure 4a: Simulated crop water use efficiency (a) Yield-ET productivity

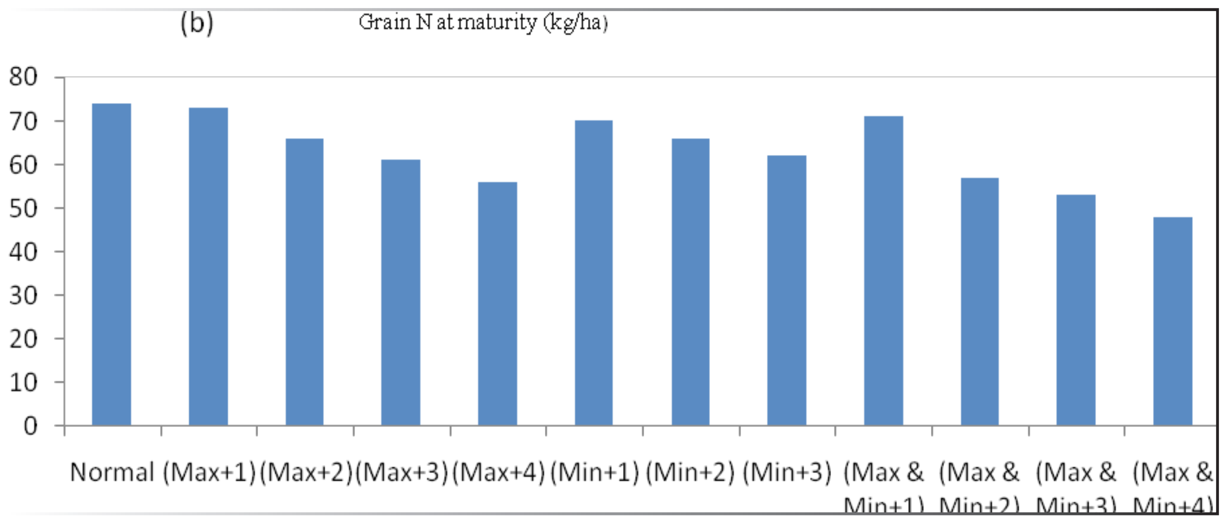

Figure 4b: Simulated crop water use efficiency (a) Grain N at maturity (kg/ha)

nitrogen uptake (48 kg/ha) was recorded when both maximum and minimum temperature were increased by +4°C, However, an increase in temperature irrespective of maximum, minimum or both resulted in continuous decline in grain nitrogen content. More definite effects of decreased grain nitrogen content at harvest were realised with every 1°C increment in maximum temperature as against minimum temperature(Fig.4-b).

5. Conclusion

The CSM-CERES-Maize Model was well validated under the temperate condition of Kashmir and has shown the great scope of using this model as a tool for estimating yield. Increase in temperature, solely or in combination of minimum and maximum temperature lead to decrease in grain yield, irrigation water productivity, evaporation, transpiration and ET. However increase in temperature by 1°c in combination Max.+ Min. lead to improvement in all parameters further increase in either in maximum or minimum temperature or combination of both decrease the maize irrigation productivity and yield.

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