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Studying Yield and Water Productivity of Maize at Enhanced Level of Temperature Using DSSAT 4.7.5

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Authors' contributions

This work was carried out in collaboration among all authors. Author BAL designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AF, SQ, NAD, ZAD, PS, SK and FR managed the analyses of the study. Authors NA and NM managed the literature searches. All authors read and approved the final manuscript.

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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. Agriculture, with its allied sectors, is unquestionably are highly dependent on weather conditions, any weather aberrations cause atmospheric and other forms of stress and in turn, will increase the vulnerability of these farmers to economic losses. 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. The 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). A decrease of about 20 quintals was recorded when maximum temperature was enhanced by +4°C and about 10 quintals decreased at +2°C. Enhancement of minimum temperature by +3°C shows a decrease of about 16 quintals in tops weight. Combination of both minimum and maximum temperature remarkably decreased grain yield at (maximum & minimum +2°C) up to 25.41%. Max. temperature

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lead to staggering in the irrigation water productivity, however, a consistant 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 the both max and minimum temperature by +1°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 registerd when both max. as well as min. temp. was raised by +4°C minimum temperature.

Keywords: DSSAT; CERES maize model; enhanced temperature; yield; dry matter-ET productivity.

1. INTRODUCTION

Maize is widely cultivated throughout the world and produced each year greater than any other grain. Maize is cultivated on an area of 161.82 million hectares in the world with production of 844.36 million tonnes FAO, [1] and productivity of 5.22 tonnes ha^{-1}. The average yield of 1566 kg/ha D.E.S, 2015-16, [2] of this crop has also nearly doubled since 2000. This increase in yield has been mainly achieved by an increase in the area under high yielding varieties. However, the genetic potential of the improved varieties is at least three times of the present average yield of the state. Sweet corn grown under temperate conditions of Kashmir should be grown with an integrated nutrient management approach Shahid Rasool et al. [3]. A validated model with known genetic constants for varieties can be used as a powerful tool for studying the performance of varieties in contrasting environments, soil types, diverse cultural practices and management inputs Boote, K.J., [4]. The DSSAT v 4.5 CERES-Maize Crop Simulation Model which was tested over a wide range of environments Tsuji et al. [5]; Hoogenboom et al. [6] has been used in present investigation. The fundamental difficulty in all the models was that, most of them were based on collection of hypothesis and hence cannot be validated inherently Oreskes et al. [7]. The CERES – maize model has been extensively tested under tropical conditions of Hawaii, Indonesia and Philippines Singh [8] USA and Europe, Kenya Keating et al. [9] and India Rajireddy [10]; Sheikh and Rao [11]. The CERES-maize model was calibrated for the US corn belt by deriving varietal coefficients for each station based on minimal growth stages and yield data. Hence, validation is the essential process in modelling and ensures that models perform correctly when tested against observed dat Srinivasarao et al. [12]; Bal and Minhas [13].

The impact of climate, the fact is that climate change is real. Indian agriculture is likely to suffer losses due to heat, erratic weather, and decreased irrigation availability Lone et al. [14]. Future crop production will be adapted to climate change by implementing alternative management practices and developing new genotypes that are adapted to future climatic conditions. Long term weather data of Kashmir valley revealed (Fig. 1) that there is increasing trend in temperature both maximum and minimum. Average annual maximum and minimum temperature has increased by 1°C during last 30 years. The objective of this study is to calibrate, Validate and evaluate the CSM–CERES–maize model's ability in simulating yield of Maize at enhanced levels of temperature. Maize crop is highly sensitive to the environmental variability. Lone et al., 2011 observed a decrease in yield of maize by 1% with the elevation in temperature above 30°C under normal growing condition and 1.7% under drought stressed condition. 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.

2. MATERIALS AND METHODS

Field experiment was conducted for model calibration and Validation. Experiment was laid in split-plot design assigning three planting dates 22nd May (D_1), 30th May (D_2) and 8thJune (D_3) main plots and Four Nitrogen levels 80 $kgNha^{-1}$(N_1),120 $kgNha^{-1}$(N_2),160 $kgNha^{-1}$(N_3) and 200 $kgNha^{-1}$(N_4)sub-plots at research farm Division of Agronomy 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. The average annual precipitation over past twenty five years is 786 mm and more than 80 per cent of precipitation is received from western disturbances during winter/spring months. The mean maximum and minimum temperature for entire crop growth period of maize crop was 33.5 and 20.0°C, respectively and corresponding values. Future climate for 2011-2090 from A1B scenario extracted from PRECIS run shows that overall maximum and minimum temperature increase by 5.39°C (±1.76) and 5.08°C(±1.37) also precipitation will decrease by 3094.72 mm to 2578.53 (±422.12).

Detailed soil and weather information from Srinagar location and season were collected according to the minimum data sets required for calibration of CERES–maize model as suggested by Jones and Kiniry (1986). Soil properties (Table.1) of location which shows that the soil was silty clay loam, with neutral in reaction and medium in available nitrogen, phosphorus and potassium. 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 production practices on crop yields, growth rates, and nutrient losses, and also it helps improve our understandings of crop physiology, genetics, soil management, and weather effects on crop production and environmental quality (Cabrera et al., 2007;). DSSAT 4.7 is a software package which was used to access the impact of enhanced levels of maximum and minimum temperature on growth development and yield of maize. Jones et al. [15].

On the basis of above, the following environmental modifications Table 2 were studied with respect to growth, yield and water productivity of maize using CERES maize model. Yearly mean maximum and yearly mean minimum temperature from 1980 to 2016 at the location of the study reveals that there is increasing trend in both maximum and minimum temperature (Fig. 1 and Fig. 2). Using DSSAT, Jones and Thornton [16] and Lobell and Benziger [17] simulated the impact of climate change on maize production in Africa and Latin America and showed that there is 10% decrease in aggregate maize production by 2055.

Keeping this in consideration study was carried out with the objective to access the impact enhanced levels of temperature on growth yield and water productivity of maize.

2.1 Model Calibration

For simulation of CERES maize model, minimum data sets (MDS) on crop management, macro and micro-environmental parameters associated with weather, soil and crop are required as input. Input data files of CERES-maize model are as per IBSNAT standard input/output formats and file structure described in DSSAT v.4.7.5 Hoogenboom et al. [5] Hoogenboom et al. [18,19]. Model was run repeatedly till simulated yield was close with observed yield. The available data included planting date, germination date, emergence date, anthesis date, maturity date, maximum LAI, grain yield and stover yield.

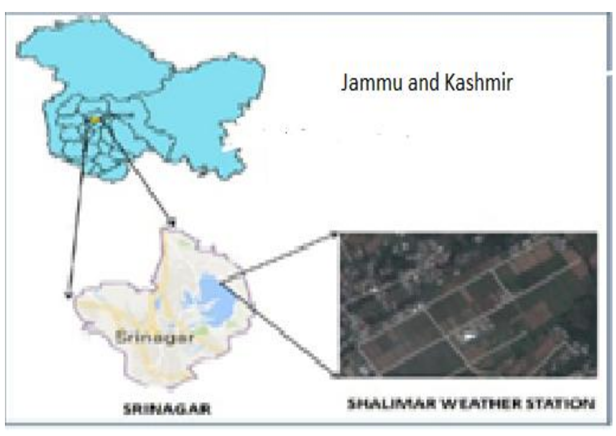
3. RESULTS AND DISCUSSION

Observed weather data of Shalimar main campus of University for growing seasons 2015 was used for calibrating the coefficients of maize cultivar. The coefficients for cultivar were estimated from field experiment by adjusting coefficients until close match were achieved between simulated and observed phenology and yield. Model was run repeatedly till simulated yield was close with observed yield. Prediction capabilities of the model were tested by judging the performance of the crop in terms of LAI, grain yield, Stover yield and biological yield.

Validation between observed data sets and simulated data sets was carried out with treatment combinations of twelve {Three planting dates 22nd May (D_1), 30th May (D_2) and 8th June (D_3) and Nitrogen Levels 80 kg Nha^{-1} (N_1),120 kg Nha^{-1} (N_2) ,160 kg Nha^{-1} (N_3) and 200 kg Nha^{-1} (N_4) }. The agreement between simulated and observed LAI was good. Observed LAI ranged from 1.24 to 5.97compared to Simulated 2.39 to 6.32 for LAI under different treatment combinations (Fig. 3). The RMSE (Root mean square error) and Mean observed and predicted values for all the treatments was 0.72 and 0.53. Maize sown on 30th May (D_1) gave the maximum observed LAI which decreased with delayed sowing. Validation results revealed that maize grain yield could be predicted well. Observed and simulated grain yield ranged between 42.43 to 57.40 q ha^{-1}. The RMSE for the grain yield was 1.90 q ha^{-1} and mean value of 3.64 indicating observed and simulated data matched well. The comparison of observed and predicted grain yields both over and underestimated by the model; however, the trend noted for the field-observed and model simulated grain yields matched well. The comparison of observed and predicted Stover yields both over and underestimated by the model however, the trend noted for the field-observed and model simulated Stover yields matched well . Simulated and observed yield (q ha^{-1}) was good (Figs. 5 and 6). Also Simulated Vs observed biological predicted well (Fig. 2).

Deviation in maturity from normal was observed while increasing maximum temperature by 1°C to 4°C and minimum from 1°C to 3°C and combination of both. Maize shows early maturity by 6 days with an increase in maximum temperature by 1°C. Increase in maximum temperature by +2°C, +3°C and +4°C maize crop matures earlier by 9, 11 and 15 days respectively. Increase in minimum temperature alone also shows decrease in maturity date by 5, 9 and 12 days at an increase of +1°C , +2°C and +3°C respectively (Table 3, Fig. 7). At combination of both maximum and minimum temperature increase by +1°C maize matures earlier by 10 days. Increased level of maximum and minimum temperature by +2°C , 3°C and 4°C, maize shorten its duration by 15, 20 and 26 days respectively which implies the growth duration is decreased so yield also will be decreased at enhanced levels of temperature. Jones and Thornton [15], also simulated the impact of climate change on maize production in Africa and Latin America and showed that there is 10 % decrease in aggregate maize production by 2055. The intergovernmental panel on climate change (IPCC) has projected that the global mean surface temperature is predicted to rise by 1.1 – 6.4°C by 2100 with the different amplitudes of temperatures and CO_2 for different scenarios of 2020, 2050 and 2080 IPCC, [20].

Tops weight goes on decreasing as maximum temperature was enhanced from normal to +1°C, +2°C, +3°C and +4°C and minimum temperature enhanced by +1°C, +2°C and +3°C also combination of both enhanced levels of (maximum and minimum temperature) also decreased the tops weight this may be attributed because of early maturity of crop. On higher temperature crop shifts earlier and maturity gets decreased and ultimately the decrease in tops yield. Decrease of about 20 quintals was record when maximum temperature was enhanced by +4°C and about 10 quintals decreased at +2°C enhancement of minimum temperature by +3°C shows decrease of about 16 quintals in tops weight. Maize grain yield goes on decreasing as we increase maximum or minimum temperature deviation in grain yield of about 26% decrease was at maximum temperature increase by +4°C at +3°C and 18% and 12% at +2°C increase in minimum temperature by 1°C shows decreased in grain yield by 5.67% and at +2°C 11.45% and 17.6% + 3°C (Fig. 10). Combination of both minimum and maximum temperature remarkably decreased grain yield at (maximum & minimum +2°C) upto 25.41% (Table 4, Fig 9). High temperature hastens the crop phenology; doubling temperature variability can reduce the maize yield upto 50% Wheeler et al. [21]. Lone et al. [22] also observed that elevation of maximum and minimum temperature by 4°C anthesis and maturity of maize was 14 days earlier with a deviation of 18% and 26 days with a deviation of 20% respectively (Table 5, Fig. 7).



Map 1. Location of the site

Chart 1. Genetic coefficients of maize cultivar

Cultivar	Parameters					
	P-1	P-2	P-5	G-2	G-3	PHINT
C4	280	0.3000	789	650	6.030	48.00

3.1 Water Productivity

In this study it was observed that an increase in Max. temperature lead to staggering in 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 max and minimum temperature by +1°C lead to maximum irrigation water use efficiency of 22.4 (kg[yield]/ha/mm[irrig]), thereafter consistently 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 +4°C 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. 11a)

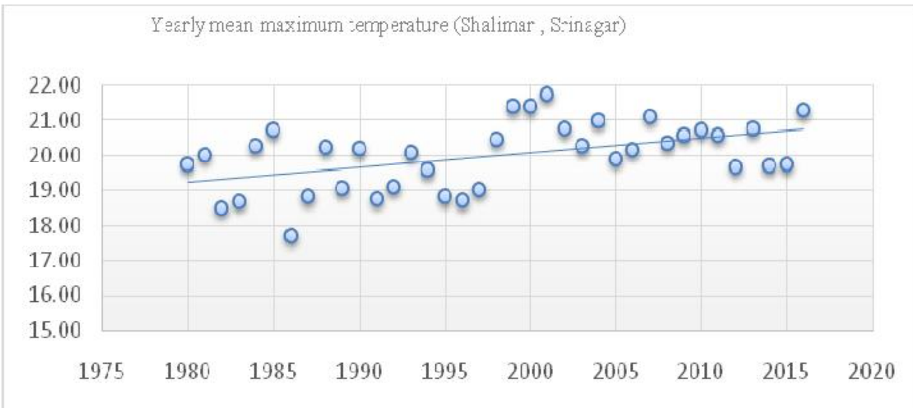


Fig. 1. Yearly mean maximum temperature (Shalimar, Srinagar) from 1980 to 2016

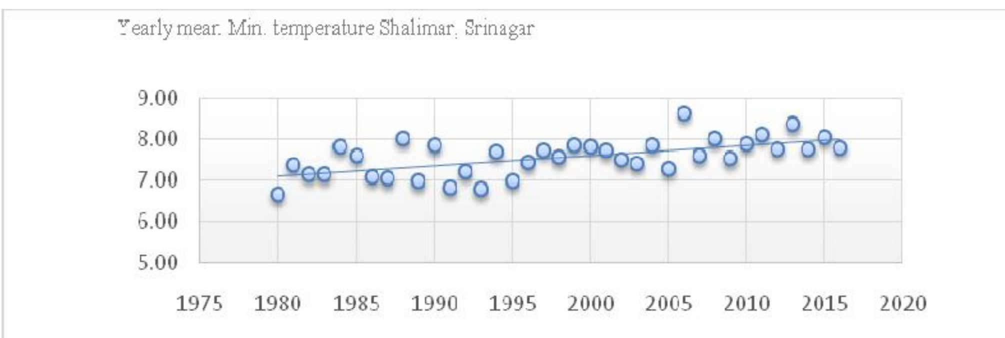


Fig. 2. Yearly mean minimum temperature (Shalimar, Srinagar) from 1980 to 2016

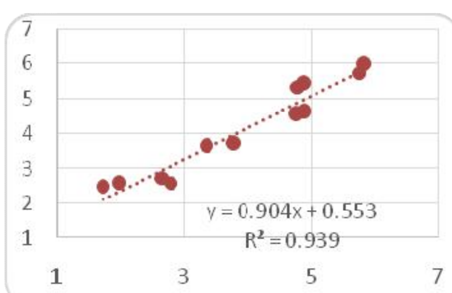


Fig. 3. Simulated Vs observed LAI weight of maize

Table 1. Soil profile data

Soil depth cm	Lowercm3 /c	Upper limit m^3	Sat Sw cm3/cm^3	Extr. SW cm	Init. S W 3/cm^3	Root D.	Bulk density g/cm^3	pH	NO3 ugN/g	NH4ugN /g	OR.C. %
0- 5	0.204	0.34	0.392	0.136	0.322	1	1.45	6.9	11.2	1.2	2.19
15-May	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

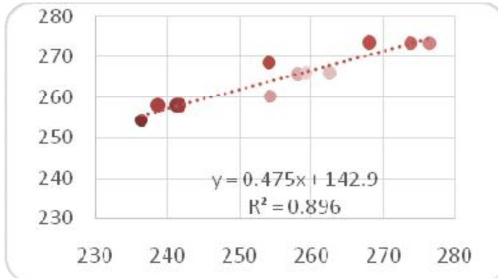


Fig. 4. Simulated Vs observed biological

Table 2. Environmental modifications studied

Environmental modifications studied
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)

Table 3. Simulated results at enhanced levels of temperature obtained from DSSAT. 4.7

Treatment	Maturity date	Culm weight at maturity	Harvest weight at maturity	Biological weight at harvest
Normal	252	26276	4357	22109
(Max+1)	246	25851	4261	21776
(Max+2)	243	25295	3843	21646
(Max+3)	241	25047	3547	21698
(Max+4)	237	24257	3213	21236
(Min+1)	247	26000	4110	22079
(Min+2)	243	25032	3858	21360
(Min+3)	240	24690	3590	21294
(Max & Min+1)	242	25825	4141	21872
(Max & Min+2)	237	24682	3250	21631
(Max & Min+3)	232	23771	3041	20922
(Max & Min+4)	226	22733	2671	20252

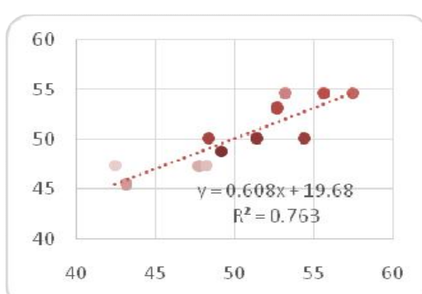


Fig. 5. Simulated Vs observed grain yield

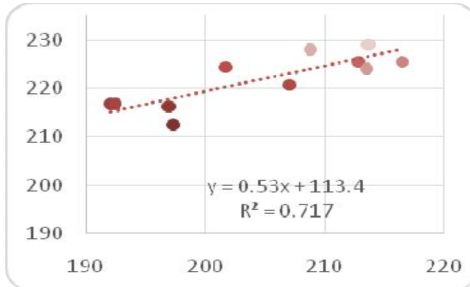


Fig. 6. Simulated Vs observed stover yield

Table 4. Deviation in maturity, tops weight and grain yield as a function of enhanced levels of temperature

Treatment	Deviation in days from normal maturity	Deviation from normal Tops weight yield kg/ha	Deviation from normal Grain yield kg/ha
Normal	-	-	-
(Max+1)	-6	-425	-96
(Max+2)	-9	-981	-514
(Max+3)	-11	-1229	-810
(Max+4)	-15	-2019	-1144
(Min+1)	-5	-276	-247
(Min+2)	-9	-1244	-499
(Min+3)	-12	-1586	-767
(Max & Min+1)	-10	-451	-216
(Max & Min+2)	-15	-1594	-1107
(Max & Min+3)	-20	-2505	-1316
(Max & Min+4)	-26	-3543	-1686

Table 5. Deviation in maturity as a function of enhanced levels of temperature

Treatment modifications	%Deviation from normal biological yield	%Deviation from normal Grain yield
Normal	-	-
(Max+1)	-1.62	-2.20
(Max+2)	-3.73	-11.80
(Max+3)	-4.68	-18.59
(Max+4)	-7.68	-26.26
(Min+1)	-1.05	-5.67
(Min+2)	-4.73	-11.45
(Min+3)	-6.04	-17.60
(Max & Min+1)	-1.72	-4.96
(Max & Min+2)	-6.07	-25.41
(Max & Min+3)	-9.53	-30.20
(Max & Min+4)	-13.48	-38.70

3.2 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. 4) 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 produced with increase in Max. temperature. With every 1°C rise in temperature 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°C. Though 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 evapo-transpiration 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°C in Max. + Min. temperature (Fig. 11b). 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°C. Same result was seen by Muslim et al. [23]. This decrease in crop water use efficiency with elevation in temperature can be attribute to suboptimal level of photosynthesis owing to low stomatal conductance and higher maintenance respiration needs (Rezaei et al. [24].

Table 6. Simulated harvested weight, total season evapotranspiration, total season transpiration, total season soil evaporation

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

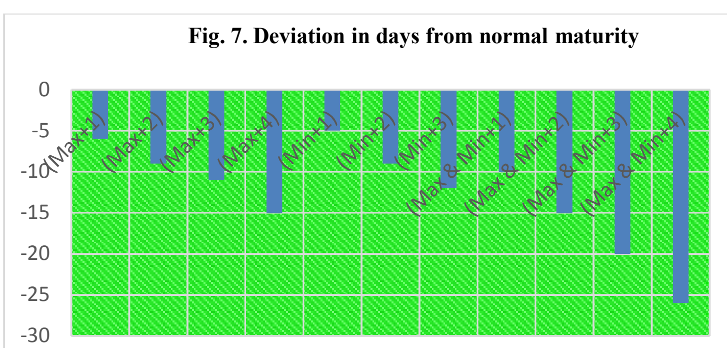


Fig. 7. Deviation in days from normal maturity

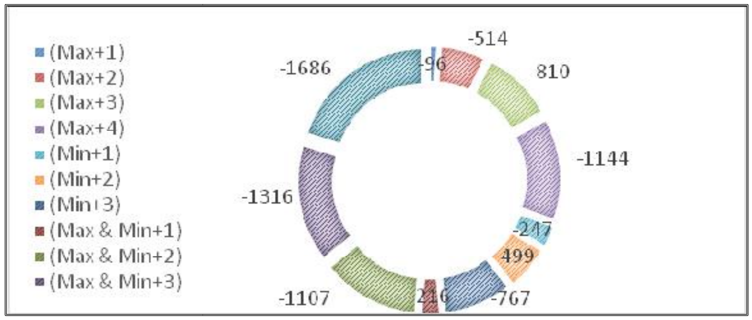


Fig. 8. Deviation in kg grain yield/ha

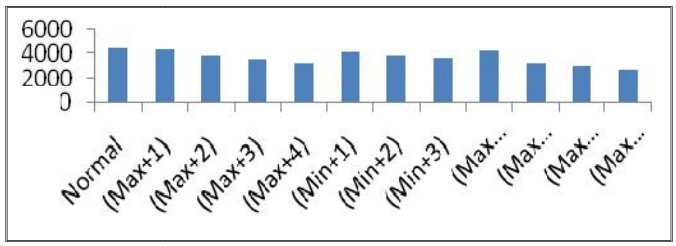


Fig. 9. Harvest weight at harvest kg grain yield /ha

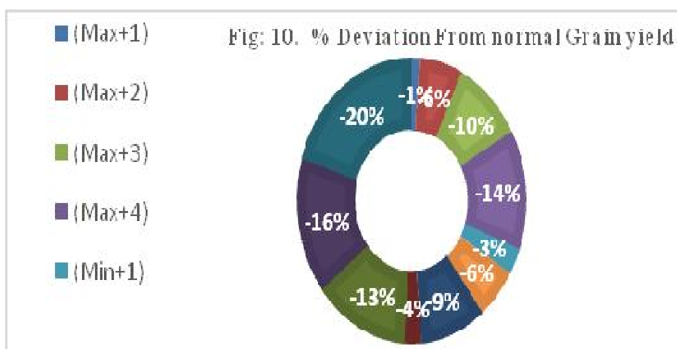


Fig. 10. % Deviation from normal grain yield

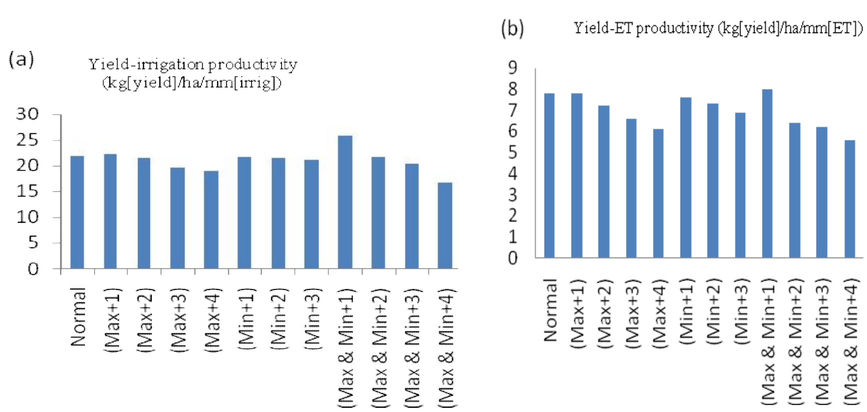


Fig. 11. Simulation of yield irrigation productivity and Yield ET productivity

4. CONCLUSION

For higher productivity and increasing demand of the maize, we should follow the climate change adaptation studies especially for Composite breeds and specialty maize. 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 and yield gaps and study on different climatic scenarios. For wider application of models and using it for better decision support system, there is a real need of further testing and verification of model in different agroecological areas of Kashmir. Increase in the maximum temperature, minimum temperature or combination of both adversely affect the growth and yield of maize under temperate conditions of Kashmir (Lone et al., 2019). Further studies needs to be carried out with respect to different maize verities for tolerance against the enhanced levels of temperature for future use. 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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