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Application of csm- ceres-maize model for seasonal and multi-decadal predictions of maize yield in under subtropical condition of Chitwan, Nepal

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ABSTRACT

The average maize yield of 2.5 t/ha in sub-tropical terai and inner terai of Nepal has been very less than its potential yield of about 5.0 t/ha, for which changing climatic scenarios have been reported the critical factors. Cropping system Model (CSM)-Crop Estimation through Resource and Environment Synthesis (CERES)-Maize, embedded under Decision Support System for Agro-technology Transfer (DSSAT) ver. 4.2 was evaluated from a datasets of field experimentation by growing four diverse maize genotypes viz. full season OPV (Rampur Composite), Quality Protein Maize (Posilo Makai-1), Hybrid (Gaurav) and Pop corn (Pool-12) under three different planting dates (September 1, October 1 and November 1) in 2009-10 at Rampur Campus, Chitwan. The experiment was laid out in two factor factorial randomized complete block design (RCBD) with three replications in slightly acidic (pH 6.7) sandy loam soil having low soil available N(0.49%) and K (148 kg/ha) and medium P (16.3 kg/ha) status. The ancillary and yield data obtaining from field experiment was analyzed from the M-Stat C software and recorded that Gaurav hybrid produced significantly higher yield under September 1 planting (5.86 t/ha) followed by Posilo Makai 1 (5.55 t/ha), Rampur Composite (5.1t/ha) and the least with Pool-12 (3.45 t/ha). Further, the heat use efficiency of diverse maize genotypes were also calculated by using the mean temperature based accumulative heat unit system and found the stable yields only with Rampur Composite for all planting dates and the rest genotypes were suitable only to the early winter plantings. Model calibration was done by using September 1 planting date for all 4 maize genotypes while validation was accomplished by using the remaining treatments for predicting growth and yield of different maize genotypes. The year 2006- 07 was found 13, 18, 23 and 7% higher in producing the maize yield than the standard year 2009-10 for Rampur Composite, Posilo Makai-1, Gaurav and Pool-12, respectively. Further, the different climate change scenarios as advocated by IPCC (2007) for 2020, 2050 and 2080 from base line of 2009-10 was studied to simulate the growth and yield performance of diverse maize genotypes with September 1 planting date and found that there would be increment in winter maize yield up to 2020 scenario of climate change and the drastic yield loss would be on 2050 to 2080 scenarios under the present levels of agronomic management options and urged for the new climate change adaptation and mitigation production technologies.

INTRODUCTION

Maize (*Zea mays* L.) is the second most important staple food crop after rice in terms of area and production in Nepal (Adhikari, 2007) and third among major cereal crops in the world with the 146.7 m ha global areas and production of 699 m tones (Gupta *et al*., 2010).

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In the sub-tropical Nepalese terai and inner-terai including Chitwan, Bara, Parsa, Rupandehi and Nawalprasi districts are becoming popular for growing winter maize and the area under it has been increasing over the years with the depletion of mustard and wheat yields (MoAC, 2009). The higher yield of winter maize is the main reason for its easy and rapid adaptation and its coverage area is about 20-25% of total maize area in Nepal (Gurung, 2010). It has also been reported that the overall demand for maize will be increased by 6-8% per annum largely for the next two decades as a result of increased demand for food in hills and feed in terai, inner terai and this increased demand could only be met by increasing the productivity of maize per unit of land (NMRP, 2009).

Proper selection of planting time and genotypes play a key role in growth and development of growing crops. If matching properly, it ensures the adequate temperature for germination and growth, avoid extreme temperatures that could cause stress or difficulty in setting and developing seeds, provide adequate moisture for growth and completing life cycle of any crop and minimize other stresses during the growing period. But, due to the intensive cultivation practices (>300 % cropping intensity) in the major domain areas of terai and inner-terai of Nepal, winter maize planting time sometimes gets delayed due to the late harvest of the preceding crop or lack or surplus rainfall during September. Delayed planting particularly in late October to December, results poor yield due to low temperature induced delayed germination and slow vegetative growth Similarly, very early planting in late August or early September is not conducive to the maize growth and yields because of negative consequences of higher temperature and rainfall at the initial growth stages (NMRP, 2004). NMRP has already recommended more than two dozen varieties of maize in Nepal (NMRP, 2009) suited for different agro-ecological zones of Nepal of which the inbred maize cultivar Rampur Composite having potential yield of 5.0 t/ha has attainable yield of only about 3.5 t/ha, but the actual yield in farmer's field is far less i.e. 1.9 t/ha (NMRP, 2004). The specialty maize cultivars like hybrids, quality protein maize (QPM) and pop corns are the new diversification on maize plantings. The QPM seeds are the recent advancement in maize breeding in Nepal, where the cereal lacking amino-acids Lysine and Tryptophan can also be available. The protein profile of QPM maize is much better and it is 90% of milk protein while to the other maize it is only 40% (Gupta *et al.*, 2010). Gaurav, the single Nepalese hybrid genotype has very high potential yield of 9.0 t/ha with actual yield of 5.5 t/ha, however, could not become popular over the Indian hybrids in farmers field. Pop corns, the common snack item is a special maize group characterized by dwarf stature and high N requirement and are gaining momentum on these days and hence its' productivity should also be increased with different agronomic approaches (Banerjee and Singh, 2003). Research addressing the issue of yield gaps and identifying factors responsible for these gaps is important both for increasing food security and national revenue generation as well as for increasing resource use-efficiency and sustainability. From several researches, it has also been reported that hybrids can give 20-50% more grain yield than the inbred variety (Masthana *et al.*, 2001, Gupta *et al.*, 2010). But, the hybrid and improved cultivars of any crops are more sensitive to the environment of climatic variability than the local genotypes and yield reduction is more on them (Lamsal and Amgain, 2010; Bhusal *et al.*, 2009). Hence, empirical investigation on the real magnitude on yield loss of most prominent genotypes should be known to harvest optimum yield. The inter-governmental panel on climate change (IPCC) has projected that the global mean surface temperature is predicted to rise by 1.1 – 6.4 ^{0}C by 2100 with the different amplitudes of temperatures and CO_2 for different scenarios of 2020, 2050 and 2080 (IPCC, 2007). IPCC (1996) has also projected the increase in mean temperature by 0.4 to 2.0 ^{O}C during monsoon and 1.1- 4.5 ^{O}C during winter by 2070. The recently advanced climatic adverseness could bring increase in CO_2 concentration, increase or decrease rainfall amount and intensity, change in solar radiation including global dimming, temperature variations and variations in relative humidity etc, as a whole the global climate change is negatively affecting the crop growth and yield in general. These all have also been common in Nepal and will have an adverse affect on Nepalese agriculture (Malla, 2008). Increase in CO_2 concentration brings increase in temperature and ultimately decrease the crop yield by reducing the crop growth duration. Climate change via increasing atmospheric concentration of CO_2 can affect global production of the C_4 crops like maize through change in photosynthesis and transpiration rates and ultimately lower production. The beneficial effect of 700 ppm CO_2 would be nullified by an increase of only 0.9^{0}C in temperature (Chatterjee *et al.*, 2003). There is an immense potential to capitalize the proportion of un-harvested yield and now research has to focus for alternative technological approaches to break this yield barrier. With the advancement of the applied science, different types of crop models have been evolved. Among them, DSSAT ver. 4.0 is one which can help to investigate a range of issues from crop management (Jones *et al.*, 2003). The CSM-CERES-Maize can estimate the seasonal and sequential trend analysis for the long-historical periods and cropping sequences (Jones *et al.*, 2003) and its scope has been widened recently. The CSM-CERES-Maize embedded in DSSAT model (version 4.2) has not been tested over a wide array of location except a very few locations in Nepal (Sapkota et *al.*, 2008; Bhusal *et al.*, 2009) but found satisfactory. Further testing of this version covers the sub-tropical climate of Nepal and will be a highly valued scientific work for proper decision making especially with regards to winter season maize. Hence, this concurrent field and simulation modeling studies was done to find out the optimum time of planting to cope up with the climatic adverseness for different diverse maize genotypes and to simulate the effect of changing climatic scenarios and multi-year attributable predictions on growth, phenology and yields of various prominent maize genotypes grown under sub-tropical environment of central Nepal.

MATERIALS AND METHODS

Field experimentation

A field experiment consisting of the combination of the four diverse maize genotypes {full season OPVs (Rampur Composite), Quality Protein Maize (Posilo Makai 1), Hybrid (Gaurav), and Pop corn (Pool-12)} with three different planting dates (September 1, October 1 and November 1) was accomplished at the Agronomy Farm of Rampur Campus, Chitwan during winter season of 2009-10 representing the sub-tropical climate of terai and inner terai. The experiment was carried out in two factor factorial randomized complete block design having three replications. The soil of the experimental research site was sandy loam in texture and slightly acidic (pH 6.7) in reaction. Total nitrogen and soil available potassium was found to be lower (0.49% N and 148 kg K/ha, respectively) in surface soil profile, but soil available phosphorous was found to be of medium (16.3 kg/ha) level and most of all parameters were found decreasing with increasing profile depth up to 1 m depth. The maximum and minimum temperatures, sunshine hours and rainfall data during the cropping periods and historical weather records were collected from the National Climatic Observatory of National Maize Research Program. The maize crops were grown with the principle of yield maximization by providing the recommended packages of practices (Reddy, 2009). The various ancillary, phenology and yield data obtaining from field experiment was analyzed with the M-Stat-C software and mean data was further subjected to model evaluation under the sub-tropical environment of central southern Nepal. The agro-climatic indices like growing degree days (GDD) and heat use efficiency were calculated and expressed to identify the best agro-climatic indices for different cultivars of maize.

Model evaluation and application

The data were taken in consideration to making appropriate input files (file X, file A, file T, Soil file and Weather file) required for CSM-CERES-Maize ver. 4.2. Model evaluation was done by standard model procedures on various climate change factors to simulate the growth and yield performance of diverse maize genotypes with September 1 planting treatment. At first, the model was calibrated by using the best performing treatments (September 1 planting date for all four diverse maize genotypes), while validation was accomplished for the remaining eight treatments over the ancillary parameters viz. days to anthesis and physiological maturity, above ground biomass at harvest, unit grain weight and grain yields. Moreover, simulation to different scenarios of climatic parameters was accomplished by comparing the growth and yield performance of maize genotypes for various weather years (2005-06 to 2008-09). The proportionate increase or decrease in maximum and minimum temperature, solar radiation and increase of CO_2 concentration on the input file (File-X) of maize was done by changing their respective magnitude to predict the growth and yield performance of maize as advocated by IPCC (2007) for 2020, 2050 and 2080 scenarios. The scenarios given are in the range of increase of 2-4^0 C temperatures and of CO_2 concentration of 420 to 570 ppm for those periods, respectively (Abdul Haris, 2010).

RESULTS AND DISCUSSIONS

Grain yield and yield gaps in maize

The grain yields of Rampur Composite (4.18 t/ha), Poshilo Makai-1 (4.47 t/ha) and hybrid (Gaurav) genotypes (4.71 t/ha) were significantly higher than Pool-12 genotype (2.63 t/ha) but, the Poshilo Makai-1 was statistically at par both with Rampur Composite and Gaurav (Table 1).

Table 1. Grain yield of different diverse maize genotypes as influenced by planting date at IAAS, Rampur, Chitwan

Treatment	Grain yield (t/ ha)			
	Planting dates			Mean
Maize genotypes	September 1	October 1	November 1	
Rampur Composite	5.10	4.0	3.43	4.18
Poshilo Makai-1	5.55	4.27	3.64	4.47
Gaurav	5.86	4.45	3.83	4.71
Pool-12	3.45	2.42	2.02	2.63
Mean	4.98	3.79	3.23	
$LSD_{(0.05)}$ (Genotypes)		0.680		
$LSD_{(0.05)}$ (Planting dates)		0.922		
$LSD_{(0.05)}$ (Interaction)		NS		

Higher grain yield of all composite, QPM and hybrid was because of higher number of kernel rows and number of kernels and test weight resulting from higher dry matter and LAI as compared to Pool-12 which obviously was a small seeded and earlier cultivar. Walker *et al*. (2008) has also reported 17 to 20% higher yield in hybrid than the inbred cultivars. The grain yield of maize due to planting time was significant only for September planting and this might be due to higher thermal units (heat use efficiency) taken by all the maize varieties.

Table 2. Grain yield observed (t/ha) and yield reduction due to delayed planting in different maize cultivars

Maize cultivars	Grain yield (t/ha)			Yield reduction (%) due to late sowing		
	Sept 1	Oct 1	Nov 1	Sept vs Oct	Oct vs Nov	Sept vs Nov
Rampur Comp.	5.1	4.0	3.43	21.52	14.25	32.75
Posilo Makai-1	5.50	4.27	3.64	22.36	14.75	33.82
Gaurav	5.86	4.45	3.83	24.06	13.93	34.46
Pool-12	3.45	2.42	2.02	29.86	16.53	41.45

The date of planting is major governing factors in crop production and it is considered to be low-cost and high monetary returning management practices. For a condition of sudden rise in ambient temperature and CO_2 concentrations, the changes in variety and planting time could be the best adaptive measures to minimize the yield loss. September planting maize has been producing higher yield than the subsequent late plantings. The percentage reduction in yield was high for September versus (*vs*) October planting than the October *vs* November planting and the highest for Sept *vs* November planting (Table 2) in all the maize cultivars. Late planting was negatively affected by low temperature longer from the initiation of heir early vegetative growth, which reduced the major sources and sinks and thus resulted more yield gaps. Rao and Singh (2007) have also recorded the fewer yields of course cereals including pearl millet when planted delayed in Rajsthan, India.

Heat use efficiency and stability of maize yield

From the result (Table 3) it was observed that all maize cultivars were more efficient to show higher heat use efficiency on normal planting condition than their subsequent late plantings.

Under 1st September planting condition, Gaurav had markedly higher HUE (3.46) followed by Posilo Makai 1 (3.30), Rampur Composite (3.03) and the lowest with Pool-12 (2.13).

Table 3. Heat use efficiency (HUE) of different maize cultivars as affected by planting time

Maize cultivars	Heat use efficiency (HUE)			Reduction (%) due to late sowing		
	Sept 1	Oct 1	Nov 1	Sept *vs* Oct	Sept *vs* Nov	Oct *vs* Nov
Rampur Comp.	3.03	2.94	2.44	3.29	19.73	17.0
Posilo Makai-1	3.30	3.19	2.53	3.33	22.33	20.68
Gaurav	3.46	3.13	2.60	9.83	24.86	16.67
Pool-20	2.13	1.90	1.66	10.38	21.70	12.63

At both of the late planting conditions all the cultivars significantly reduced their HUE in various magnitudes compared to normal growing condition by following the same trend as that of normal planting. The reductions in HUE for maize cultivars planted late were higher for September *vs* November planting than the October *vs* November planting and the least with September *vs* October planting. The decrease in HUE due to late sowing was due to sensitiveness of variety to the adverse cold temperature and found to be higher in Gaurav Hybrid (24.86%) followed to Posilo Makai-1 (22.33%), Pool-12 (21.70%) and the least with Rampur Composite (19.73%) in between September v*s* November planting. The similar trend was also noticed for September *vs* October planting too, however their effects were quite smaller. Rampur Composite has less reduction in HUE amongst all the planting date. Hence, it can be concluded that Rampur Composite is the best for timely and for late winter planting too. The specialty corn cultivars QPM (Posilo Makai-1), hybrid (Gaurav) and Pop-corn (Pool-12) have not shown the stability in HUE. In spring and winter maize the same result has been noted by Amgain (2011). Paul and Sarker (2000) have also reported the similar result on late planted wheat in Bangladesh.

Model evaluation

Model parameterization

The following genetic coefficients for all four diverse maize genotypes were adjusted by running the models several times by trial and error methods (Table 4). The model calibration was accomplished by adjusting the proximity values between observed and simulated values on 75% dates of anthesis, and physiological maturity and adjustable grain yield for all four maize cultivars planted on 1 September by changing the values of genetic coefficients (P_1, P_2, P_5, G_2, G_3 and PHINT). The observed anthesis days of 63, 66, 68 and 60 days was first brought to proximity by making the changes in P_1 and P_2 values and physiological maturity dates of 135, 136, 138 and 123 days with changing in the values of P_5 to Rampur Composite, Posilo Makai-1, Gaurav and Pool-12 cultivars of maize, respectively. The adjustment in observed grain yield of 5100, 5500, 5860 and 3450 kg/ha, respectively for above mentioned genotypes in succession was done by changing the values of G_2, G_3 and PHINT and tried to come to proximity between the observed and simulated grain yield. The simulated anthesis

physiological maturity was 134, 136, 138 and 123 days and grain yield was 5260, 5680, 5920 and 3540 kg/ha, respectively. The results obtained were found to be slightly over-estimated but within the range of 10 per cent which normally be accepted.

Table 4. Estimated genetic coefficients of maize genotypes under different planting dates during 2009-10 at Rampur, Chitwan, Nepal

Maize genetic co-efficient	Rampur Composite	Posilo Makai- 1	Gaurav	Pool-12
Thermal time from seedling emergence to end of juvenile phase (P_1)	250	300	275	240
Extent of development days to get the days adjusted in this model param was 63, Rampur Mal Composite, Posilo Gau optimum photoperiod (P_2)	0.60	0.65	0.70	0.50
Thermal time from silking to physiological maturity (P_5)	850	860	875	760
Maximum possible number of kernels/plant (G_2)	650	720	700	620
Kernel filling rate (mg/day) (G_3)	7.50	8.75	10.50	8.00
Phyllochron interval (PHINT)	45	50	55	40

Model Validation

Statistical results in maize showed good agreement between observed and predicted grain yield (RMSE = 257.8 kg/ha and D-index = 0.96), test weight of grain (RMSE of 0.008g/kernel and D-index of 0.89) anthesis days (RMSE = 1.0 day and D-index = 0.86) and maturity days (RMSE = 1.56 days and D-index = 0.82). However, biological yield at maturity showed fairly satisfactory agreement (RMSE = 2475.15 kg/ha and D-index = 0.68) between observed and simulated values as simulated values were over-predicted to all observed yields with acceptable level. Most of the tested parameters showed valid result except some of the discrepancies and that might be due to the variations in initial soil nitrogen status indicating low to moderate soil fertility as it was found in the research field.

Sensitivity to weather years

CERES-Maize was found to be sensitive to weather years and recorded that year 2006-07 was best for all the maize cultivars in which Rampur Composite, Posilo Makai-1, Gaurav and Pool-12 recorded about 13, 18, 23 and 7 percent higher yield than the base year 2009-10, respectively (Table 5). This might be attributed to the better sunshine hour recorded in the year 2006-07 and the winter rainfall was also well-distributed and higher than the other years. This decline in the yield for the rest of the years under simulation study was due to the slightly lower temperature resulting from the less solar radiation and irregular and minimum rainfall in those particular years. This sort of simulation study of the past years highlighted that maize crop is sensitive of weather parameters and basically the lowering winter temperature with global dimming is causing the lower maize yield and some adaptation measures like changes in planting dates and cultivars should be followed to harvest the optimum maize yield. Such sort of trend may be repeated in the future and this will make the crop growers to follow early warning system.

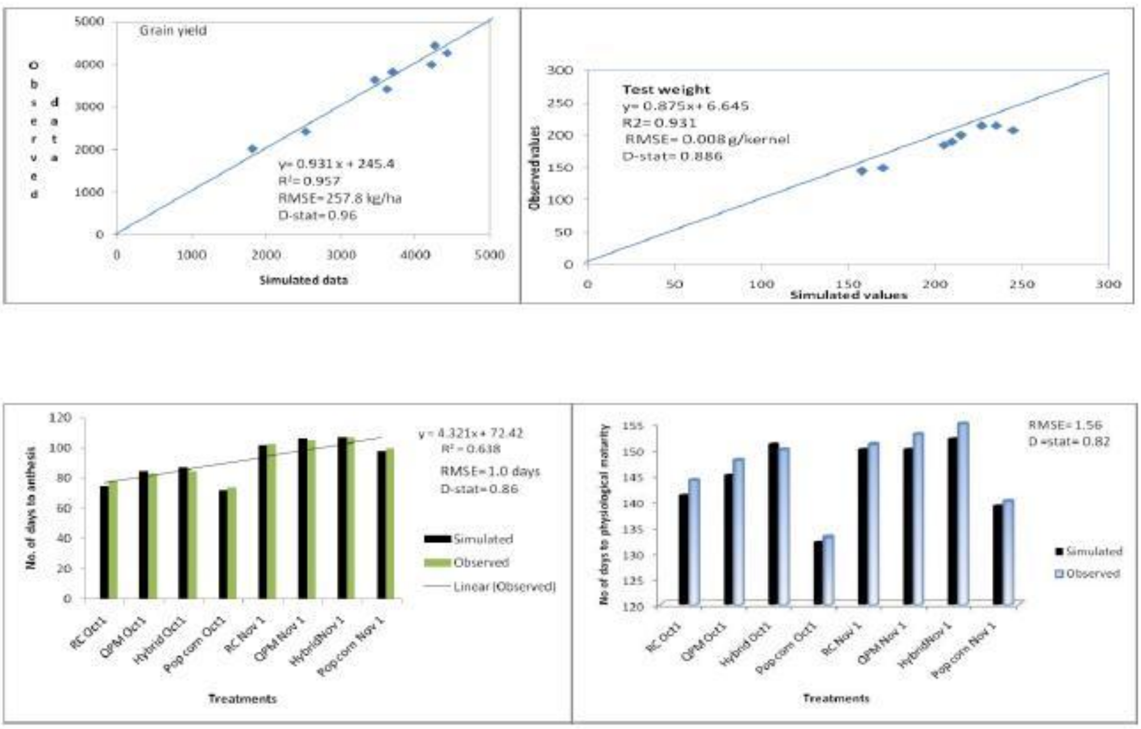

Figure 1. Simulated and observed grain yield (kg/ha), unit grain weight (g), anthesis days and physiological maturity days for four maize cultivars

Table 5. Sensitivity of simulated yield and phenology of maize cultivars to weather years with September 1 planting date

Maize varieties	Weather years	Simulated yield (kg/ha)	Percent yield	Anthesis (days)	Physiological maturity (days)
	2009-10 [a]	5260	100	63	134
Rampur Composite	2008-09	5103	97	62	133
	2007-08	5680	108	64	135
	2006-07	5942	113	64	136
	2005-06	5523	105	63	134
Posilo Makai-1	2009-10 [a]	5680	100	65	136
	2008-09	5395	95	64	135
	2007-08	6410	113	65	137
	2006-07	6705	118	66	138
	2005-06	6190	109	65	136
Gaurav	2009-10 [a]	5920	100	68	138
	2008-09	4915	83	67	136
	2007-08	6864	116	69	139
	2006-07	7282	123	70	139
	2005-06	6512	110	68	138
Pool-12	2009-10 [a]	3540	100	60	123
	2008-09	3295	93	60	121
	2007-08	3682	104	60	123
	2006-07	3785	107	61	124
	2005-06	3610	102	60	123

[a] Standard years

Sensitivity to climate change parameters and multi-year prediction

The model was sensitive to various scenarios of climate change parameters (temperature, solar radiation and CO_2 concentrations). Change in maximum and minimum temperatures upto 2^0 C (+ 2^0C) and CO_2 concentrations upto 420 ppm (+50 ppm) with change in solar radiation (+1MJ m^{-2} day^{-1}) resulted maximum increase in yield of Rampur Composite, Posilo Makai, Gaurav and Pool-12 by 11, 12, 13 and 15 percent (Table 6) while the maximum increase in the maximum and minimum temperatures by 4^0 C along with 100 and 200 ppm CO_2 concentration showed the yield decline of 28, 35, 42 and 22 percent each to Rampur Composite, Posilo Makai-1, Gaurav hybrid and Pool-12 than the standard model treatment (without changing the weather parameters). This reflected that the hybrids are more sensitive to the adverse climatic variability. The existing varieties of maize could not sustain the yield potential of the present level in future after 2020 and hence it should be opined to adopt the climate change adaptation or mitigation strategies over the long-run. Increased CO_2 concentrations would reduce transpiration and nutrient losses and increase water, nutrient and radiation use efficiencies and that might have increased yield under decreasing temperature. Similar result was also resulted by Bhusal *et al.*, (2009), Singh and Padilla (1995). The maize being C_4 crop it can take advantage of lower concentration of CO_2 which could not be possible in C_3 crop plants. Even though increase in ambient CO_2 does not have significant direct effects on C_4 (C_4 carbon fixation pathway) photosynthesis of maize crop (Leakey *et al*. 2004, 2006), increase in ambient CO_2 leads to higher water use efficiency in water stress conditions and thereby influences dry matter production and grain yield (Byijesh *et al.*, 2010). But the increasing temperature will make it negatively affecting. Several studies have revealed the temperature sensitivity of maize. High temperature hastens the crop phenology; doubling temperature variability can reduce the maize yield upto 50% (Wheeler *et al.*, 2000).

Table 6. Sensitivity analysis of different maize genotypes as according to the different climate change scenarios for 2020, 2050 and 2080

S. No	Max temp (°C)	Min temp (°C)	SR (MJ/m²/day)	CO_2 conc. (ppm)	Treatments	Simulated yield (kg/ha)	% yield change	Growth duration (days)
1 [a]	+0	+0	+0	370	Rampur Comp.	5260		134
					Posilo Makai-1	5680		136
					Gaurav	5920		138
					Pool-12	3540		123
2	+1	+1	+0	370	Rampur Comp.	5465	+4	134
					Posilo Makai-1	5920	+4	135
					Gaurav	6355	+7	137
					Pool-12	3820	+8	122
3	+1	+1	+1	+ 50	Rampur Comp.	5645	+7	134
					Posilo Makai 1	6150	+8	135
					Gaurav	6545	+8	136
					Pool-12	3935	+11	122
4	+2	+2	+1	+ 50	Rampur Comp.	5820	+11	133
					Posilo Makai-1	6235	+12	134
					Gaurav	6675	+13	136
					Pool-12	4055	+15	122
5	+3	+3	+1	+ 100	Rampur Comp.	4505	-6	133
					Posilo Makai-1	5154	-9	134
					Gaurav	5320	-10	136
					Pool-12	3357	-5	121
6	+3	+3	+1	+ 200	Rampur Comp.	44085	-14	133
					Posilo Makai-1	4725	-17	134
					Gaurav	4565	-23	136
					Pool-12	3070	-13	121
7	+4	+4	+1	+ 200	Rampur Comp.	3785	-28	131
					Posilo Makai-1	3650	-35	132
					Gaurav	3430	-42	133
					Pool-12	2760	-22	120

Note: 1[a] : Standard climatic conditions (model default), 2, 3 & 4: Climate change scenario 2020, 5 & 6:. Climate change scenario 2050 and 7: Climate change scenario 2080 as given by IPCC (2007).

CONCLUSION

To achieve the higher productivity and increasing demand of the maize, there should follow the climate change adaptation studies especially for open pollinated Composite breeds and specialty maize like, Hybrids, QPM and Pop corn. T*he* CSM-CERES-Maize Model was well validated under the sub-tropical condition of central southern *Nepal* and has shown the immense scope of using this model as a tool for estimating yield gaps and study on different scenarios of climate changes. 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 large agro-ecological areas of Nepal.

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