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Simulation of growth and yield of rainfed maize under varied agronomic management and changing climatic scenario in Nawalparasi, Nepal

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ABSTRACT

A field experiment and simulation modeling study in combination for different maize cultivars planted at different sowing dates were accomplished at Kawasoti-5, Nawalparasi during spring season of 2013 to assess the impact of climate change scenario as predicted by IPCC in rainfed spring maize by using CSM-CERES-Maize model. Result showed that RML-4/RML-17 produced higher kernel rows/ear (13.77), kernel per row (30.42) and test weight (244.9 g). Significantly higher grain yield was also found for RML-4/RML-17 (6.03 t/ha) compared to Poshilo makai-1 (4.73 t/ha), Arun-2 (3.55 t/ha) and Local (2.92 t/ha). Earlier sowing date (7th April) actually produced higher kernel/row (27.97), kernel rows/ear (12.89) and 1000 grain weight (230 g). Significantly higher grain yield (5.13t/ha) was obtained in earlier sowing date (7th April). The CSM-CERES-Maize model was calibrated and found well validated with days to anthesis (RMSE= 0.426 day and D-index= 0.998), days to physiological maturity (RMSE=0.674 day and D-index= 0.999), number of grain/m^2 at maturity (RMSE= 85.287 grain /m^2 and D-index= 0.993), unit weight at maturity (RMSE=0.012 g/kernel and D-index= 0.854) and grain yield (RMSE=54.94 kg/haand D-index= 1.00). The model was found sensitive to climate change parameters. The sensitivity for various climate change parameter indicated that there was severely decreased trend in simulated rainfed spring maize yield with the increment of maximum and minimum temperature, decrease in solar radiation and decrease carbondioxide concentration. Even 2^0C rise in temperature can decrease around 15-20% yield of spring maize and this negative effect was even more pronounced in hybrid than other cultivars.

INTRODUCTION

Maize (*Zea mays* L.) is the second most important staple food crops both in term of area and production after rice in Nepal. It has the highest yield potential over other cereals and thus known as ‘the queen of cereals’ (Singh, 2002). It is grown in about 906253 ha land with 206772 metric tons total production and 2.33 mt/ha productivity (Agricultural Diary, 2069). Maize contributes 9.5% AGDP and 3.15% GDP (MoAD, 2012). Maize occupies about 28.32% of the total agricultural land cultivated, and shares about 23.89% of the total cereal production in Nepal (MoAC, 2009/10). 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 feeds in terai and inner terai and, this increased demand could only be met by increasing the productivity of maize per unit area of land (NMRP, 2009). The rainfed

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farming means the cultivation of crops on relatively dry land that lacks easy access to irrigation and moisture requirement at any growth and development stages of crop. Rainfed farming areas fall mainly in arid, semi arid and dry sub-humid zones in the world but the Nepalese sub-tropical region is also rainfed. In Nepal, about 65% of the total arable land is under rainfed (Thapa, 1995). The variation in rainfall under rainfed zone especially during spring season feels long dry spell, early withdrawal and also increasing temperature caused stressful environment to plant growth, all of which strongly influence the productivity level of maize. Through a series of observations and modeling studies, the Inter-Governmental Panal on Climate Change (IPCC) has shown that the earth temperature has increased by 0.74 ^{0}C between 1906 and 2005 due to increase in anthropogenic emissions of green house gases. By the end if this century, temperature increase is likely to be 1.8-4 ^{0}C (IPCC, 2007). This would lead to more frequent hot extremes, floods, droughts, cyclones and gradual recession of glaciers, which in turn would result in greater instability of flood production. The increase in GHGs was 70% between 1970 and 2008 (IPCC, 2007). The global increases in CO_2 concentration are due to use of fossil fuel and land use change, while those of methane and nitrous oxide are primarily due to agriculture. It has also been estimated that crop production loss in south Asia by 2100 AD could be 10-40% despite the beneficial effects of higher CO_2 on crop growth. Agriculture contributes the significant of green house gas emission in south Asia primarily due to CH_4 and N_2O emission from rise by the application of manure and nitrogenous fertilizer in to the soils. Simple adaptation strategies such as change in planting dates and varieties could also help in reducing the impacts of climate change to some extent. Cropping system model (CSM-CERES-Maize) is a decision support tool used widely to evaluate and/or forecast the effects of environmental conditions, management practices, and different genotypes on crop growth, development and yield (Asadi and Clement, 2003). Earlier version of the DSSAT model (ver. 4.5) have been evaluated across rice growing environment of Asia and Australia and their performance has been generally satisfactory, but variation exists (Timsina and Humphreys, 2003). Similarly, Pathak *et al.* (2002), Timsina *et al*. (2004), Amgain *et al.* (2006) and Amgain and Timsina (2007) evaluated the CERES-Rice model (ver. 4.0) for soil mineral N and loss processes from rice fields under Rice-Wheat systems for Dehli, Modipuram and Punhab in north-west India. In context of Nepal, the CERES-Maize model had not been tested over different locations of country except few studies conducted in maize, e.g, by Sapkota *et al.* (2008) in winter maize and Bhusal et al.(2008) in spring maize. In this context an attempt has been tried to study the field performance of different maize cultivars under different sowing dates and simulation results of CSM-CERES-Maize model on the growth and yield under changing climatic scenarios of sub-tropical condition of central Nepal.

MATERIALS AND METHODS

Field experimentation

The field experiment was conducted at kawasoti-5, Nawalparasi district on maize (*Zea mays* L.) during late spring (April to August) season, 2013. The area is located at 27^{0}66’ N latitude and 84^{0}13’E longitude with an elevation of 220 M above mean sea level. The place is situated in humid sub tropical climate but resembles the foot hill and inner terai cllimate. During the cropping period, maximum temperature was recorded in May (Monthly average= 34.12 ^{0}C). After rainfall started from May, maximum temperature decreased slightly; however, minimum temperature was found increasing consistently and dropped slightly after July only. The highest minimum temperature was recorded during July (monthly average= 26.05 ^{0}C). Total rainfall received during research period (7th April to 27th August) was 2789.1 mm.The experiment was carried out in two factorial randomized complete block design with three replications. The treatment consists of combination of four maize cultivars (Local, Poshilo makai-1, RML-4/RML-17 and Arun-2) and three sowing dates (7th April, 22nd April and 7th May). The soil of the research site was silt loam and slightly acidic to basic in soil reaction (pH 6.2-7.4). The recommended agronomic management practices were followed to accomplish the experimentation except the fertilizer treatments. Yield and yield attributing characters were recorded, tabulated and analyzed using MSTAT-C computer software and statistical package as mentioned by Gometz and Gometz (1984).

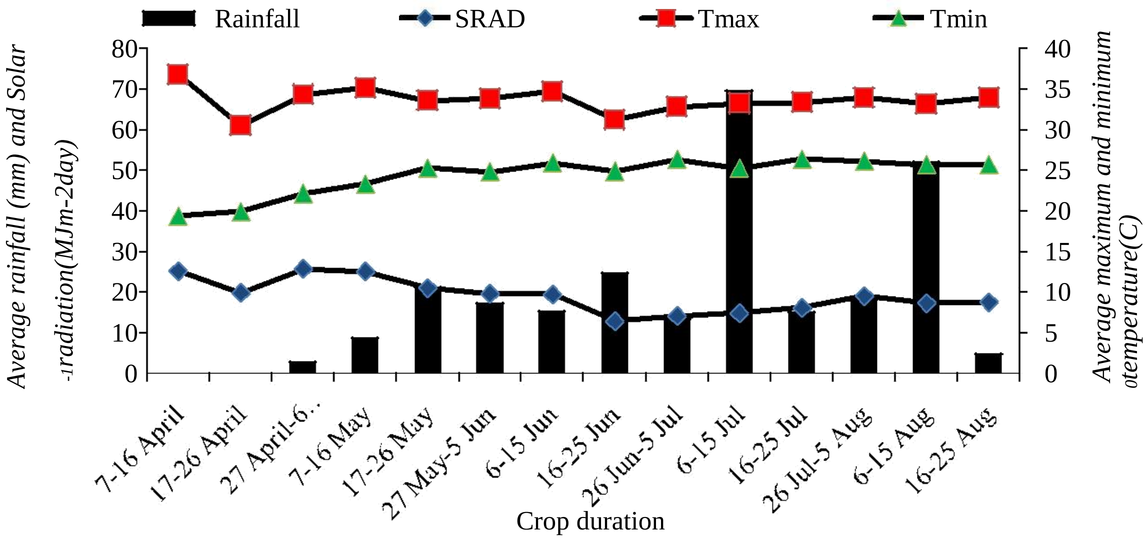

Figure 1. Average weather records during research period (10 days interval) at kawasoti-5, Nawalparasi, 2013 (Department of Hydrology and meteorology)

Simulation modeling

Various data on experimental field crops were taken in consideration for making appropriate input files required to run the DSSAT ver 4.5 crop models. Those characters include data sets required for experimental file (file X), yield attributes (file A), growth attributes (file T), Soil file (file S) and Weather file (file W). Model calibration was performed for all four maize cultivars those sown in 7th April. Model validation was done using maize cultivars planted in 22nd April and 7 th May. The parameters used for model validation were days to anthesis, day to physiological maturity, grain yield, unit grain weight and number of grain per unit area. Sensitivity analysis was accomplished using maize cultivars planted in 7th April. Simulation to different scenarios of climate change was completed altering maximum and minimum temperature by $\pm$ $2^{0}C$, solar radiation by $\pm$ $1MJm^{-2}$/day and increasing carbon dioxide concentration by 20 ppm than present weather scenarios.

RESULTS AND DISCUSSION

Table 1 clearly indicated that number of ears/ha was insignificant for all sowing dates and maize cultivars. Kernel row/ear (12.89) and kernels/row (24.47) in 7th April planted maize were recorded highest followed by 22nd April and 7th April planted maize cultivars. It might be due to favorable temperature in early sown maize cultivar. A number of factors could be responsible for reduction in number of kernels per row under heat stress, such as reduced pollen viability and receptivity of silk, increased frequency of kernel abortion, decreased cell division in endosperm, reduced silk capacity of developing kernels, reduced starch grain number and overall starch synthesis, increased soluble sugar accumulation, duration of grain filling, kernel development and enzyme activities (Duke and Doehlert, 1996). In case of cultivars, RML-4/RML-17 had highest kernel row ear-1 (13.77) and kernels/row (30.42) than other cultivars. The reason for best performance for most of the traits for hybrid might be due to added traits called heterosis. It is observed that maize 1000 grain weight were higher and statistically similar in maize planted 7th April (232.0 g) and 22nd April (231.3 g) than 7th May (224.3 g). Suwa *et al.* (2010) reported depression in source-sink activity under high temperatures. Heat stress decreased seed filling duration (Hellewell *et al.*, 1996; Prasad *et al.*, 2006) due to which test weight of 7th May sown cultivars were found less. Similarly, test weight of RML-4/RML-17 (244.9 g) and Poshilo Makai-1 (241.2 g) were found higher as these cultivars were long durational and had longer seed fill durations than short durational cultivars i.e, Local and Arun-2. Similarly, grain yield was found higher in 7th April (5.126 t/ha) followed by 22nd April (4.104 t/ha) and those planted in 7th May (3.692 t/ha) had least grain yield. High night temperatures result in loss of more sugars for respiration and reduce the availability for kernel filling, thereby lowering potential grain yield (Thomison, 2010). In case of maize cultivars, RML-4/RML-17 had highest grain yield as hybrid possess hybrid vigor. It had longer crop duration, high seed fill duration, long leaf stay green character, higher leaf area index etc. Unlike grain yield, 22nd April (14.26 t/ha) and 7th April (14.35 t/ha) sowing dates had higher stover yields. But, here also hybrid RML-4/RML-17 (17.18 t/ha) had highest stover yield than other cultivars.

While in case of harvest index, 7th April (0.347) planted maize cultivars had highest harvest index but remaining both sowing dates had similar and least harvest index. This finding was in agreement with Jasemi *et al.* (2013) who found harvest index was higher for plant sown on 22nd May than 13th July. But, in case of maize cultivars, both long durational cultivars had higher harvest index than short durational cultivar. It was due to longer seed fill duration, higher leaf area index, higher leaf area duration.

Model calibration

The genetic coefficients of maize cultivars were adjusted by running the model for 15 times with various possible changes in the genetic coefficients till the simulated values for parameters such as days to anthesis, days to physiological maturity, grain yield matches with observed values for maize cultivar planted in 7th April. The value such as 230 (P1). 0.520(P2), 940(P5), 360(G2), 9.28(G3) and 38.90(PHINT) were adjusted for Local; 400(P1), 0.600(P2), 1130(P5), 590.9(G2), 8.38(G3) and 18.90(PHINT) were adjusted for Poshilo makai-1; 380 (P1). 0.260(P2), 1290(P5),

816.9(G2), 7.36(G3) and 8.9(PHINT) were adjusted for RML-4/17; 230 (P1). 0.520(P2), 910(P5), 440(G2), 9.88(G3) and 38.90(PHINT) were adjusted for Arun-2.

Table 1.Effect of sowing dates and varieties on yield attributing characters of maize during spring, 2013 at Kawasoti-5, Nawalparasi

Factor	Number ofears/ ha	Kernel rows/ ear	Kernels/ row	1000 grain weight (g)	Grain yield at 15% MC (t/ha)	Stover yield(t/ha)	Harvest index
Sowing dates							
7th April	59070	12.89[a]	27.97[a]	232.0[a]	5.126[a]	14.35[a]	0.347[a]
22nd April	57590	12.47[b]	24.47[b]	231.3[a]	4.104[b]	14.26[a]	0.289[b]
7th May	58150	12.22[c]	22.73[c]	224.3[b]	3.692[c]	12.58[b]	0.290[b]
SEm $\pm$	800.7	0.075	0.301	1.686	0.078	0.289	0.009
$LSD_{0.05}$	NS	0.219	0.883	4.946	0.227	0.849	0.027
Varieties							
Local	59750	11.31[d]	21.10[d]	204.4[c]	2.920[d]	10.64[d]	0.278[b]
Poshilo makai-1	56540	13.17[b]	26.13[b]	241.2[a]	4.725[b]	14.47[b]	0.326[a]
RML-4/RML-17	58270	13.77[a]	30.42[a]	244.9[a]	6.030[a]	17.18[a]	0.351[a]
Arun-2	58520	11.86[c]	22.58[c]	226.3[b]	3.554[c]	12.62[c]	0.282[b]
SEm $\pm$	980.7	0.092	0.369	2.065	0.089	0.334	0.011
$LSD_{0.05}$	NS	0.268	1.082	6.058	0.262	0.980	0.033
CV %	4.76%	2.07%	4.16%	2.55%	6.23%	7.30%	9.15%

Means followed by common letter (s) within each column are statistically similar at LSD 0.05

Table 2. Genetic coefficients for maize cultivars

Coefficient	Local Cultivar	Poshilo makai-1	RML-4/RML17	Arun-2
P1	230	400	380	230
P2	0.520	0.600	0.260	0.520
P5	940	1130	1290	910
G2	360	590.9	816.9	440
G3	9.28	8.38	7.36	9.88
PHINT	38.90	18.90	8.9	38.90
Simulated				
Anthesis day	49	61	56	49
Physiological maturity day	94	114	116	92
Grain yield	3121	5933	7684	3765
Observed				
Anthesis day	49	61	56	49
Physiological maturity day	94	114	116	92
Grain yield	3124	5931	7685	3768

Model validation

Genetic coefficients of four maize cultivars determined through calibration of the model were used for validation of the model. Model evaluation was performed using RMSE and Index of agreement (D-index) as suggested by Willmott (1982) and Willmott *et al.* (1985). Model validation was done by comparing model performance against data collected on days to anthesis (RMSE= 0.426 and D-index= 0.998), physiological maturity (RMSE=0.674 day and D-index= 0.999), number at maturity(RMSE= 85.287 grain m^{-2} and D-index= 0.993), unit weight at maturity (RMSE=0.012 g $kernel^{-1}$ and D-index= 0.854) and grain yield (RMSE=54.94 kg ha^{-1} and D-index= 1.00) for all eight treatments (22^{nd} April and 7^{th} May planted varieties).

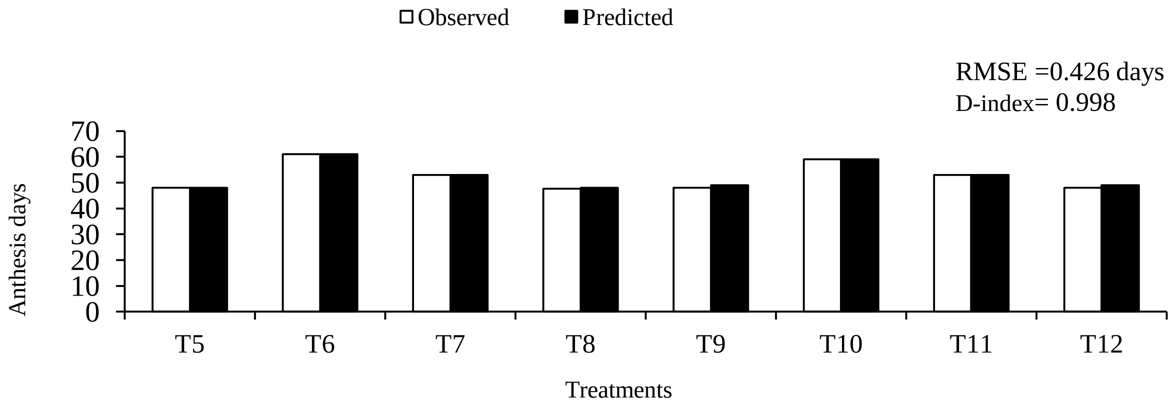

Figure 2. Simulated and observed anthesis days of various treatments

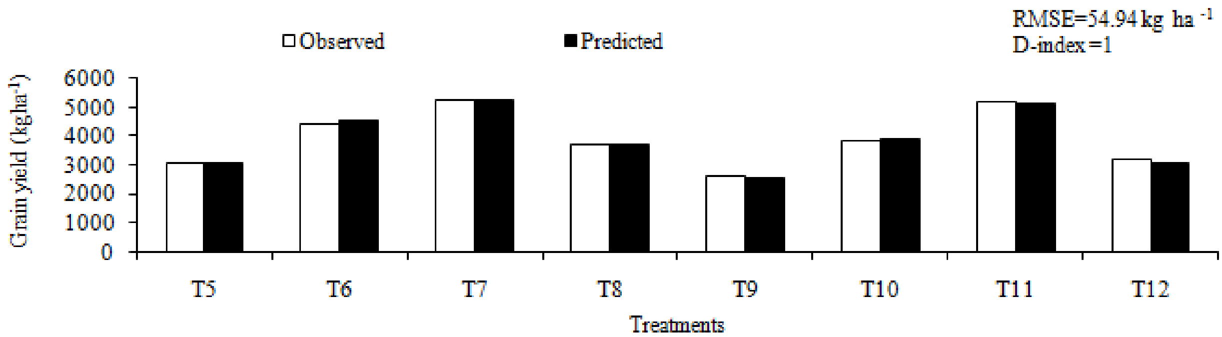

Figure 3. Simulated and observed physiological maturity days of various treatment

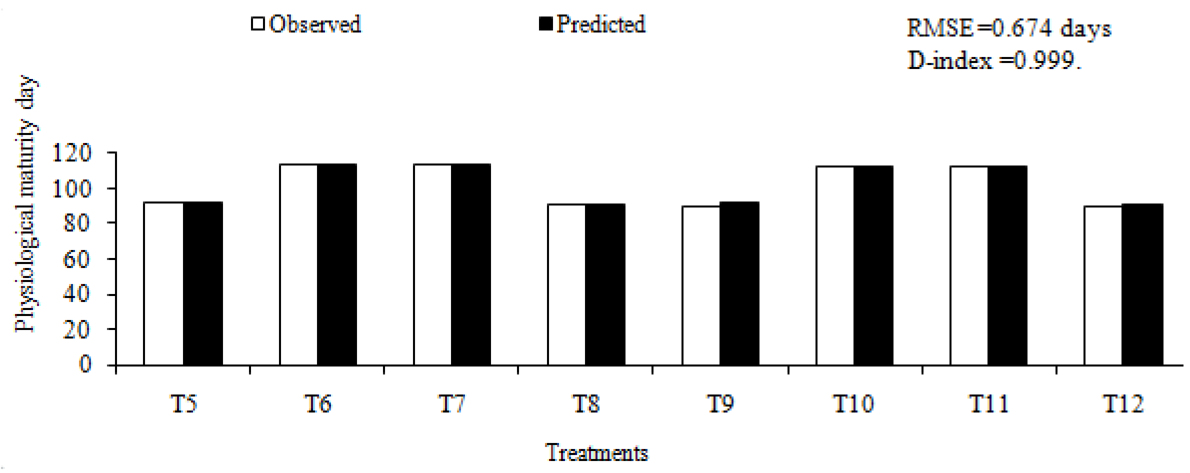

Figure 4. Simulated and observed grain yield of various treatments

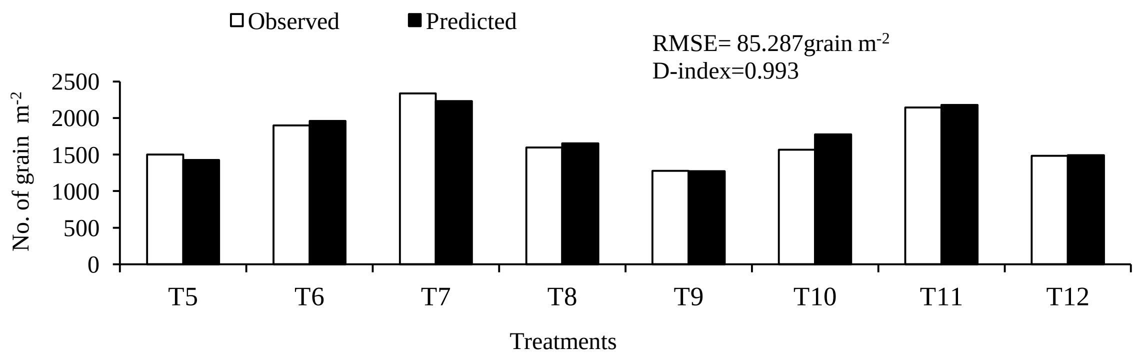

Figure 5. Simulated and observed number of grains per m^2 of various treatments

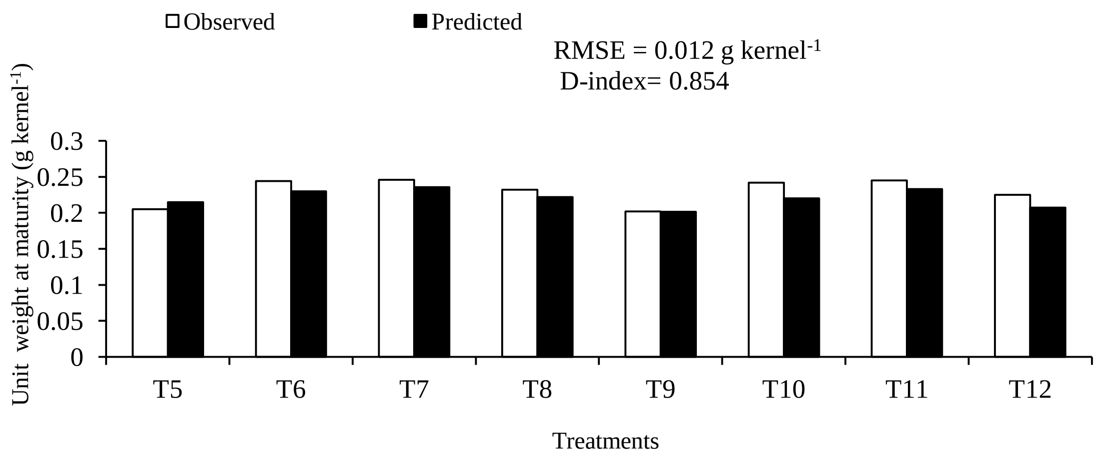

Figure 6. Simulated and observed unit weight at maturity for different various treatments

Table 3. Sensitivity analysis of maize cultivars with changes in temperature, solar radiation and CO2 concentration

Max Temp (^{0}C)	Min temp (^{0}C)	CO_2 Conc Ppm	Solar radiaton (MJ/m^2/day)	Variety	Simulated Grain yield	% yield change (kg/ha)	Growth duration (day)
+ 0	+0	380	+0	Local	3068	100	94
				Poshilo makai-1	5902	100	114
				RML-4/RML-17	7459	100	116
				Arun-2	3710	100	92
+2	+2	380	+0	Local	2697.69	-12.07	88
				Poshilo makai-1	4844.36	-17.92	106
				RML-4/RML-17	5966.45	-20.01	108
				Arun-2	3274.45	-11.74	87
-2	-2	380	+0	Local	3289.20	+7.21	101
				Poshilo makai-1	6810.32	+15.39	123
				RML-4/RML-17	8977.65	+20.36	126
				Arun-2	4181.17	12.70	99
+2	+2	+20	+0	Local	2733.59	-10.9	88
				Poshilo makai-1	4945.88	-16.2	106
				RML-4/RML-17	6093.26	-18.31	108
				Arun-2	3320.45	-10.5	87
-2	-2	+20	+0	Local	3381.24	+10.21	101
				Poshilo makai-1	6985.02	+18.35	123
				RML-4/RML-17	9126.83	+22.36	126
				Arun-2	4284.31	+15.48	99
+2	+2	+20	+1	Local	2792.49	-8.98	88
				Poshilo makai-1	5020.24	-14.94	106
				RML-4/RML-17	6225.28	-16.54	108
				Arun-2	3395.76	-8.47	87
+2	+2	+20	-1	Local	2677.44	-12.73	88
				Poshilo makai-1	4809.54	-18.51	106
				RML-4/RML-17	5958.99	-20.11	108
				Arun-2	3248.48	-12.44	87
-2	-2	+20	+1	Local	3591.09	+17.05	101
				Poshilo makai-1	7157.36	+21.27	123
				RML-4/RML-17	9591.53	+28.59	126
				Arun-2	4416.01	+19.03	99
-2	-2	+20	-1	Local	3299.32	+7.54	101
				Poshilo makai-1	6671.03	+13.03	123
				RML-4/RML-17	8597.99	+15.27	126
				Arun-2	4041.30	+8.93	99

Simulation to climate change parameters

The validated CSM-CERES Maize (Ver. 4.5) data were used to find sensitivity of model in Kawasoti-5, Nawalparasi. Validated CSM-CERES-Maize model was used to find out possible changes that can occur in rainfed spring maize that is grown in upland condition. The model was sensitive to climatic parameters (temperature, CO_2, concentration, solar radiation and rainfall) on yields of crops. Increments in both maximum and minimum temperatures by 2 ^{0}C, decreased yields of Local, Poshilo makai-1, RML-4/RML-17 and Arun-2 by -12.07, 17.92, -20.01 and -11.74 respectively as compared to base scenario with current weather data. By increasing maximum and minimum temperature by 2 ^{0}C and carbondioxide concentration upto 20 ppm more, decreased yield 10.9, 16.2, 18.31 and 10.5 percent in Local, Poshilo makai-1, RML-4/RML-17 and Arun-2 respectively. Further more if solar radiation was increased by + 1 MJ/m^2/day then, yields of Local, Poshilo makai-1, RML-4/RML-17 and Arun-2 will be decreased by 8.98, 14.94, 16.54 and 8.47 percent respectively. Instead of increasing when solar radiation was decreased by 1 MJm^{-2}day^{-}1along with increased in both maximum and minimum temperature by 2 ^{0}C and carbondioxide by 20 ppm then yields of Local, Poshilo makai-1, RML-4/RML-17 and Arun-2 decreased by 12.73, 18.51, 20.11 and 12.44 respectively. But opposite consequences in yield of maize cultivars were noticed with reversing the phenomenon. When maximum and minimum temperature were decreased by 2 ^{0}C, increased yield of Local, Poshilo makai-1, RML-4/RML-17 and Arun-2 were noticed by following magnitudes; 7.21, 15.39, 20.36 and 12.70 percent respectively as compared with base scenario with current weather data. By deceasing mimimum and maximum temperature by 2 ^{0}C and increasing carbondioxide concentration upto 20 ppm more, increased yield 10.21, 18.35, 22.36 and 15.48 percent in Local, Poshilo makai-1, RML-4/RML-17 and Arun-2 respectively. But when decreased maximum and minimum temperature by 2 0C, increased carbondioxide by 20ppm and decreased solar radiation by 1 MJm^{-2}day^{-1} then yield of Local, Poshilo makai-1, RML-4/RML-17 and Arun-2 changed by 7.54, 13.03, 15.27 and 8.93 percent respectively. But instead of decreasing when solar radiation was increased by 1MJ/m^2/day then yield slightly increased by 17.05, 21.27, 28.59 and 19.03 percent respectively in Local, Poshilo makai-1, RML-4/RML-17 and Arun-2 respectively. The model was found to be sensitive to climate change parameters (temperature, solar radiation and CO2 concentration). Change in maximum and minimum temperatures ($\pm$2 ^{0}C), CO_2 concentration (+ 20 ppm from the base 380 ppm) with change in solar radiation ($\pm$1 MJ/m^2/day) resulted in much difference in grain yield. The result showed that with the decreasing scenarios of maximum and minimum temperature by 2^{0}C other factor remaining constant the yield of Local, Poshilo makai-1, RML-4/RML-17 and Arun-2 increased by 7.21%, 15.39%, 20.36% and 12.70% respectively. But when maximum and minimum temperature were increased by 2 ^{0}C than yield of Local, Poshilo makai-1, RML-4/RML-17 and Arun-2 decreased by 12.07%, 17.92%, 20.01% and 11.74% respectively. What we saw here was hybrid to be more sensitive to increased temperature than others. Higher temperature decreased the duration of growth and grain yield, despite high levels of radiation (Muchow et al, 1990).

CONCLUSION

Rainfed maize cultivation in late spring season is very risky. However, maize planted on 7th April had higher growth rate, higher yield and its attributing characters as it was facilitated by relatively favorable temperature. Among the cultivars, Hybrid (RML-4/RML-17) was noted best as it had higher grain and stover yield. Due to increasing temperature beyond optimum level, yield of maize cultivars planted in 22nd April and 7th May decreased by 20.015% and 27.975% respectively when compared with yield obtained from 7th April plantation. Changing climate has threatened rainfed spring maize cultivation. As temperature is increasing, under this changing scenario CSM-CERES-Maize model was used to evaluate its impact in spring maize production. We found yield of maize will decrease by 15-20 % if temperature increases by 2 ^{0}C and its impact was found even more serious in hybrid maize.

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