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Research Article

Agronomic management and climate change scenario simulations on productivity of rice, maize and wheat in central Nepal using DSSAT ver 4.5 crop model

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ABSTRACT

Average productivity of 3.50 t/ha of rice, 2.50 t/ha of maize and 2.45 t/ha of wheat in Nepal have been very less than their potential productivity for which précised agronomic management and changing climatic scenarios have been reported the most challenging factors at present. Cropping system Model (CSM)-Crop Estimation through Resource and Environment Synthesis (CERES)- Rice, Maize and Wheat, embedded under Decision Support System for Agro-technology Transfer (DSSAT) ver. 4.5 was evaluated from a datasets of farmers' field experimentations of the central Nepal (Terai-Nawalpur and mid-hill-Kaski districts), and showed high sensitivity of model over change in different agronomic management and climate change scenarios. Model calibration was done by using maximum attainable yield treatments for all tested cultivars while validation was accomplished by using the remaining treatments for predicting growth, phenology and yield of all crop cultivars and results were found perfectly matched with the observed results. Further, the different agronomic management options and climate change scenarios as advocated by IPCC for 2020, 2050 and 2080 from base line of 1995 was studied to simulate the growth and yield performance of diverse crop cultivars. The hybrids and short duration cultivars of all three cereals were found more affected due to climate change than the local and long duration crop cultivars. The model simulation results obtained on rice, maize and wheat using DSSAT ver 4.5 model highlighted that there is utmost importance to develop new climate ready crop cultivars to feed the future generation over different climate change scenarios as suggested by IPCC, 2007 and the simulation results should be extrapolated to the major domains of similar agro-ecozones in Nepal. It is suggested that CSM- CERES- model would be reliable and valid approach for getting strategic decision support system especially with regards to the climate change adaptation measures in Nepal.

Keywords: Agronomic management and climate change scenarios, DSSAT ver. 4.5 crop model, Maize, Rice, Wheat, Simulation

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INTRODUCTION

The major cereal crops cultivated in Nepal are rice, maize, wheat, millet and barley. Among these major crops, rice (*Oryza sativa* L.), maize (*Zea mays*. L) and wheat (*Triticum aestivum* L.) are indeed the important components to the caloric food requirement and expected national economy because cereals contribute about 49.2% of the agricultural gross domestic products in Nepal (MoAD, 2014). Rice and wheat are mostly cultivated at lower elevations and in valley bottoms in the mid-hills and in most areas of Nepalese Terai. In most of these areas, mostly the rice-wheat, rice-maize, rice-wheat-rice or rice-wheat-maize cropping systems are practiced (Timsina & Conner, 2001; Timsina et al., 2010: Gadal et al., 2019). The cereal-based cropping systems in Terai and mid-hills of Nepal are highly intensive, but are facing the sustainability problems due to fragile ecologies and increased dominance of cereals devoid of legumes in the systems (Devkota et al., 2018).The average grain yield of major crop cultivars in any particular region or the whole country is inevitably smaller than yield potential. Preliminary research works in Nepal have shown a large gap between rice yields in farmers' fields (<3.5 t ha^{-1}) and on research stations (around 1.5-2.5 t ha^{-1}) (Amgain & Timsina, 2005; Dhakal, 2016; Amgain et al., 2018). Maize, the second important crop of Nepal after rice in terms of area accounts 2.2 million tons production with 2.45 t ha^{-1} productivity (ABPSD, 2017; Shrestha, 2015). Wheat is grown in 0.74 mha with a total production and productivity of 1.7 m tons and 2.45 t ha^{-1}, respectively in Nepal (MoALD, 2017, Marasini, 2016).

These yields are far behind the average world level yield and Nepalese farmers are facing the problems of food insecurity over the years. Central Terai and hills of Nawalpur and Kaski districts being located in central Nepal, the agriculture in these eco-zones is mainly affected by series of climatic anomalies and their induced effects like abiotic and biotic stresses (Amgain & Timsina, 2005) and research on farmers' field would be more vulnerable to climate change and hence urge for innovative research (Amgain et al., 2018). In spite the large research efforts to lift the system yields by various allied sectors of agriculture in these areas; there are still large gaps between biologically and climatically achievable potential yields and research station and on-farm yields and urged for the precision agriculture research like crop simulation modeling (Timsina & Connor, 2001; Timsina et al., 2004; Amgain, 2004).

Globally, it has been suggested that one major way to increase cereals yield is to increase resource use efficiency by better agronomic management mainly physical inputs even under abnormal weather events (Wang et al., 2004; Wang et al., 2011; Sapkota et al., 2014). 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 cereal crops are more sensitive to the environment of climatic variability than the local genotypes, and yield reduction is more on hybrids (Lamsal & Amgain, 2010; Bhusal et al., 2008). Hence, empirical investigation on the real magnitude on yield loss of most prominent cultivars should be known to harvest optimum yield.

All over the world, concern now exists about the possible climate change caused by an increase in the concentration of greenhouse gases such as CO_2, CH_4 and N_2O in the atmosphere (Watson et al., 1996, Timsina & Humphreys, 2006). The inter-governmental

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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 (Bajracharya et al., 2007; IPCC, 2007). IPCC (1996) has also projected the increase in mean temperature by 0.4 to 2.0 ^{O}C in *kharif* and 1.1- 4.5^{O}C in *rabi* by 2070. Climate change via increasing atmospheric CO_2 concentration can affect global agricultural production through changes in photosynthesis and transpiration rates for examples 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). Although the solar radiation received at the surface will be variable geographically, on an average it is expected to decrease by about 1% (Hume & Cattle, 1990; Pathak *et al*., 2004; Amgain et al., 2006). Various studies have reported the marked effects of climate change more in rice and wheat yield because of its photo-respiration cycle (Timsina & Humphreys, 2003). Major rice models indicate a reduction in yield of about 5% per ^{0}C rise in mean temperature (Matthews et al., 1995). This would largely offset any increase in yield as a consequence of increased CO_2. 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. Effect of temperature is more significant in wheat yield for e.g. wheat yield was dramatically reduced under both dry land and irrigated conditions of Pakistan due to a shorter season caused by temperature increase (Qureshi & Iglesias, 1994). The yield decreases were partly counteracted by the physiological effects of increased CO_2. Several studies have been done to develop an integrated assessment of the effect of the climate change on regional and global food supplies and demand (Rosenzweig & Parry, 1994, Adams et al., 1995). The decreasing yield of major cereals rice, maize and wheat are severely affected by the negative effect of climate change and hence the food security is threatened.

Crop simulation models have many current and potential uses for improving research understanding, crop management decisions, policy planning and implementation and adapting to the current and future climate change (Timsina & Humphreys, 2006). Earlier versions (version 3.5 and 4.0) of the CERES-Rice, Maize an Wheat models embedded in Decision Support System for Agro Technology Transfer (DSSAT) have been evaluated across Asia and their performance have been generally satisfactory but variable (Timsina et al., 1995; Timsina et al., 1997, Hundal & Kaur, 1996; Amgain & Timsina, 2005, 2006, 2007). Except few the recent version (ver. 4.5) of CSM-CERES-Rice, Maize and Wheat models have, however, not been evaluated in Nepal (Timsina & Humphreys, 2003; Pathak *et al*., 2004; Devkota, 2005; Lamsal & Amgain, 2010; Amgain et al., 2006; Amgain & Timsina, 2007, 2008; Sapkota et al, 2008; Bhusal et al., 2008).

Therefore, these studies were done to understand the yield gaps between experimental station and farmer's field yield for major cereals in central Terai and mid-hill agro eco-zones of Nepal and to extrapolate the precise agronomic management and climate change scenarios simulations on phenology and yield of various cultivars of rice, maize and wheat planted under diverse agronomic, edaphic and climatic conditions of Terai and mid-hills.

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MATERIALS AND METHODS

Site of field experimentations and profile soil characteristic details

The field experiments on rice, maize and wheat to evaluate CSM-CERES- Rice, Maize and Wheat models were carried out in farmer's field at Dhaubadi (27.68 ºN, 84.08 ºE, 235 masl.) and Kawasoti (27^0 66’ N ,84^0 13’ E, 220 masl.) in Nawalpur, and at Dhuikurpohari (28° 1' N, 82° 5' E 920 masl.) in Kaski districts, respectively (Figure 1). The experiment was conducted during July to November, 2014 in rice, April to August, 2013 in maize and November 2014 to April 2015 in wheat. The physico-chemical properties of soil to run the CSM-CERES models have been presented in Table 1 and 2. The physico-chemical properties analyzed from the composite soil samples of the particular locations at Dhaubadi and Kawasoti in Nawalpur and at Dhikurpokhari in Kaski were found congenial to grow rice, maize and wheat, respectively.

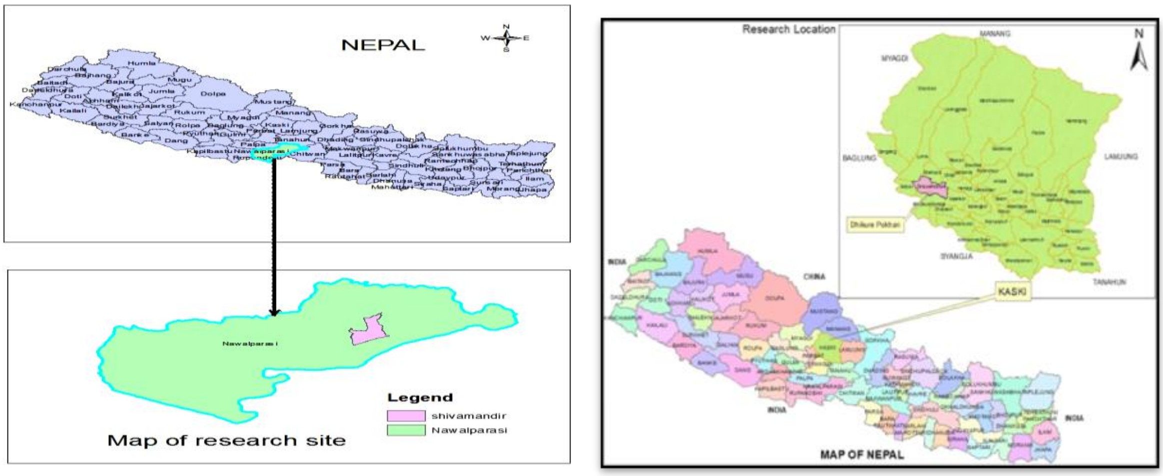

Figure 1: The topological map of research sites at Kawaswoti in Nawalpur and at Dhikurpokhari, in Kaski

Data inventory for CSM-CERES- Rice, Maize and Wheat models and model calibration

To understand the impact of different agronomic management and climate change scenarios on rice, maize and wheat, the CSM-CERES - Rice, Maize and Wheat modules embedded in DSSAT ver 4.5 model was selected.

CSM-CERES-Rice, Maize and Wheat require a well- defined set of input data to simulate actual crop conditions (Benioff and Smith, 1994). The various date include experimental details (i.e., agronomic management) as FILEX, daily weather data as FILEW (with extension name WTH.), soil profile data as FILES, and cultivar (with extension name CUL.) files. The treatment details and treatments used for model calibration, validation and sensitivity analysis are presented in Table 3.

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Table 1: Soil physical properties of DSSAT Model experimental sites in Nawalpur and Kaski

Soil depth	Drained upper limit (DUL) (bars)	Drained lower limit (DLL) (bars)	Soil moisture saturation (bar)	Bulk density (Db) (gcm^{-3})
Rice experimentation site at Dhaubadi, Nawalpur				
0-20 cm	0.259	0.162	0.389	1.62
20-40 cm	0.259	0.162	0.389	1.56
40-60 cm	0.259	0.162	0.389	1.47
60-80 cm	0.259	0.162	0.389	1.52
80-100 cm	0.259	0.162	0.389	1.58
Maize experimentation site at Kawaswoti, Nawalpur				
0-20 cm	0.338	0.183	0.433	1.35
20-40 cm	0.336	0.178	0.432	1.35
40-60 cm	0.306	0.164	0.417	1.40
60-80 cm	0.287	0.153	0.37	1.53
Wheat experimentation site at Dhikurpokhari, Kaski				
0-20 cm	0.333	0.129	0.424	1.48
20-40 cm	0.312	0.132	0.458	1.36
40-60 cm	0.296	0.118	0.493	1.37
60-80 cm	0.306	0.133	0.458	1.45
80-100 cm	0.284	0.123	0.424	1.53

Table 2: Soil chemical properties of DSSAT Model experimental sites in Nawalpur and Kaski

Soil depth	Soil p^H	NH_4^+ N (%)	NO_3^- N (%)	Total N (%)	P_2O_5 (Kg ha^{-1})	K_2O (Kg ha^{-1})	Organic carbon (%)
Rice experimentation site at Dhaubadi, Nawalpur							
0-20 cm	5.53	0.0097	0.0167	0.12	51.86	285.9	1.38
20-40 cm	4.92	0.0063	0.0103	0.08	43.05	254.6	0.90
40-60 cm	4.78	0.0053	0.0097	0.06	35.53	245.6	0.73
60-80 cm	4.73	0.0053	0.0097	0.06	52.90	245.6	0.67
80-100 cm	4.70	0.0050	0.0097	0.06	37.67	232.3	0.65
Maize experimentation site at Kawaswoti, Nawalpur							
0-20 cm	6.2	0.008	0.015	0.35	58.01	132.5	1.45
20-40 cm	6.3	0.006	0.018	0.30	48.03	123.5	1.40
40-60 cm	6.6	0.006	0.019	0.27	46.12	120.0	1.30
60-80 cm	7.4	0.005	0.021	0.25	40.42	117.0	1.20
Wheat experimentation site at Dhikurpokhari, Kaski							
0-20 cm	6.18	0.08	0.19	0.27	45.36	221.6	2.09
20-40 cm	6.45	0.03	0.13	0.15	26.35	194.1	1.82
40-60 cm	6.42	0.05	0.09	0.15	32.27	209.7	1.67
60-80 cm	6.80	0.03	0.08	0.12	25.07	192.1	1.47
80-100 cm	7.00	0.02	0.07	0.11	21.31	201.0	1.32

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Table 3: Treatment details of rice, maize and wheat experimentation for the evaluation of DSSAT model

Particulars	Rice	Maize	Wheat
Site	Dhaubadi, Nawalpur	Kawaswoti, Nawalpur	Dhikurpokhari, Kaski
Treatments (Factor A)	Land Preparation SRI: System of Rice Intensification ICM: Integrated Crop Management CON: Conventional transplanting	Planting Date D_1: 7th April D_2: 22nd April D_3: 7th May	Land Preparation T1: Zero tillage with straw mulch @ 5 ton/ha T2: Conventional tillage without straw mulch
Treatments (Factor B)	Cultivars V_1: Sukkha-3 V_2: Sukkha-4 V_3: Sukkha-5 V_4: Hardinath-2 (check)	Cultivars V: Local maize V_2: Poshilo Makai-1 V_3: RML-4/17 V_4: Arun-2	Cultivars V1: Farmers Local V2: WK-1204 V3: Annapurna-4 V4: Gautam
Treatments (Factor C)	-	-	Planting date D1: November 15 D2: November 30
Replications	3	3	3
Design adopted	Split plot	RCBD	Strip-split plot
Treatment calibration	Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2 with SRI	All cultivars planted on 7th April	All cultivars with zero tillage under November 15 planting
Treatments validation	All rice cultivars with ICM and CON	All maize cultivars planted on 22nd April and 7th May	All wheat cultivars with zero tillage under November 30 planting
Treatment simulation	All rice cultivars under SRI	All maize cultivars under 7th April planting	All wheat cultivars grown on 30 Nov planting and conventional tillage

Crop performance files, FILEA (yields and yield attributes including phenology) and FILET (time series data recorded in minimum of 15 days intervals on dry matter, LAI, SLA, LAD etc.) are needed to enter in the specific files to run the individual modules smoothly and to see the simulation results. The model evaluation in general denotes the process of calibration, validation and simulations. All processes accomplished for the evaluation of CERES-Rice, Maize and Wheat models have been presented with suitable Tables and Figures, and the examplatory soil file has been given in Table 1 and 2.

CSM-CERES-Rice, Maize and Wheat Model validation and sensitivity analysis

The biometric parameters *viz.* days to anthesis and physiological maturity, above ground biomass at harvest, LAI maximum, unit grain weight and grain yields etc. were selected variables to validate the model. Moreover, simulations over diverse agronomic management options like change in planting dates, Nitrogen management, soil moisture stress, and different scenarios of climate change were accomplished by running CSM-CERES- Rice, Maize and Wheat models by comparing the growth and yield performance of crop genotypes for various weather years.

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 rice, maize and wheat was done by changing their respective magnitude to predict the growth and yield performance of major caereals as advocated by IPCC (2007) for 2020, 2050 and 2080

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scenarios. The changes in different scenario to the yield of major cereals represent the continuously increasing population and emission characteristics more suited to South Asian conditions. 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 et al., 2010).

RESULTS AND DISCUSSION

CSM-CERES- Rice, Maize and Wheat model parameterization/ calibration

Determination of genetic coefficients of four rice cultivars (Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2), four maize cultivars (Local, Posilo makai-1, RML-4/17 and Arun-2) and four wheat cultivars (Farmer's local variety, WK-1204, Annapurna-4 and Gautam) were estimated from several runs of model with different possible changes in the values for genetic coefficients and the estimated genetic coefficients have been given in Table 4- 6.

Table 4: Estimated genetic coefficients, observed and simulated values of various rice cultivars under different management practices during 2014 at Dhauwadi, Nawalpur, Nepal

Rice genetic coefficients	**Sukkha-3**	**Sukkha-4**	**Sukkha-5**	**Hardinath-2**
Basic vegetative phase of the plant (P1)	470	410	560	200
Extent to which phasic development leading to panicle initiation is delayed (P2R)	160	160	160	180
Time period in GDD (^{0}C) from beginning of grain filling (P5)	470	500	440	540
Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate (P2O)	12	12	12	11.8
Potential spikelet number co-efficient (G1)	96	97	94	96
Single grain weight (g) under ideal growing conditions (G2)	0.050	0.028	0.040	0.070
Tillering co-efficient (G3)	1.09	1.09	0.98	0.80
Temperature tolerance coefficient (G4)	1.0	1.0	1.0	1.03
Observed values (Experimental mean)				
Anthesis days (75%)	64	61	68	52
Physiological maturity days (75%)	96	94	98	86
Grain yield ((kg ha^{-1}))	5354	5037	5726	5003
Simulated values (CSM-CERES- Rice predicted)				
Anthesis days (75%)	64	61	68	56
Physiological maturity days (75%)	96	94	98	92
Grain yield (kg ha^{-1})	5357	5045	5735	4726

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Table 5: Estimated genetic coefficients observed and simulated values of various maize cultivars under different planting dates during spring of 2014 at Kawasoti, Nawalpur, Nepal

Maize genetic co-efficient	Local	Poshilo makai-1	RML-4/17	Arun-2
Thermal time from seedling emergence to end of juvenile phase (P_1)	230	400	380	230
Extent of development days to get the optimum photoperiod (P_2)	0.520	0.600	0.260	0.520
Thermal time from silking to physiological maturity (P_5)	940	1130	1290	910
Maximum possible number of kernels/plant (G_2)	360	590.9	816.9	440
Kernel filling rate (mg/day) (G_3)	9.28	8.38	7.36	9.88
Phyllochron interval (PHINT)	38.90	18.90	28.90	38.90
Observed values (Experimental mean)				
Anthesis days (75%)	49	61	56	49
Physiological maturity days (75%)	94	114	116	92
Grain yield ((kg ha^{-1}))	3124	5931	7685	3768
Simulated values (CSM-CERES-Maize predicted)				
Anthesis days (75%)	49	61	56	49
Physiological maturity days (75%)	94	114	116	92
Grain yield (kg ha^{-1})	3121	5933	7684	3765

Table 6: Estimated genetic coefficients, observed and simulated values of various wheat cultivars under different planting dates during 2014/15 at Dhikurpokhari, Kaski

Wheat genetic co-efficient	Local	WK-1204	Annapurna-4	Gautam
Days, optimum vernalizing temperature required for vernalizaion (P1V)	1.0	3.0	2.0	4.0
Photoperiod response (P1D)	18	39	15	10
Grain filling (excluding lags) phase duration (P5)	250	315	290	350
Kernel number per unit canopy weight at anthesis (G1)	50	40	40	50
Standard kernel size under optimum conditions (G2)	23	71	55	33
Sstandard, non-stressed mature tiller wt (including grains) (wt dwt) (G3)	0.7	0.9	0.5	1.0
Interval between successive leaf tip appearance (^{0}C.d) (PHINT	46	64	72	40
Observed values (Experimental mean)				
Anthesis days (75%)	113	118	114	112
Physiological maturity days (75%)	147	152	149	153
Grain yield ((kg ha^{-1}))	3000	3556	3500	2970
Simulated values (CSM-CERES-Wheat predicted)				
Anthesis days (75%)	114	119	113	112
Physiological maturity days (75%)	147	152	149	153
Grain yield (kg ha^{-1})	3000	3356	3948	2971

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Model validation

The CERES-Rice model was tested and validated by using the genetic coefficients of all tested four cultivars under their respective crop management practices (Table 3 and 4). Observation on anthesis and physiological maturity dates, grain yield and tops weight at maturity were used for the model validation. Predicted physiological maturity date was well agreed with observed physiological maturity date (RMSE=2.55, d-stat =0.925 and R^2=0.839). Similarly, close agreement was observed between observed and simulated anthesis date (RMSE=2.525, d-stat =0.956 and R^2=0.895). The agreement between observed and simulated grain yield (RMSE=1504.495, d-stat =0.307 and R^2=0.545), and tops weight at maturity (RMSE=3715.596, d-stat =0.283 and R^2=0.531) (Figure 2). These validation results showed that the CERES-Rice model could be safely used as a tool for simulation of different agronomic and climate change parameters to the sub-humid sub-tropical weather condition of central-western Terai and can be extrapolated the simulation work in similar agro-climatic condition.

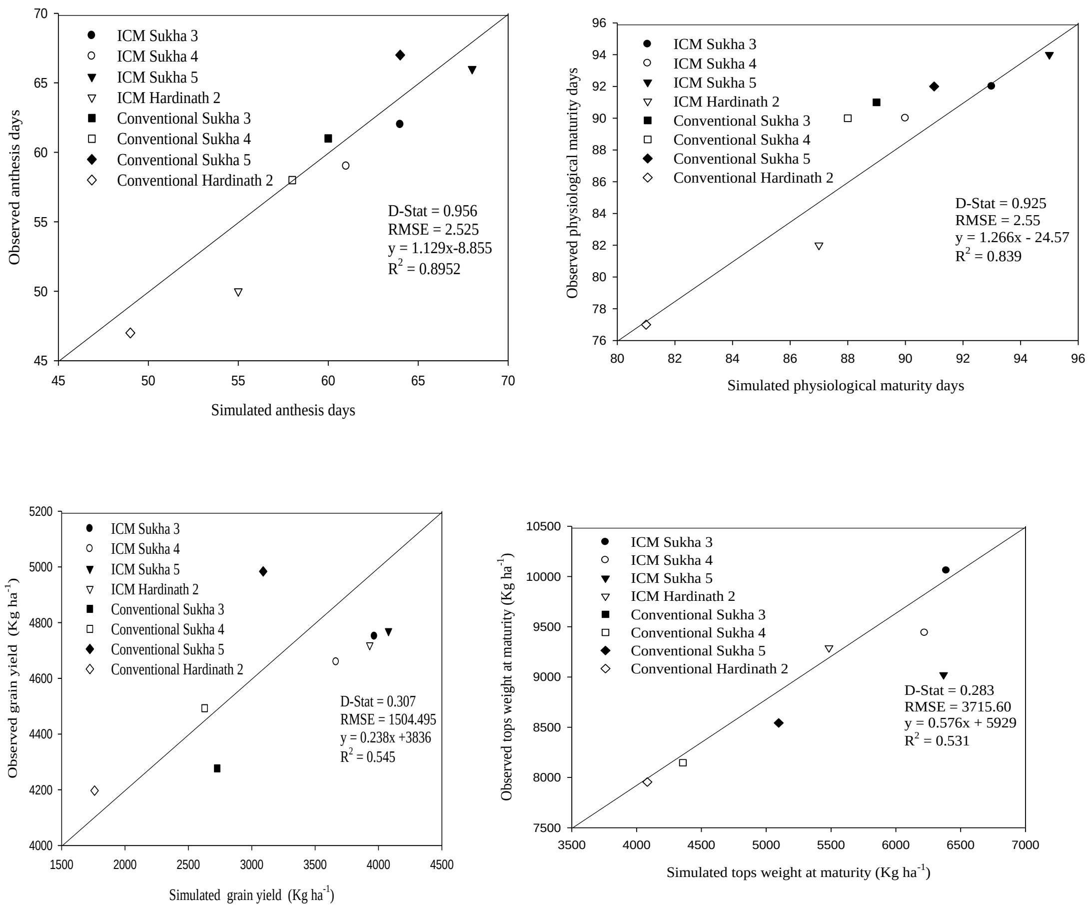

Figure 2: Simulated and observed i) anthesis days, ii) physiological maturity days, iii) grain yield and iv) tops weight at maturity for ICM and CON practices and four rice cultivars at Dhaubadi, NawlpurAs similar to CSM-CERES- Rice, CSM-CERES-Maize model

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validation was done by comparing model performance using the genetic coefficients (Table 3 and 5) for the rest treatments except the treatments used for model calibration (Table 3), and found that model fairly predicted days to anthesis, days to physiological maturity, number at maturity (no. m^{-2}), unit weight at maturity (g[dm]/unit area) and grain yield. Days to anthesis was well simulated with RMSE of 0.426 days and D-index of 0.998. Similarly, days to physiological maturity was simulated with RMSE of 0.674 days and D-index of 0.999. Agreement between simulated and observed grain number at maturity with RMSE of 85.29 grains m^{-2} and D-index of 0.993 was found satisfactory. In addition to this, a good agreement between observed and predicted unit weight at maturity with RMSE of 0.012 g $kernel^{-1}$ and D-index of 0.854 was found. The grain yield was simulated with RMSE of 54.94 kg ha^{-1} and D-index of 1.0 against observed values of grain yield for all eight treatments.

Overall performance of CSM-CERES-Maize embedded in DSSAT 4.5 was found satisfactory at, Kawaswoti, Nawalpur. The CSM-CERES-Wheat model was tested and validated by using the genetic coefficients of four wheat varieties grown under zero tillage and 30 November sowing (Table 3 and 6).

Model was validated using treatments except those used for model calibration for all wheat varieties. Predicted grain yield was well agreed with observed yield (RMSE=734.299, d-stat =0.631). Similarly, close agreement was observed between measured and simulated anthesis date, physiological maturity dates (RMSE =3.189, d-stat=0.923), and maximum leaf area index (RMSE=2.485 d-Stat=0.536). These validation results showed that the CSM-CERES-Wheat model could be safely used as a tool for simulation of different agronomic and climate change parameters under central mid-hills condition.

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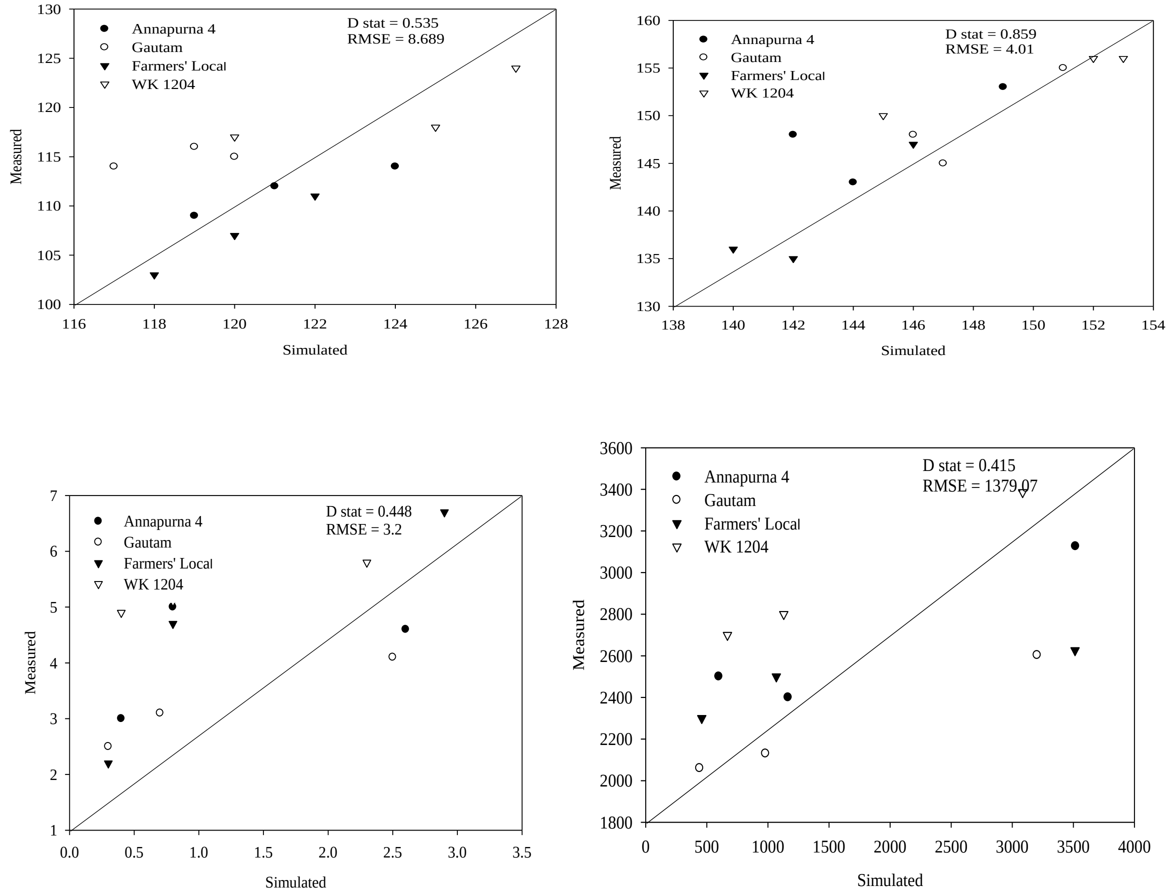

Figure 3: Simulated and measured i) anthesis days, ii) physiological maturity days, iii) LAI maximum, and iv) grain yield for Farmer's local variety, WK-120, Annapurna-4 and Gautam cultivars of wheat at Dhikurpokhari, Kaski

Simulation studies on CSM-CERES- Rice, Maize and Wheat models

Simulations to weather years of rice

CSM-CERES-Rice was run for the standard treatment using different years (2008-2014) of weather data of Nawalpur. It was revealed that the higher reduction in yield was in 2012 for all rice cultivars. There was 8.34%, 6.63%, 28% and 8.04% yield declined in Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2, respectively in 2012 (Table 7).

This decline in the yield was due to the less rainfall in the year 2012 as compared to the 2014. Low rainfall created water related stresses and reduces the yield (Sarvestani *et al.*, 2008). The physiological maturity days was increased for all the weather years when compared over standard year (2014), due to low daily average temperature for all the weather years than standard year.

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Table 7: Sensitivity of simulated yield and phenology of rice cultivars to weather years

	Weather years	Simulated yield (kg ha^{-1})	Percent yield	Anthesis (days)	Physiological maturity (days)
Sukkha-3	2014[a]	3967	100.00	64	93
	2012	3636	91.66	70	102
	2010	3712	93.57	71	104
	2008	3821	96.32	72	106
Sukkha-4	2014[a]	3665	100.00	61	90
	2012	3422	93.37	66	100
	2010	3510	95.77	67	102
	2008	3581	97.71	68	104
Sukkha-5	2014[a]	3090	100.00	64	91
	2012	2225	72.00	69	100
	2010	2357	76.28	71	102
	2008	2383	77.12	73	106
Hardinath-2	2014[a]	3931	100.00	55	87
	2012	3615	91.96	59	94
	2010	3623	92.16	60	96
	2008	3722	94.68	61	98

Note: [a] Standard year (2014)

Simulations of CSM-CERES- Rice over different climate change scenarios

After running the CSM-CERES-Rice model for the climate change scenarios for 2020, 2050 and 2080 scenarios as predicted by IPCC (2007), it was found that the model is sensitive to the various climate change scenarios. The results showed that there would be increment in the yield up to 2020 scenario of climate change and the gradual yield loss would be from 2050 to 2080 scenarios under the present levels of agronomic management options suggest to develop the temperature stress crops cultivars with high nutrient and water use efficiency.

Table 8: Sensitivity analysis of different rice cultivars over the different climate change scenarios for 2020, 2050 and 2080

S.N.	Max temp (°C)	Min temp (°C)	CO_2 conc. (ppm)	Solar radiation (MJ m^{-2} day^{-1})	Cultivars	Simulated yield (kg ha^{-1})	Percent yield	Growth duration (days)
1[a]	+0	+0	398	+0	Sukkha-4	3665	100	90
					Hardinath-2	3931	100	87
2	+1	+1	398	+0	Sukkha-4	3663	99.9	88
					Hardinath-2	3868	98.4	84
3	+1	+1	+50	+1	Sukkha-4	3880	105.9	87
					Hardinath-2	3993	101.6	84
4	+2	+2	+50	+1	Sukkha-4	3758	102.5	87
					Hardinath-2	3683	93.7	84
5	+3	+3	+100	+1	Sukkha-4	3112	84.9	85
					Hardinath-2	2976	75.7	83
6	+3	+3	+200	+1	Sukkha-4	3365	91.8	85
					Hardinath-2	3264	83.0	83
7	+4	+4	+200	+1	Sukkha-4	2341	63.9	84
					Hardinath-2	1644	42.3	82

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)

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Simulations of CSM-CERES-Maize model on agronomic management (sowing date)

Four sowing dates of maize were studied for the sensitivity on simulated maize yield by using CSM-CERES-Maize model. The response of maize cultivars to sowing dates was different for each cultivar. Short duration cultivars had positive effect on yield with increment of yield. Local cultivar increased yield by 11.78% and 16.61%, while Arun-2 increased yield by 12.71% and 18.81% when sensitivity analyses were done for 12th April and 17th April, respectively. Simulation for 27th April showed decrease in yield by 16.87% in Local and 15.84% in Arun-2 and it was decreased by 18.28% in Local and 18.13 % in Arun-2, when simulation was done for 2nd May planting. In contrast to the early matured cultivars, the effect of sowing dates seemed to be negative on yield of longer duration maize cultivars. The yield of Poshilo makai-1 decreased by 31.33%, 35.12%, 23.84% and 25.88% when sensitivity analysis was done for 12th April, 17th April , 27th April and 7th May, respectively. In case of RML-4/17, yield increased slightly by 2.51% when sensitivity was done for 12th April but it's yield also decreased by 28.11%, 20.01% and 23.84 % when sensitivity analysis was done for 17th April, 27th April and 2nd May, respectively. For all varieties, postponing sowing date had shortening effect on growth period of all varieties.

Simulation of CSM-CERES-Maize model on agronomic management (moisture management)

Maize planted on 7th April faced pre-vegetative drought stress so a simulation study on grain yield of maize cultivars under no water stress condition was done for their possible yield output. Under no water stress condition, model predicted yields of Local, Poshilo makai-1, RML-4/17 and Arun-2 have been increased by 6.183%, 11.951%, 18.230% and 6.634%, respectively (Table 9).

Table 9: Sensitivity of no water stress condition to simulated yields of maize cultivars

Water management options	Varieties	Simulated grain yield (kgha^{-1})	% yield Change
Rainfed condtion*	Local	3121	100
	Poshilo makai-1	5931	100
	RML-4/17	7685	100
	Arun-2	3768	100
No water stress condition	Local	3314	106.2
	Poshilo makai-1	6639	111.9
	RML-4/17	9086	118.2
	Arun-2	4018	106.6

**denotes standard treatment*

Simulations of CSM-CERES-Maize model on climate change parameters

Various scenarios of temperature, carbon dioxide concentration and solar radiation were selected for running sensitivity analysis of yields simulated by CSM-CERES-Maize for different maize cultivars (Table 10). Compared to simulated yield of standard treatment, the increase in yield were 7.21%, 15.39%, 20.36% and 12.70% for Local, Poshilo makai-1, RML-4/17 and Arun-2, respectively when temperature (both max and min temperatures) were decreased by 2 ^{0}C and CO_2 concentration maintained constant at 390 ppm with no change in solar radiation. But, when temperature was increased by 2 ^{0}C yield of Local,

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Poshilo makai-1, RML-4/17 and Arun-2 decreased by 12.07%, 17.92%, 20.01% and 11.74%, respectively.

Table 10: Sensitivity analysis of maize cultivars with changes in temperature, solar radiation and CO_2 concentration at Kawaswoti, Nawalpur

Max Temp(^{0}C)	Min Temp (^{0}C)	CO_2 Conc (ppm)	Solar Radiation ($MJm^{-2}\ d^{-1}$)	Varieties	Simulated Grain yield	% yield change (Kg ha^{-1})	Growth duration (days)
+0	+0	390	+0	Local	3068	100	94
				Poshilo makai-1	5902	100	114
				RML-4/17	7459	100	116
				Arun-2	3710	100	92
+2	+2	390	+0	Local	2697.69	-12.07	88
				Poshilo makai-1	4844.36	-17.92	106
				RML-4/17	5966.45	-20.01	108
				Arun-2	3274.45	-11.74	87
-2	-2	390	+0	Local	3289.20	+7.21	101
				Poshilo makai-1	6810.32	+15.39	123
				RML-4/17	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-4/17	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-4/17	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-4/17	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-4/17	5958.99	-20.11	108
				Arun-2	3248.48	-12.44	87

Elevated CO_2 by 20 ppm along with raise in temperature by 2 ^{0}C had resulted in decrease of yield by 10.9%, 16.2%, 18.31% and 10.5% for Local, Poshilo makai-1, RML-4/17 and Arun-2, respectively. There was increment in yield of Local, Poshilo makai-1, RML-4/17 and Arun-2 by 17.05%, 21.27%, 28.59% and 19.03%, respectively when temperature decreased by 2 ^{0}C and increased solar radiation by 1 $MJm^{-2}day^{-1}$ with 20 ppm increased in CO_2 concentration. But, when temperature decreased by 2 ^{0}C and decreased solar radiation by 1 $MJm^{-2}day^{-1}$ with 20 ppm increased in CO_2, there was increased in yield by 7.54%, 13.03%, 15.27% and 8.93% for Local, Poshilo makai-1, RML-4/17 and Arun-2, respectively. Increase of temperature caused shortening of growth duration and yield loss in spring maize.

Simulations of CSM-CERES-Wheat model to weather years

CSM-CERES-Wheat was run to see its sensitivity over weather years using Farmer's local variety cultivar with ZT and WK-1204, Annapurna-4 and Gautam cultivars with CT, all cultivars on November 30 sowing date (Table 11). The simulations over weather years revealed that there was 10, 23 and 44% yield declined in Farmer's local variety, WK-1204, Annapurna-4, respectively in the year of 2012/13, whereas in Gautam, yield increment was observed about 10% in 2012/13 (Table 11). Similarly, when CSM-CERES-Wheat was run for 2006/07, it was revealed that there was 19, 13 and 9% yield declined in Farmer's local

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variety, WK-1204, Gautam, respectively, whereas Annapurna-4, recorded yield increment of about 3% (Table 11).

Table 11: Sensitivity of simulated yield and phenology of wheat cultivars to various weather years in Kaski

	Weather years	Simulated yield (kg ha^{-1})	Percent yield	Anthesis (days)	Physiological maturity (days)
Farmer's local variety	20014/15[a]	3063	100	113	142
	2012/13	2771	90	110	138
	2006/07	2480	81	107	136
	2001/02	3033	99	115	145
WK-1204	20014/15[a]	2743	100	117	150
	2012/13	2122	77	114	147
	2006/07	2379	87	115	148
	2001/02	3602	131	126	159
Annapurna-4	20014/15[a]	2167	100	112	144
	2012/13	1215	56	110	140
	2006/07	2232	103	113	146
	2001/02	3313	153	116	157
Gautam	20014/15[a]	1842	100	112	148
	2012/13	1018	110	110	145
	2006/07	1663	91	113	149
	2001/02	3368	183	116	152

2014/15[a] default treatment

It was found that average temperature was lower in the year of 2006/ 07, which increased maturity days of Farmer's local variety, WK-1204, Annapurna-4 and Gautam. Singh and Padila (1995) reported that decreased temperature increase wheat yield significantly.

Simulations of CSM-CERES-Wheat model to nitrogen management

Sensitivity of CSM-CERES-Wheat on grain yield and different nitrogen levels revealed that nitrogen splitting in twice, half at basal and remaining half at 30 DAS was sensitive (Table 12). N stressed in Farmer's local variety, WK-1204, Annapurna-4 and Gautam resulted yield reduction by 68, 75, 75 and 79%, respectively on the soil of Lumle, Kaski. The result was in conformity with Amgain and Timsina (2008) who reported simulated yield reduction by 46% by reducing level of N from 120 to 0 kg ha^{-1} at Punjab Ludhiana soil. Plant growth is adversely affected due to deficiency of nitrogen as it restricts the formation of enzymes, chlorophyll and proteins necessary for growth and development (Reddy and Reddy, 2009). N level of 120 kg ha^{-1} showed increase in the yield in Farmer's local variety, WK-1204, Annapurna-4 and Gautam by 8, 3, 3 and 5% respectively. N level of 40 kg ha^{-1} showed decrease in the yield in Farmer's local variety, WK-1204, Annapurna-4 and Gautam by 42, 22, 5 and 17% respectively. The result was in line with Sommer et al. (2012) who observed that the application of 120 kgN/ha gave significantly higher grain yield (4.82 ton/ha). Since wheat was sown rainfed, the recommended nitrogen of 80 kg/ha when increased to 120 kg/ha could not show major changes in yield. The water limited condition might have hindered the uptake of N even at higher dose of N application.

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Table 12: Sensitivity of simulated yield and phenology of wheat cultivars to level of nitrogen

Levels of nitrogen (kg N ha^{-1})	Variety	Simulated yield (kg ha^{-1})	Percent change
0	Farmer's local variety	990	32
	Wk-1204	686	25
	Annapurna-4	538	25
	Gautam	391	21
40	Farmer's local variety	1080	58
	Wk-1204	2425	88
	Annapurna-4	2062	95
	Gautam	1538	83
80[a]	Farmer's local variety	3063	100
	Wk-1204	2743	100
	Annapurna-4	2167	100
	Gautam	1842	100
120	Farmer's local variety	3505	108
	Wk-1204	2823	103
	Annapurna-4	2228	103
	Gautam	1937	105

Simulations of CSM-CERES-Wheat model to climate change parameters

Various scenarios of temperature, carbon dioxide concentration and solar radiation were selected for running sensitivity analysis of yields simulated by CSM-CERES-Wheat for each cultivar (Table 13).

Table 13: Sensitivity analysis of wheat cultivars with changes in temperature, solar radiation and CO_2 concentration in Kaski, during 2014/15

Max temp (ºC)	Min temp (ºC)	CO_2 conc. (ppm)	Solar radiation ($MJm^{-2}day^{-1}$)	Treatments	Simulated yield (kg ha^{-1})	% yield change	Growth duration (days)
+0[a]	+0	390	+0	Farmer's local variety	3063	100	142
				WK-1204	2743	100	150
				Annapurna-4	2167	100	144
				Gautam	1822	100	148
+4	+4	390	+0	Farmer's local variety	2063	67	113
				WK-1204	698	25	121
				Annapurna-4	461	21	123
				Gautam	533	29	118
+4	+4	+20	+0	Farmer's local variety	2111	69	113
				WK-1204	712	26	121
				Annapurna-4	472	22	123
				Gautam	543	30	118
-4	-4	+20	+0	Farmer's local variety	3858	126	182
				WK-1204	4221	154	188
				Annapurna-4	3750	175	196
				Gautam	3923	212	187
+4	+4	+20	+1	Farmer's local variety	2169	71	113
				WK-1204	761	28	121
				Annapurna-4	481	22	123
				Gautam	592	32	118

Compared to simulated yield of standard treatment, the decrease in yield was 32, 74, 78 and 71 for Farmer's local variety, WK-1204 Annapurna-4 and Gautam, respectively with the increase in both maximum and minimum temperature by 4^{o}C, but decrease in both maximum and minimum temperature by 4^{o}C yield was increased by 25, 53, 74, and 112% for Farmer's local variety, WK-1204, Annapurna-4 and Gautam, respectively.

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Elevated CO_2 by 20 ppm along with increased temperature had resulted in decrease in grain yield by 31, 74, 78 and 70%, respectively for Farmer's local variety, WK-120, Annapurna-4 and Gautam. But, in combination with decreased temperature, there was increased in yield by 26, 54, 75 and 112%, respectively for Farmer's local variety, WK-120, Annapurna-4 and Gautam. Decrease in yield by 34, 75, 79 and 72% for Farmer's local variety, WK-1204, Annapurna-4 and Gautam, respectively with the decrease in solar radiation by 1 MJ m^{-2} day^{-1} along with increase in temperature (by 4^oC) and CO_2 concentration (by 20 ppm). Under decreased temperature (by 4^oC), increased CO_2 concentration (by 20 ppm), changes in solar radiation amount (1 MJ m^{-2} day^{-1}) had increased the simulated yield of three cultivars. Under increased temperature condition (along with elevated CO_2 and increased or decreased solar radiation), the growth duration of wheat cultivars was found decreased and consequently decreased in yield. Likewise, it was found to be increased in crop duration and yield for decreased in maximum and minimum temperature by 4^oC (Table 13).

Temperature primarily affected growth duration with lower temperature increasing the length of time that the crop could intercept radiation. Amgain et al. (2006) reported that increase in minimum and maximum temperature by 4^0C over the base scenario decreased the wheat yield by 4%. Reduction of minimum and maximum temperature by 4^0C and increase in CO_2 by 20 ppm showed increase in yield (Amgain, 2004). Increased CO_2 concentration and increased temperature increased growth duration and yield, while increased temperature shortened growth duration and reduced leaf area, biomass and yield (Qureshi and Iglesias, 1994; Timsina et al, 1997).

The increased temperature and reduced solar radiation decreased the net photosynthetic active radiant (PAR) interception. The less interception of PAR caused lower assimilate formation in wheat and produced lower yield under increasing temperature and reduced light which was reported by Amgain et al. (2006). Increasing temperatures reduced growth duration, and probably decreased photosynthesis, increased water use, and reduced water use efficiency as reported by Imai (1988). Increased CO_2 concentration and decreased temperature increased growth duration and yield, while increased temperature shortened growth duration and reduced leaf area, biomass and yield (Timsina et al., 1997; Rao and Sinha, 1994; Qureshi and Iglesias, 1994).

CONCLUSIONS

To achieve the higher production and increasing demand of the rice, maize and wheat and increase the balance in national food security, precision agriculture tools like crop simulation modeling has been suggested the best approaches. The CSM-CERES-Rice, Maize and Wheat Models were well calibrated, found to be fairly valid under the sub-tropical condition of central southern Terai of Nawalpur and mid hills of Kaski and could be suggested to use the DSSAT ver 4.5 crop model as a tool for sensitivity analysis and in estimating yield gaps. The study on different agronomic management and climate change scenarios as suggested by IPCC (2007) advocated to think over the declining yield trends of major cereals and should initiate the precision agriculture practices. 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 with diverse cultivars in large agro-ecological areas throughout Nepal.

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Author contributions

Lal Prasad Amgain - Planned to frame this compiled article as a major supervisor of the concerned students at PG Program of IAAS, Rampur, Chitwan and Kirtipur, Kathmandu
Bishal Dhakal- Accomplished M Sc Ag Agronomy thesis on rice,
Umesh Shrestha - Accomplished M Sc Ag Agronomy thesis on maize, and
Srijana Marasini- Accomplished M Sc Ag Agronomy thesis on wheat

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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