Modeling the sensitivity of CERES-Rice model: An experience of Nepal

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Abstract

The experiment was conducted with four levels of nitrogen (40, 80,120 and 160 kg/ha) and 3 different cultivars (Prithivi hybrid), Masuli (HYV) and Sunaulo Sugandha (Aromatic).RMSE value (747.35 kg/ha, 1.106 days, 2.58 days and 0.004 kg/ha) and D-stat value (0.793, 0.99, 0.99 and 0.633) for grain yield, anthesis days, maturity days, and individual grain weight respectively. The objective of this study was to identify whether CSM-CERES-Rice model can be used in Nepalese condition and to evaluate the sensitivity of model with impact of climate change on rice production. Eight different climate scenarios were built by perturbing maximum and minimum temperature (± 4^0C), CO_2 (± 20ppm), solar radiation (±1MJ/m^2/day) using interactive sensitivity analysis mode in DSSAT. Among the scenario evaluated, temperature (± 4^0C), CO_2 concentration (+20 ppm) with change in solar radiation (±1MJ m^{-2} day-1) resulted maximum increase in yield (by 62, 41 and 42%) under decreasing climatic scenarios and sharp decline in yield (by 80, 46 and 40%) was observed under increasing climate change scenarios, in Prithivi, Masuli and Sunaulo Sugandha cultivars respectively.Not surprisingly, increasing yield by (48, 25 and 27 %) and decrease in yield by(77, 41 and 34) by perturbing only maximum and minimum temperature by (± 4) shows that the temperature is most sensitive for yield potentiality of cultivars than other. CERES-Riceversion 4.0 was well calibrated in Chitwan Nepal condition. The model applications show that model could be a tool for precision decision-making. There was variation in yield in response to the change in climatic scenario in the study. RMSE value (747.4 kg/ha, 1.11days, and 2.58 days), and d-stat (0.79, 0.99 and 0.99) for grain yield, anthesis, and maturity days confirm the possibility of CERES-Riceuse in Nepalese agriculture. The finding showed that there was sharp decrease in rice yield due to change in temperature, CO_2 and solar radiation. Climatic scenario developed by CERES-Rice model in sensitivity analysis resulted yield reduction up to 80%. Among the cultivar, hybrid rice shows more vulnerability with climate change. Decrease in yield were mainly associated with lowering growth duration along with increasing temperature, where as there is very less counter effect of increasing carbon dioxide concentration and solar radiation.

Keywords : CERES-Rice, sensitivity, yield, and cultivars

Introduction

Rice (*Oryza sativa L.*) is one of the most important food crops of Asia and three fifth home of the humanity(Auffhammer*, et al.*, 2012). In Nepal, rice ranks the first on the basis of area (1.48 million ha.)and production (4.02 million ton) with theproductivity of 2.71 t/ha, which contributes more than 20% agriculture gross domestic product (AGDP) (MOAC, 2010/11). Variation of extreme weather pattern rise in temperature,varied precipitation resulted declining production of crop in major region of Asia (Tragolraam et al 2011). Despite of rapid advancement in agriculture sector, weather is still key factor impacting crop productivity and declining yield (Sapkota*, et al.*, 2010). Last 32 years of climatic data of Nepal showed that temperature has been increased by 1.8°C with average rise of

0.06°C per year along with high intensities of rainfall and less number of rainy days (Malla, 2009) where as computer simulation indicate that average global temperature will rise by 1.1-6.4°C by end of the 21st century. Concerning food security of underdeveloped country like Nepal, negative impact of climate change on rice yield can be a serious issue in near future. It is, therefore, most essential to quantify possible impact of climate change and adopt mitigation measures to solve the problem of food scarcity.

Impact of climate change on agriculture production varies depending on varying region(Vucetic, 2011) which enable researcher to study their impact at local, regional and global level. The decision support system for agro technology transfer (DSSAT) developed by the International Benchmark Systems Network for Agro-technology Transfer (IBSNAT) embedded with CERES-Rice is a process based simulation model (Jones et al 2003) which enables user to quantify variability of crop performance with response to variability in seasonal weather condition and long term impact of climate change (Timsina, *et al.*, 2010). CERES-Rice has been widely used all over the world (Aggarwal, *et al.*, 2002; Lal, *et al.*, 1998; Mahmood, 1998; Rosenzweig, *et al.*, 1994; Yao, *et al.*, 2007) for investigating climate change impact on rice production. Having variety-specific in nature (Jones, *et al.*, 2003), the CERES-Rice model perform based on individual genetic coefficient which enable model to perform more precisely.

There are various method evolved to evaluate the impact of uncertainty in model input. Here we select the most important tools; sensitivity analysis (Saltelli, 2002). Very few sensitivity analysis method have been used for crop model (DeJonge, *et al.*, 2012). Noticeable studies have been carried out (Aggarwal, *et al.*, 2002; Pathak, *et al.*, 2004) and evaluated the sensitivity of rice model with respect to weather parameter.The objective of this study was to evaluate the Ceres-rice model in Nepalese condition and to quantify the impact of climate change on growth and development of hybrid and HYV's variety of rice. In addition sensitivity of Ceres-rice yield with perturbing climatic data set (Temperature, CO_2, solar radiation and weather years).

Material and methods

The study was conducted with data from experimental site located in central Nepal, at the Institute of Agriculture and animal science (IAAS) Chitwan, Nepal (27°37' N and 84°25'E, 256 above sea level). It is climatically characterized as humid sub tropical with medium rainfall resembling the foot-hill and inner-Terai climate. The site annually receives about 2000 mm of rain, about 80% of which occurs from mid June to mid September. Humidity starts rising up from May (average 50%) and reaches to its extreme (100%) in December and January. Daily rainfall, maximum minimum temperature, sunshine hours and relative humidity ware collected as required by model. Sun shine hours were converted in to the solar radiation with the wgen-based weather generator (richardson, et al., 1984), included in weatherman (tools of DSSAT).

$$R_s = R_a(a + b(\frac{n}{N})$$

Where, R_s = Total radiation, R_a= Extra terrestrial radiation, a & b = Angstrom Coefficient and approximate to latitude, n= Sunshine hours and N= Day length

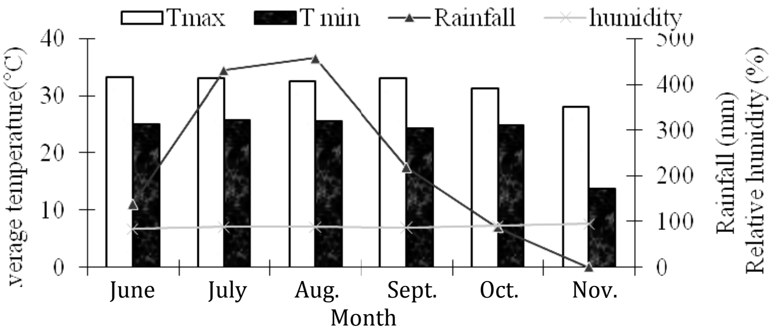


Fig 1. Weather data of experimental location for crop growing period at Rampur, chitwan, Nepal during 2008

Soil analysis

As of DSSAT requirement (jones, et al., 2003), soil samples from vertical profile up to 100 cm were taken for physical and soil profile about a week before transplanting. Table 1 shows the detail characteristics of the soil profile of the experimental site. Soil at the experimental site was sandy loam. Four levels of nitrogen (40, 80, 120 and 160 n kg/ha) with different cultivar (hybrid- Prithivi, aromatic-Sunaulo Sugandha (SS) and inbred- Mansuli) were used. Experiment was conducted considering two factorial randomized complete block design *(RCBD).*

Table 1. Soil characteristics of experimental site during 2008 at IAAS, Rampur, Chitwan, Nepal

(CM)	*DUL*	*DLL*	*BD G/CM 3*	*SAT (CM)*	pH	NH_4^+ (%)	NO_3^- (%)	Tot N (%)	P_2O_5 Kg ha^{-1}	K_2O Kg ha^{-1}	OC (%)	Silt %	Clay %
0-20	0.188	0.104	1.47	42.6	6.8	*0.0252*	*0.0084*	0.14	37	67	1.58	5	7
20-40	0.207	0.105	1.50	43.7	6.8	*0.0248*	*0.0087*	0.11	27	24	1.26	17	9
40-60	0.154	0.075	1.43	45.6	6.7	*0.0248*	*0.0082*	0.05	15	86	0.53	15	7
60-80	0.142	0.077	1.42	46.2	6.6	*0.0248*	*0.0087*	0.02	15	34	0.23	11	9
80-100	0.100	0.047	1.47	46.68	7.0	*0.0252*	*0.0084*	0.02	37	34	0.22	7	3

CSM CERES Rice model

Crop simulation model was build with aiming to simulate crop growth, development and yield along with change in soil water, carbon and nitrogen balance under the cropping system (Jones, *et al.*, 2003) CERES- Rice is a individual sub module embedded with DSSAT (Decision support system for agro-Transfer technology) that simulates phenology, daily growth and partitioning, plant nitrogen and carbon demands, senescence of plant material, etc. CERES-Rice model embedded with DSSAT v 4 shell (Jones, *et al.*, 2003) is widely used model for various purposes, with major focus on climate change impact assessment (Rosenzweig, *et al.*, 1994). CERES-Rice simulate yield (Evans, 1993; Ritchie, *et al.*, 1998) and biomass based on equation as follows.

$$Y = I_{H\eta R} \sum_{i=1}^{N} (Q_{dPARi} R_{\eta} f_i \Delta_{\mathrm{Ri}})$$

Where

Y = grain yield as dry matter in g^{-2}; I_H = harvest index (grain as a fraction of the aboveground biomass), ηR = the value of the RUE in g MJ^{-2}; Q_{dPARi} = average daily total of incident PAR for a given month (i) in MJm^{-2} f_i = fraction of PAR intercepted; R_η = number of days of radiation interception; Δ_{Ri} = fraction of the maximum RUE depending on crop performance, in gMJ^{-2}; N is the number of months. Similarly total biomass production (Ritchie, *et al.*, 1998) will accompanied from average growth rate(B_T) and growth duration(d)

$$B_T = g \times d$$

Where growth of plant determined as

$$CARBO = RUE * PAR * [1 - \exp(-K * LAI)]$$

Where CARBO= net photosynthesis, RUE= radiation use efficiency, LAI= leaf area index and k= extension coefficient. Value for RUE assumed as 2.95 gMJ^{-1}, where temperature range from 14-32^{0}C

Result and discussion

Model calibration and evaluation

Calibration was done with the independent data sets of three rice cultivars viz. Prithivi and Sunaulo Sugandha with 160 Kg N/ha and Masuli with 120 Kg N/ha (Table 2) for different genetic coefficient which characterize the rice performance. Accuracy in simulation of yield, phenology and growth requires the accurate genetic coefficient (Quiring, *et al.*, 2008).These coefficients were adjusted until there was a close match between the observed and simulated dates of anthesis, physiological maturity and grain yield (Table 2)

The performance CERES-Rice was tested and evaluated using the above-determined coefficient for rest of the varieties with their respective fertilizer other than calibrated one. Two statistics were used to evaluate the model performances. (i) Root Mean Square Error (RMSE) and (ii) d stat index (Willmott, 1982) inch is illustrated in equation (1 & 2).Willmott (1982) stated that the d stat index value should approach unity and the RMSEs approach zero for good performance of the model.

Table 2. Calibrated genetic coefficient and their values

Genetic coefficient		Prithivi	Masuli	SS
P1	Basic vegetative phase of the plant.	670	840.7	891.9
P20	Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate	50.7	186.1	232
P2R	Extent to which phasic development leading to panicle initiation is delayed	330	251	220
P5	Time period in GDD ^{0}C) from beginning of grain filling	10.2	10.8	10.9
G1	Potential spikelet number coefficient	69.9	42.4	42.2
G2	Single grain weight (g) under ideal growing conditions.	0.295	0.020	0.242
G3	Tillering coefficient	0.97	1.0	1.00
G4	Temperature tolerance coefficient.	1.13	1.0	1.00

a. Root Mean Square Error

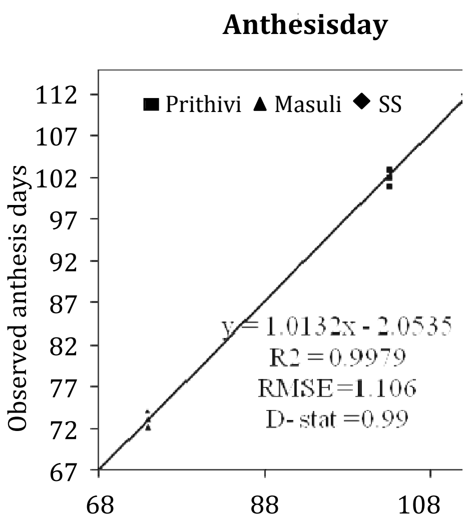
$$RMSE = \left[\sum_{i=1}^{n} \frac{(P_i - O_i)^2}{n}\right]^{0.5} \qquad [1]$$

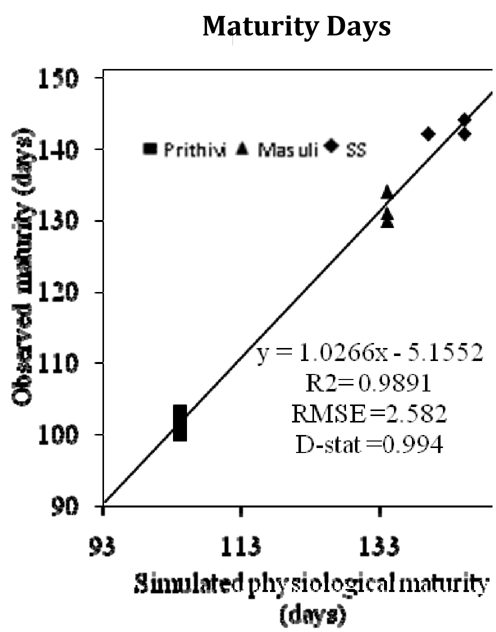
b. D-stat index

$$d = \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum(|P_i - O_{iavg}|) + (O_i - O_{iavg})^2} \qquad [2]$$

Where, O_i = Observed Value, P_i=, Predicted Value, O_{iavg} = average of the obeserved value, n= number of observation

Observation on anthesis, physiological maturity days, grain yield, and unit grain weight were used for the model validation (Fig 2). Predicted grain yield was well agreed with observed yield (RMSE=747.4 kg/ha, d-stat =0.79). Similarly, close agreement was observed between observed and simulated anthesis date (RMSE = 1.11 d-Stat = 0.99) and physiological maturity dates (RMSE = 2.58 days, d-stat = 0.99). Also fairly satisfactory agreement was found with the unit grain weight (RMSE = 0.004 mg, d-stat = 0.63). Thus these validation results showed that the CERES-Rice model could be safely used as a tool for simulation of different agronomic and climate change parameter.





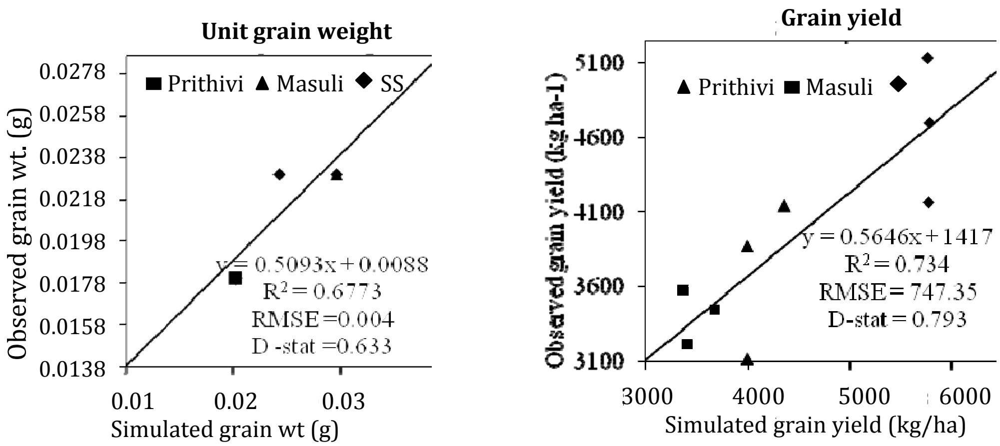


Fig 2. simulated and observed Anthesis days (a), maturity days (b), Unit grain weight (c), and Grain yield (d)

Sensitivity analysis

Sensitivity analysis is the study of how the variation in the output of a model can be apportioned to different sources perturbing input (Saltelli, 2002). Sensitivity of CERES-Rice was made using systematic changes in Weather years, Maximum and minimum temperature, Co_2 concentration and solar radiation.

Sensitivity to weather years

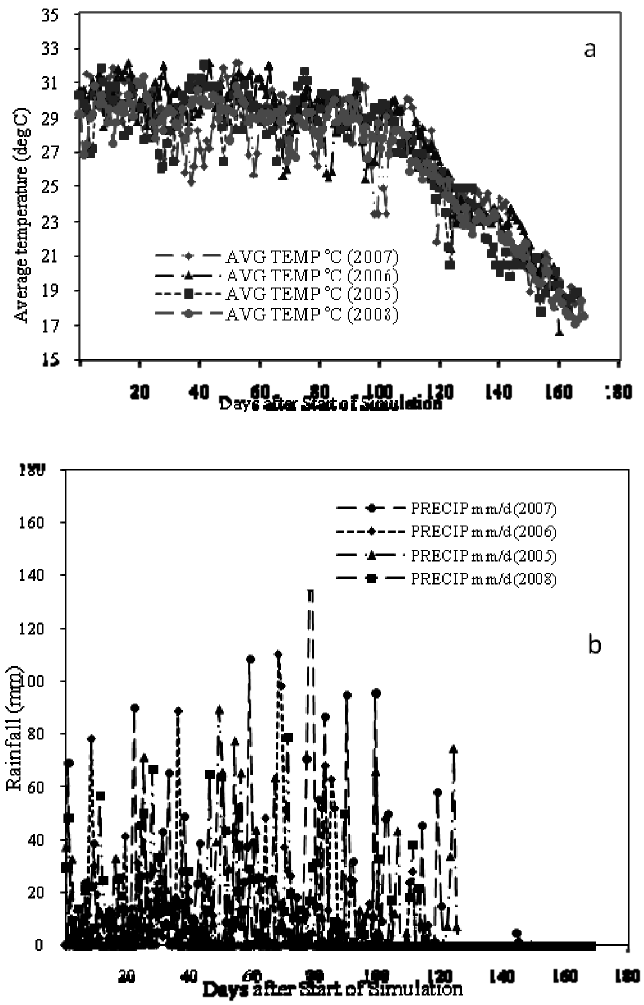
CERES-Rice was run for the standard treatment using 4 years of weather data (2005-2008) and found sensitive (Fig. 4 and Table 3). Hybrid cultivar Prithivi found more sensitive with change in weather years with reducing yield by 17 and 20 % in year 2007 and 2005 (Fig 4**).** In addition, year 2007 showed the 12% lowered yield from HYV's Masuli and Sunaulo Sugandha (Fig 4). Lower yield of the hybrid variety was due to the lower spikelet fertilization rate with high temperature. Lower the availability of solar radiation and high rainfall rate during critical stages (Buan, *et al.*, 1996) and high temperature with scanty rainfall (Amien, *et al.*, 1996) leading to lower yield.

Table 3. Sensitivity of simulated yield and phenology of rice cultivars to weather years

Cultivars	Weather years	Simulated yield (kg ha^{-1})	Anthesis (days)	Maturity (days)
Prithivi	2008[a]	5754	74	104
	2007	4759	75	105
	2006	5679	75	104
	2005	4629	75	103
Masuli	2008[a]	3892	103	134
	2007	3420	102	132
	2006	3530	99	128
	2005	3640	101	133

Sunaulo	2008[a]	4468	112	145
Sugandha	2007	3939	111	142
	2006	4098	108	137
	2005	4208	110	143

[a] Standard years



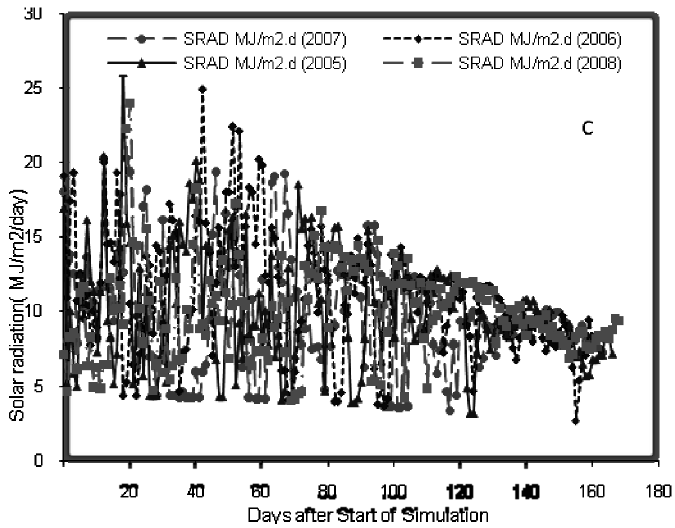


Fig 3. Daily temperature (a), rainfall (b), and solar radiation (MJ/m^2/day) during rice season

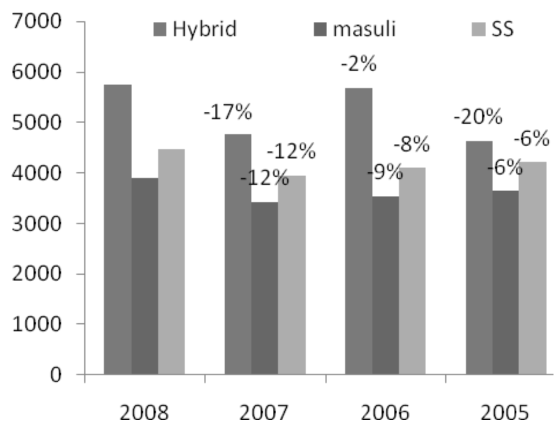


Fig 4. Percentage change in yield in response to different weather years

Sensitivity to daily weather series

As we already discussed, ambiguities exist in perturbing the different climate years. Furthermorequestion arise how the model is sensitive to change in daily weather pattern. To suggest the answer, various climatic scenarios were assumed to perform sensitivity analysis. Scenarios were developed with perturbing maximum and minimum temperature, solar radiation and carbon dioxide concentration. Details of the scenarios are presented in Table 4.

Table 4. Description of climatic scenario used for sensitivity analysis

Scenario	Description
A1	Tmax + 4°C, Tmin +4°C
A2	Tmax - 4°C, Tmin -4°C
A3	Tmax +4°C, Tmin+4°C and CO_2+ 20ppm
A4	Tmax - 4°C, Tmin -4°C and CO_2 + 20ppm
A5	Tmax +4°C, Tmin +4°C and CO_2+ 20ppm and SRAD + 1 $MJm^{-2}day^{-1}$
A6	Tmax +4°C, Tmin +4°C and CO_2+ 20ppm and SRAD -1 $MJm^{-2}day^{-1}$
A7	Tmax -4°C, Tmin - 4°C and CO_2+ 20ppm and SRAD +1 $MJm^{-2}day^{-1}$
A8	Tmax -4°C, Tmin - 4°C and CO_2+ 20ppm and SRAD -1 $MJm^{-2}day^{-1}$

Varieties	Standard (Days)	Scenarios Growth duration (days)							
		A1	A2	A3	A4	A5	A6	A7	A8
Prithivi*	104	96	139	139	96	139	96	139	139
Masuli*	134	111	212	212	111	212	111	212	212
SS*	145	117	226	226	117	226	117	226	226
	Yield (kg/ha)	Grain yield (kg/ha)							
Prithivi*	5754	1320	8533	1360	8686	1548	1177	9342	7976
Masuli*	3892	2310	4895	2365	5144	2613	2104	5486	4624
SS*	4468	2928	5684	2994	6027	3294	2686	6385	5278

What about -20ppm CO_2?

Table 5. Simulated rice growth duration (days) and grain yield (kg/ha) with changes in temperature, solar radiation and CO_2 concentration

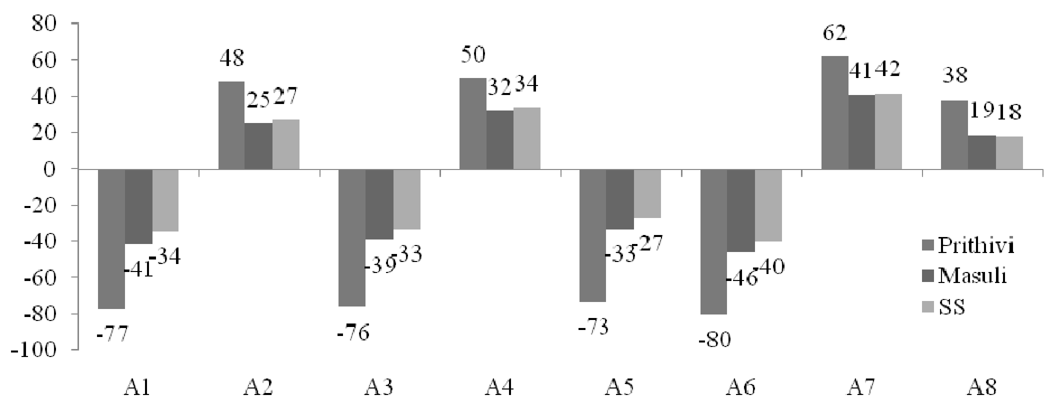


Fig 5. Percentage change in grain yield with respect to various climatic scenarios

Result clearly indicates that maximum and minimum temperatures are key responsible to determine the yield. Increasing temperature alone by 4°C clearly shows drastic reduction of yield up to 34 to 77% from HYV's and hybrid rice. Decreasing temperature was found to increase yield up to 27 and 48% (for the same variety)-optional. Furthermore, result showed that the decreasing scenarios of maximum and minimum temperature by 4°C along with increasing CO_2 concentration and solar radiation by 20 ppm and 1 MJ/day/m^2 results in increased grain yield by 62, 41 and 42 % from Prithivi, Masuli and Sunaulo Sugandha. In most site of china, Jin, *et al.* (1995) observed that the direct effects of increased CO_2 concentration compensate the negative effectsof increased temperature on rainfed rice. In contrast, maximum reduction in yield (80, 46 and 40%)was simulated from the scenario of increasing temperature by 4°C and decreasing solar radiation (1 MJ/day/m^2). The decline in rice yield in association with increasing temperature were also noticed in India(Aggarwal, *et al.*, 2002; Saseendran, *et al.*, 2000);(Seino, 1995); South Asia (Aggarwal, *et al.*, 2002); Philippines (Peng, *et al.*, 2004). Among the cultivars, hybrid rice seems more sensitive to climatic factors than others.

The solar radiation response was related to the amount of incident radiation and the fraction of radiation intercepted by the crop. Takuya, *et al.* (1999) reported that insufficient grain filling of hybrid rice was due to shortage of solar radiation which led to the abnormal physio-chemical properties. Light stress was found to decrease total biomass, yield and yield components. The reduction in the ultimate grain yield was due to increased number of ill-filled spikelets (Vijayalakshmi, *et al.*, 1991). However, higher temperatures generally decrease yield by speeding up the development of a plant so that it matures sooner; they often also exacerbate stress on water resources that are essential for crop growth.

Fig 5 and 6 showed that decreased temperature accompanied with increment in CO_2 concentration and solar radiation resulted in longer crop duration and higher yield. Similar result was observed by (Karim, *et al.*, 1994). In general, higher CO_2 levels in the atmosphere, increase growth and yield, mainly due to their reduced stomatal openings, thereby reducing transpiration per unit leaf area (Peart, *et al.*, 1989) and enhancing photosynthesis effect (Hendrey, *et al.*, 1994).

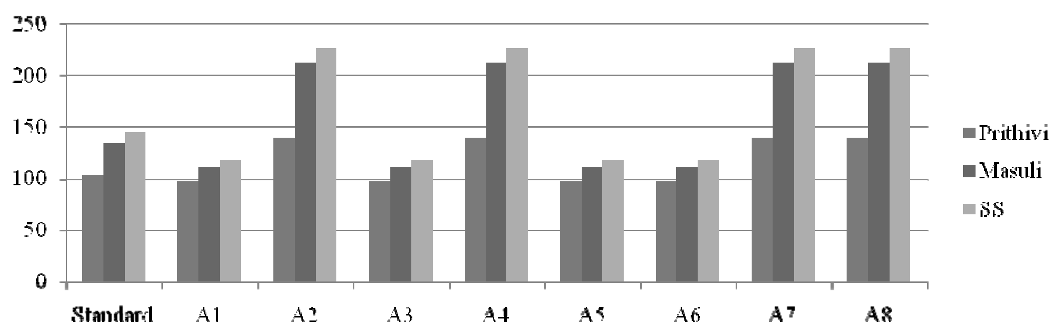


Fig 6. Simulated growth duration with respect to various climatic scenarios

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