SIMULATION OF GROWTH AND YIELD OF RICE UNDER DIFFERENT AGRONOMIC MANAGEMENT AND WITH CHANGING CLIMATIC PARAMETERS IN CENTRAL TERAI, NEPAL

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ABSTRACT

An experiment was conducted in Chitwan, Central Tarai, Nepal in three factorial strip-split plot design to simulate the effect of agronomic management and climate change parameters on growth and yield of rice under two crop establishment methods (transplanted in puddling and direct seeded in zero tillage); two residue retention levels (residue kept at 3 t/ha and no residue); and two nitrogen (N) levels (recommended dose: 100 kg N/ha and farmers dose: 50 kg N/ha) using the variety 'Ramdhan' during the rainy season of 2016. Soil of the experiment site was sandy loam and moderately acidic. Decision Support System for Agrotechnology Transfer (DSSAT) ver. 4.6 was used to validate the datasets of field experiment. File-A, File-T, File-W, File-X and Soil file were prepared and genetic coefficient of the variety was determined as P1 (900.00), P2O (70.00), P2R (800.00), P5 (12.60), G1 (99.00), G2 (0.035), G3 (0.02), G4 (0.85) and PHINT (83.0). Crop geometry (row spacing from 20 cm × 20 cm to 15 cm × 15 cm) increased the simulated grain yield from 5406 kg/ha to 5539 kg/ha, and simulated straw yield from 5410 kg/ha to 5797 kg/ha. Either early or late planting from 22 June decreased the simulated grain yield of rice. The increase in temperature by the years 2020, 2050 and 2080 A.D. decreased the simulated grain yield to 4518, 4098 and 2543 kg/ha, respectively, and increase in the level of CO_2 concentration and solar radiation can increase the yield slightly with increase in the minimum and maximum temperature's.

Keywords: *conservation agriculture, climate change, crop modeling, DSSAT*

INTRODUCTION

Rice is one of the world's most important food crops and has been grown for more than 6000 years is South Asia. In Asia, food security is equivalent to rice security. In Nepal, it is being cultivated in an area of 1.49 million hectare (ha) with total production of 5.61 million tons and productivity of 3.76 t/ha (MoALD, 2020). Rice is the most important staple food in the context of Nepal which supplies about 40% of total calorie requirement and economically it shares about 20% of agricultural gross domestic product and 7% of total domestic product of Nepal (CDD, 2015).

Cropping System Model (CSM)-CERES (Crop Environment Resource Synthesis) - Rice is a part of the DSSAT (Decision Support System for Agro-technology Transfer) is a process-level, comprehensive, deterministic simulation model, designed to simulate the effects of cultivars, planting density, weather, soil, water and in one of the versions, impact of nitrogen and phosphorus on crop growth, development and yield of crops (Jones & Kiniry, 1986; Kumar et al., 2006; Adam et al., 2018). Model can be used to assist both in strategic decision making, such as planning for climate change or to avoid salinization, yield forecasting and planning for national food requirements and in tactical decision making (such as irrigation scheduling and fertilizer and pest management). Models were used for predicting yield gap and trend analysis in rice in Thailand, Philippines, Southern Vietnam, India and Nepal (Saseedrann et al., 1998). A particular strength of crop models is their ability to quantify variability of crop performance due to variability in seasonal weather conditions and to predict the long term impacts of climate change and land use options. Climate change, currently world's burning issue, is one of a major concerns and the effect of climate change on the growth and yield of crop described in different ways by many researchers. IPCC (2007) has predicted climate change scenario for South Asia for different years based on the year 1995 where it is estimated that minimum and maximum temperatures, sunshine hours and CO_2 to increase by 2 °C, 2 °C, 1 MJ m^{-2} hr^{-1}, 20 ppm in year 2020 A.D., by 3°C, 3 °C, 1 MJ m^{-2} hr^{-1}, 200 ppm in year 2050 A.D. and by 4 °C, 4 °C, 1 MJ m^{-2} hr^{-1}, 350 ppm in year 2080 A.D., respectively. Considering the above facts an experiment was conducted with different nitrogen doses and residue retention practices in two crop establishment methods with the objectives to evaluate and calibrate the CSM-CERES-Rice ver. 4.6 and to simulate the effect of agronomic management and climate change parameters on growth and yield of improved rice variety "Ramdhan".

MATERIALS AND METHODS

Experimental location

The research was conducted in the research field of National Maize Research Program (NMRP), Nepal from June to November 2016. The site is geographically situated at 27.655095 North latitude and 84.357383 East longitude with the elevation of 183 m above mean sea level. The plot was under the rice maize cropping system for four years with the same treatment combination.

Weather conditions during experimentation

The average maximum temperature was 32.32°C and average minimum temperature was 22.98°C during the cropping period. The total rainfall and average relative humidity during the cropping period were 1646.20 mm and 84.58%,respectively. Average sunshine hour was 5.12 per day (Figure 1).

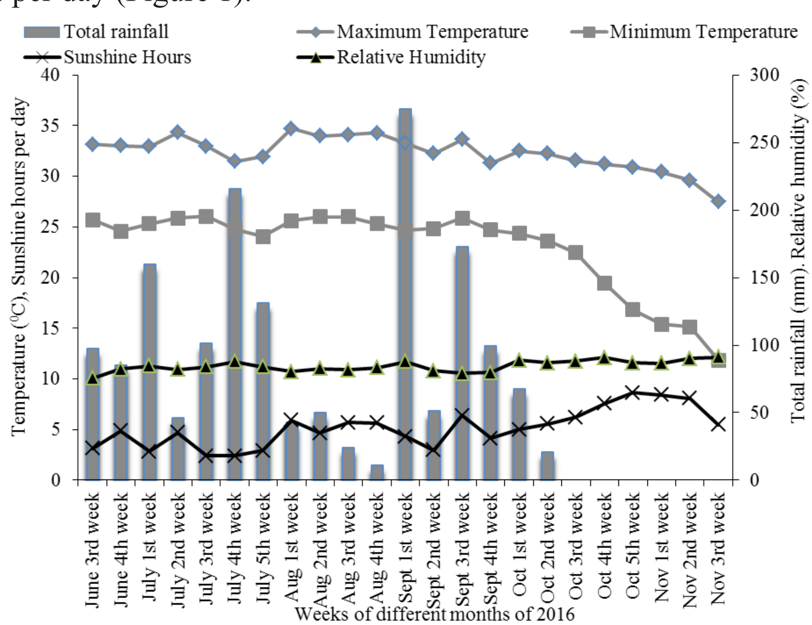

Figure 1. Weather data of experimental site for crop growing period in Central Terai, Nepal

Physical characterise of soil

Physical properties of soil, especially soil moisture content at various gradients and profile bulk densities were determined for different layers of soil profile. Compactness of soil was found to be increased along with the increasing soil depth and higher bulk densities were found at the lower layers. The values of drained upper limit (DUL) and drained lower limit (DLL) were calculated from DSSAT ver. 4.6. All the physical characteristics of soil are presented in Table 1.

Table 1. Physical properties of soil of experimental plot

Soil depths (cm)	Drained upper limit (DUL) in bars	Drained lower limit (DLL) in bars	Soil moisture content at saturation (cm)	Bulk density (g/cm^3)	Saturated hydraulic conductivity (cm/hr)
0-30	0.255	0.126	0.53	1.15	2.59
30-60	0.211	0.126	0.394	1.54	2.59
60-90	0.144	0.082	0.372	1.61	2.59
90-120	0.13	0.075	0.369	1.62	6.11

Chemical analysis of soil

Chemical parameters of the soil of the experimental plot were analyzed and the results are presented in the Table 2.

Table 2: Chemical properties of soil of experimental plot

Soil depth (cm)	Soil pH	NH_4^+N (g N/Mg)	NO_3^-N (g N/Mg)	Available P_2O_5 (kg/ha)	Available K_2O (kg/ha)	Organic matter (%)
0-30	6.0	0.08	0.14	32.3	134	2.04
30-60	6.0	0.08	0.14	21.53	93.8	0.75
60-90	5.8	0.07	0.12	20.67	80.4	0.18
90-120	5.6	0.06	0.11	19.73	67	0.09

Note: NH_4^+N = Ammonium nitrogen, NO_3^-N= Nitrate nitrogen

Experimental details

Three factorial Strip-split plot design was used with two crop establishment methods [zero till direct seeded rice (ZT-DSR) and puddled transplanting rice (Pu-PTR)] as horizontal factor, residue [residue kept and removed of previous maize crop] as vertical factor and nitrogen (N) levels [recommended dose as 100 kg N/ha (RD), and farmers' practice dose as 50 Kg N/ha (FD)] as sub plot factor with two levels in each factor replicated six times. Each plot was sized 34.02 m^2 adjusting 27 rows for both establishment methods.

Cultivation practices

Sowing of 'Ramdhan' variety of rice was done on 22 June 2016 with a seed rate of 50 kg ha^{-1} for ZT-DSR. Continuous line sowing was practiced for ZT-DSR maintaining 20 cm row spacing. For puddled transplanting, nursery was raised on the same date of seed sowing in ZT-DSR and transplanting was done after 30 days. Transplanting was done by manual labor maintaining 20 cm x 20 cm row to row and plant to plant spacing. Full dose of phosphorus and potassium at the rate of 30 kg/ha each and 1/3rd of nitrogen as basal dose were applied and remaining nitrogen was applied at active tillering and panicle initiation stages in equal splits. Pendimethalin was sprayed on the next day after sowing at the rate of

1 kg active ingredients per hectare to control the early stage narrow leaf weeds. Two hand weedings were done in the field so as to reduce crop and weed competition; first at 20 days after sowing (DAS) and second at 40 DAS. The water was supplied to the entire plot at the time of need on continuous basis and irrigation was stopped ten days before harvest. Crop was harvested from the net plot area and moisture of grain was determined by the help of grain moisture meter, and yield was adjusted at 14% moisture content.

Simulation modeling

To simulate the impact of agronomic management and climate change parameters on the performance of rice in different residue retention and nitrogen levels under different establishment methods using CSM-CERES Models, CERES-Rice model was calibrated by using the same set of data from the field experiment.

Data requirement for model evaluation

CSM-CERES-Rice requires a well-defined set of inputs to simulate actual crop conditions which include soil and weather conditions, genetic coefficients, planting details, irrigation and fertilizer schedules. Five files are very important to run the DSSAT model (Saseendran *et al.,* 1998). Five files are; File-A include performance data like grain yield, maximum leaf area (LAI), anthesis and maturity dates, etc., File-T include time course data like periodic dry matter, LAI, leaf weight, stem weight, etc., File-W include weather data like maximum and minimum temperature, solar radiation, rainfall, relative humidity, etc., File-X include agronomic management data like tillage practice, planting dates, planting density, fertilizer and irrigation practice, harvesting, etc. and Soil file include sand, silt and clay %, pH, DUL, DLL, etc. These all five files were prepared and model was run.

Model calibration

The genetic coefficient parameters were adjusted to such extent that simulated values were similar with observed values known as calibration. Using the data obtained from field experiment, genetic coefficients of Ramdhan variety of rice under study were adjusted using CSM-CERES-Rice model embodied under DSSAT ver. 4.6. The meanings of the various genetic coefficients of rice cultivars are presented below:

P1: It is the time period expressed in GDD (growing degree days) as °C above a base temperature of 10 °C for rice from seedling emergence.

P_2O: It is the longest day length expressed in hours. Also, it is called critical photoperiod and at this stage development of rice plant is at maximum rate.

P_2R: Phasic development leading to panicle initiation is delayed for each hour increase in photoperiod above P_2O. It also expressed in GDD in °C

P5: Time period expressed in GDD in °C from beginning of grain filling to physiological maturity stage.

G1: Potential spikelet number.

G2: Single grain weight (g) under ideal growing conditions.

G3: Tillering coefficient.

G4: Temperature tolerance coefficient.

PHINT: Interval between successive leaf tip appearances (^{o}C/d)

The genetic coefficient of "Ramdhan" was calculated by observing yield, biomass yield and physiological maturity of recommended nitrogen dose with residue applied in puddled as this field treatment was highest yielding as compared to other treatments.

Sensitivity analysis

Sensitivity analysis helps in studying the behavior of the model by establishing a set of base conditions. Base conditions are comprised of the set of the best estimates of each parameter and input. Simulation runs were made by changing the agronomic and climate change parameters while holding all other base conditions constants. Sensitivity analysis is valuable in assessing several useful theoretical applications including yield gap analysis, strategic decision making planning and climate change studies (Timsina & Humpherys, 2003). DSSAT has a facility to automatically do sensitivity analysis for selected variables.

RESULTS AND DISCUSSION

Determination of genetic coefficients of Ramdhan by model calibration

Changes in genetic coefficients were made during the calibration and model was run till least difference was observed between simulated and measured parameters. Finally, P1 (900.00), P2O (70.00), P2R (800.00), P5 (12.60), G1 (99.00), G2 (0.035), G3 (0.02), G4 (0.85) and PHINT (83.0) were observed to have nearest match between measured and simulated parameters.

Row spacing

Decrease in planting geometry from 20 cm × 20 cm to 15 cm × 15 cm increased the grain and straw yield to 5539 kg/ha and 5797 kg/ha, respectively but increasing the same from 20 cm × 20 cm upto 40 cm × 40 cm decreased grain yield but increased straw yield (Table 3). Bozorgi et al. (2011) observed that straw yield was significantly higher in 15 cm × 15 cm spacing than 20 cm × 20 cm and 25 cm × 25 cm spacing. Asmamaw (2017) also observed that decrease in the row spacing from 20 cm × 20 cm to 20 cm × 10 cm increased the grain yield significantly from 6.76 to 7.12 t/ha. Khaliq et al. (2014) reported that yield increases in 10 cm spacing than the 20 cm spacing plots by 16% due to suppressing effect to weeds because in narrower spacing there will be higher number of plant population as compared to wider spacing.

Table 3. Sensitivity analysis of rice cultivars with change in row spacing in different tillage, residue retention and nitrogen doses in the experiment, Chitwan

Row Spacing (cm)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Days to physiological maturity
15×15	5539	5797	142
20×20 [a]	5406	5410	141
25×25	5371	5675	142
30×30	5268	5611	142
35×35	5218	5590	142
40×40	5119	5524	142

Note: [a] = Standard base

Planting date

Sensitivity analysis for change in planting date was done and influence of planting date was observed in yield of both the establishment methods, residue retention and nitrogen doses. It was observed that either early planting or late planting can decrease the yield of rice but late planting increased the straw biomass as compared to early planting (Table 4). Dawadi and Chaudhary (2013) observed that either early or late planting of rice by 13th June decreased the grain yield.

Table 4. Sensitivity analysis of rice cultivars with changes in planting dates in different tillage, residue retention and nitrogen doses in Chitwan

Planting Date	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Days to physiological maturity
22 May	5020	4123	139
02 June	5399	4005	138
22 June [a]	5406	5410	141
2 July	4434	6431	91

Note: [a] = Standard base

Climate change scenarios

Change in the minimum and maximum temperature, CO_2 concentrations and solar radiation in different years as predicted by IPCC (2007) has changed the grain and physiological maturity days of rice drastically (Table 5). Increase in temperature by the year 2020, 2050 and 2080 A.D. decreases the simulated grain yield to 4518, 4098, 2543 kg/ha, respectively and increase in CO_2 concentration and solar radiation can increase the yield slightly with increase in the minimum and maximum temperatures. Lamsal et al. (2013) also reported the similar findings. The rate of senescence was increased due to the warm temperature which finally reduced the grain yield of rice (Hatfield & Pruegar, 2015). For each 1°C increase in growing-season minimum temperature the decline in grain yield reported was upto 10% (Peng et al., 2004).Increase in the growth and yield by higher level of CO_2 concentration was primarily due to effect of CO_2 on the photosynthetic processes of crop (Hendry & Kimball 1994). Decrease in temperature and increased concentration of CO_2 increased the crop growth duration and yield but the increase in temperature reduced duration of crop growth and biomass, leaf area and finally the crop yield. In the rainfed rice, the negative effect of increased temperature on growth and yield can be compensated by increase in CO_2 concentration (Jin et al., 1995). Vijayalakshmi et al. (1991) reported that due to the deficit of the solar radiation during growth of rice resulted in more sterility in the spikelets which finally reduced the grain yield of rice.

Table 5. Sensitivity analysis of rice cultivars with change in maximum, and minimum temperatures, CO_2 concentration and solar radiation in different years as predicted by IPCC in 2007 A.D. in different tillage, residue retention and nitrogen doses in Chitwan

Minimum temperature	Maximum temperature	CO_2 concentration	Solar radiation	Grain yield (kg/ha)	Days to physiological maturity
0 [a]	0 [a]	0 [a]	0 [a]	5406 [a]	141 [a]
By 2020 A.D.					
+2	+2	0	0	4518	131
+2	+2	+20	0	4578	131
+2	+2	+20	+1	4629	130
By 2050 A.D.					
+3	+3	0	0	4098	121
+3	+3	+200	0	4673	121
+3	+3	+200	+1	4918	120
By 2080 A.D.					
+4	+4	0	0	2543	116
+4	+4	+350	0	3718	116
+4	+4	+350	+1	3765	114

Note: [a] = Standard base

CONCLUSION

Decrease in planting geometry from 20 cm × 20 cm to 15 cm × 15 cm slightly increased the simulated grain yield of rice. It was observed that either early or late planting of rice from mid of June decreased the grain yield of rice gradually. The increase in temperature by the year 2020, 2050 and 2080 A.D. decrease the simulated grain yield to 4518, 4098, 2543 kg/ha respectively and increase in CO_2 concentration and solar radiation increase the yield slightly with increase in the minimum and maximum temperature.

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