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Review Articles

Research Articles

Research Article

SIMULATION OF GROWTH AND YIELD OF RICE AND WHEAT VARIETIES UNDER VARIED AGRONOMIC MANAGEMENT AND CHANGING CLIMATIC SCENARIO UNDER SUBTROPICAL CONDITION OF NEPAL

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ABSTRACT

The national average yield of cereal- rice and wheat are less than its potential yield, for which poor agronomic management and changing climatic conditions have been reported as the critical factors. Cropping System Model (CSM)-Crop Estimation through Resource and Environment Synthesis (CERES), embedded under Decision Support System for Agrotechnology Transfer (DSSAT) ver. 4.6 was used to valuate datasets of two different field experiments, conducted during winter season of 2014/15 and rainy season of 2015, respectively, for wheat and rice. In the case of wheat, three wheat genotypes (Tillotama, Danfe and Vijay) were sown at different sowing dates (14th November, 29th November, and 14th December), while two rice genotypes (Gorakhnath 509 and Sabitri) were planted at four nitrogen levels (0, 60, 120 and 180 kg N ha^{-1}) under conservation and conventional agriculture. Both experiments were conducted using a Strip-split plot design with three replications, and conservation agriculture (CA) treatments of both crops accommodated in the same area. The ancillary and yield data obtained from field experiment was analyzed by using R Studio software. The yield of both rice and wheat was higher in conservation agriculture (4766; 3042 kg ha^{-1}) as compared to conventional agriculture (4106; 3022 kg ha^{-1}). Application of 120 kg N ha^{-1} on rice resulted in significantly higher yield (4769 kg ha^{-1}) than lower nitrogen levels whereas timely planted wheat produced significantly higher yield (3427 kg ha^{-1}) as compared to delay planting. Sabitri (4433 kg ha^{-1}) was comparable to hybrid Gorakhnath 509 (4438 kg ha^{-1}) in terms of grain yield while Vijay (3459 kg ha^{-1}) was superior to other tested genotypes of wheat. Model calibration was done by using best treatment of the experiment based on grain yield while validation was accomplished by using the remaining treatments for predicting growth and yield. On the sensitivity analysis, of the three varieties used, only Vijay showed increasing yield by 10.09% up to December 4 sowing, identified as the best variety for the late sown condition. The sensitivity for various climate change scenarios as advocated by IPCC (2007) for 2020, 2050 and 2080 from the baseline of 214-15 indicated that there was severely decreased trend in simulated yield of varieties in different establishment method with an increase in maximum and minimum temperature, carbon dioxide concentration, and solar radiation. The simulation result showed that rise in maximum and minimum temperature by 4^{0}C resulted in yield reduction; drop in the temperature and thereby in the yield increase. Increase in CO_2 concentration (+20 ppm) showed the positive effect on yield when temperatures were dropped, but yield reduction in the case of increased temperature even if the CO_2 concentration was increased. Both hybrid and improved varieties of rice were responsible to 120 kg N ha^{-1}. CA for rice could equally produce to conventional one in temperature increased scenario, but more outstanding- in decreased temperature. Wheat variety Vijay can be grown in CA with higher yield and can also be sown up to 1st week of December with very less yield decline in the context with changing climatic variability.

Key words: CSM-CERES, conservation agriculture, sensitivity analysis, simulation

INTRODUCTION

Rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) are the principal cereal crops of the world, harvested 487.46 milled rice and 759.75 wheat million tons each year (STATISTA, 2018). Rice and wheat are the important major cereal crops in Nepal as these plays a vital role in food security of the country. The area under rice and wheat cultivation in Nepal is 15523 and 750 thousand ha with the production of 5230 and 1841 thousand ton and the productivity of 3.4 and 2.5 t ha^{-1} respectively (MOF, 2018). The productivity of both crops is far below than the world productivity (4.64 and 3.41 t ha^{-1} respectively) (FAOSTAT, 2018). The terai part of Nepal including the strip of Shivalik hills (0.6 million hectares) falls under the Indo-Gangetic Plains (IGP) where rice-wheat is the major cropping system and 84% of the total wheat is cultivated after rice harvesting (Chauhan, Mahajan, Sardana, Timsina, & Jat, 2012). With the increasing population and

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purchasing power, demand for food has also increased which is impossible to meet with the present varieties, technologies and management practices.

Rice cultivation is commonly done by transplanting in the puddled field in a conventional method while the modern method of direct seeding is gaining popularity in recent days. In puddled transplanting, puddling is main field operation which benefits rice by reducing water percolation losses, controlling weeds, facilitate transplanting and easy seedling establishment and creates anaerobic conditions that enhance nutrient availability. At the same time, it encounters several problems such as high labor and water requirement, deteriorate soil physical, chemical and microbial properties, increase the cost of cultivation, development of hardpan beneath the surface soil (Balasubramanian et al., 2003), high methane emission (Kumar, & Ladha, 2011). Late planting of wheat is a serious problem in conventional practiced rice-wheat areas of South Asia including Nepal. The late planting is often due to difficulty in land preparation resulting by excess or lack of moisture, the late harvest of rice and longer turn round period between rice harvest and wheat planting. A linear decline in yield of 30-50 kg ha^{-1} day^{-1} is observed when wheat is planted after the end of November (Giri, 1988). Late planting not only reduces yield but also the efficiency of the inputs applied. The main cause for late planting, aside from the late harvest of the rice crop preceding wheat, is so long. Conservation agriculture (CA) in the present context have advantages over conventional practices as they increase water storage, reduce water loss and erosion, improve crop yield and water productivity and labor use (Wang, 2006), increase soil organic matter, increase carbon sequestration (Uri, Atwood, & Sanabria, 1999), and produce yield equivalent to or higher than those under conventional farming (Karunatilake, Vanes, & Schindelbeck, 2000), reduce the production cost. Mulching increases infiltration (Huang et al., 2012) and decreases evaporation loss (Bezborodov et al., 2010) hence improve water use efficiency. Apart from these merits, CA has some shortcomings as high weed infestation, poor seed germination and reduced early seedling growth (Joshi et al., 2013) and more nitrogen loss through denitrification, volatilization, leaching, and runoff (Kumar, & Ladha, 2011).

Low nitrogen use efficiency due to the ineffective splitting of N application including the unbalanced use of nitrogen is one of the various factors responsible for lower rice production (Adhikari, 2006). The synchronization between crop demand and nitrogen supply is the most important aspect of increasing nitrogen use efficiency, high yields, and reduced nitrogen losses. Nitrogen demand differs from inbred and hybrid variety. Use of hybrid allows farmers to obtain 15-30% more rice than inbred (Virmani, Mao, & Hardy, 2003) but required higher nutrient during reproductive growth stages. Thus hybrid rice required different strategies for N management to maximize expression of their yield advantage.

Shrestha, Raes, Vanuytrecht, & Sah (2013) simulated the rainfed yields of the wheat (1.7 t ha^{-1}) and showed that yields were predominantly constrained by water stress. Proper selection of planting time and genotypes if matching properly, it ensures the adequate conditions for germination and growth, avoids extreme temperatures during grain setting and development, and provides adequate moisture for growth and completing the life cycle. But, due to the intensive cultivation practices (>300 % cropping intensity) in Terai and inner-terai of Nepal, wheat planting time sometimes gets delayed. Delayed planting particularly in late November to December, results in poor yield due to low temperature induced poor germination and slow vegetative growth and high temperature, especially at anthesis and post-anthesis.

The inter-governmental panel on climate change (IPCC) has projected that the global mean surface temperature is predicted to rise by 1.1-6.4^{0}C (more in winter season) by 2100. These all have been common in Nepal and have an adverse effect on agriculture (Malla, 2008). Climate change via increasing atmospheric concentration of CO_2 can affect the global production of the C_3 crops like rice and wheat through a change in photosynthesis but increase in temperature and ultimately decrease the crop yield by reducing the crop growth duration. Further testing of CSM-CERES- Rice, and Wheat embedded in DSSAT model (version 4.6) will be a highly valued scientific work for proper decision making. Hence, this concurrent field and simulation modeling studies were done to evaluate the effect of the change in climatic parameters and agronomic practices on the performance of popular rice and wheat genotypes at different establishment methods under the sub-tropical environment of central Nepal to identify the best key crop management practices for both cereals.

MATERIALS AND METHODS

Field experimentation and data analysis

Two different field experiments were conducted during winter and rainy season of 2014-2015 at the sub-tropical climate of Terai and inner terai on wheat and rice respectively in the same field. CA and conventional plots were same for both crops. For rice, the field experimentation consisting of the combination of the two establishment method (CA and conventional agriculture), two varieties (hybrid Gorakhnath 509 and inbred Sabitri) and four nitrogen levels (0, 60, 120 and 180 kg N ha^{-1}) was accomplished. The experiment was carried out using Strip split design with three replications. P_2O_5, MOP was applied at 60 and 40 kg ha^{-1} and $ZnSO_4$ at the rate of 25 kg ha^{-1} as the basal application in each plot. In the nitrogen applied plots nitrogen was used as 1/2, 1/4th and 1/4th at basal, active tiller stage and panicle initiation sage respectively. The soil of the experimental research site was sandy loam and slightly acidic (5.93). Total nitrogen (0.15%) and soil available potassium (116.85 kg ha^{-1}) lower but soil available phosphorous was medium (27.45 kg ha^{-1}) in surface soil profile and most of all parameters were found decreasing with increasing profile depth up to 1 m. in the CA plots, seeds are directly sown (50 kg ha^{-1}) on the zero till plots at 20 cm row spacing and continuous within the row while for the conventional plots, 21 days old seedlings are transplanted (2-3 seedlings per hill) at 20 cm x 20 cm spacing.

For wheat, another experiment was laid out by using Strip-split block design with the combination of 18 treatments comprising of two crop establishment methods (CA and conventional agriculture), three dates of sowing (November 14, November 29 and December 14) and three genotypes (Tillotama, Danfe and Vijay) on the subplot three replications. The fertilizer was applied on the crops with the dose of 120:50:50 kg N, P_2O_5 and K_2O ha^{-1}, respectively. The seeds were sown continuously in the rows spaced at 20 cm. Weed management was done by spraying 2,4-D at 1.4 kg a.i. ha^{-1} at 30 days after sowing for each date.

The maximum and minimum temperatures, sunshine hours and rainfall data during the cropping periods and historical weather records were collected from the National Climatic observatory of National Maize Research Program. The yield attributes and yield data obtained from field experiment was analyzed with the R-studio package software and mean data was further subjected to model evaluation by DSSAT v. 4.6.

Model evaluation and application

The data were taken into consideration to make appropriate input files (file X, file A, file T, soil file and weather file) required for CSM-CERES-Wheat and rice v 4.6. Model evaluation was done by standard model procedures to simulate the growth and yield performance of diverse wheat and rice genotypes. For wheat, model calibration was done by using the best performing treatment (Tillotama: CA, sown on November 29; Danfe and Vijay: CA, sown on November 14) while for rice using the best performing treatment 180 kg N ha^{-1} for both varieties in CA and model validation was done for second best treatment over the days to heading, days to physiological maturity and grain yield. Simulation to different sowing dates for wheat and scenarios of climatic parameters by using the DSSAT for both wheat and rice was accomplished by comparing the yield performance, anthesis days and maturity duration of both wheat and rice genotypes.

RESULTS

Yield attributes, grain yield and yield gaps in wheat

The number of effective tillers m^{-2} was insignificant for crop establishment methods and date of sowing. But it was slightly higher in CA than the conventional one. The early sowing of wheat (14th November) produced higher numbers of effective tillers than sowing at 29th November and 14th December. Variety Tillotama produced significantly higher effective tillers (344.15) than Vijay (307.58) but at par with Danfe (332.63). The number of grains per spike was also insignificant to establishment methods and sowing dates but varieties had significantly influenced. Comparatively higher number of grains per spike was recorded under CA and delaying sowing reduced the grains per spike. Vijay (43.60) had the significantly higher number of grains per spike than Tillotama (34.59) and Danfe (34.85). The thousand grain weight was not influenced by crop establishment techniques and date of sowing but it was significantly higher for Vijay (49.61 g) than Danfe (34.85 g) and Tillotama (34.59 g). The mean sterility was 41.70%, establishment methods and sowing date had no any significant effect on sterility but early sowing resulted in the lowest sterility (39.54%). Variety Tillotama was found superior with lowest sterility (38.51%) which was significant over two other varieties. However, the other two varieties, Danfe (42.44%) and Vijay (43.46%) were found to be at par with each other for sterility percentage.

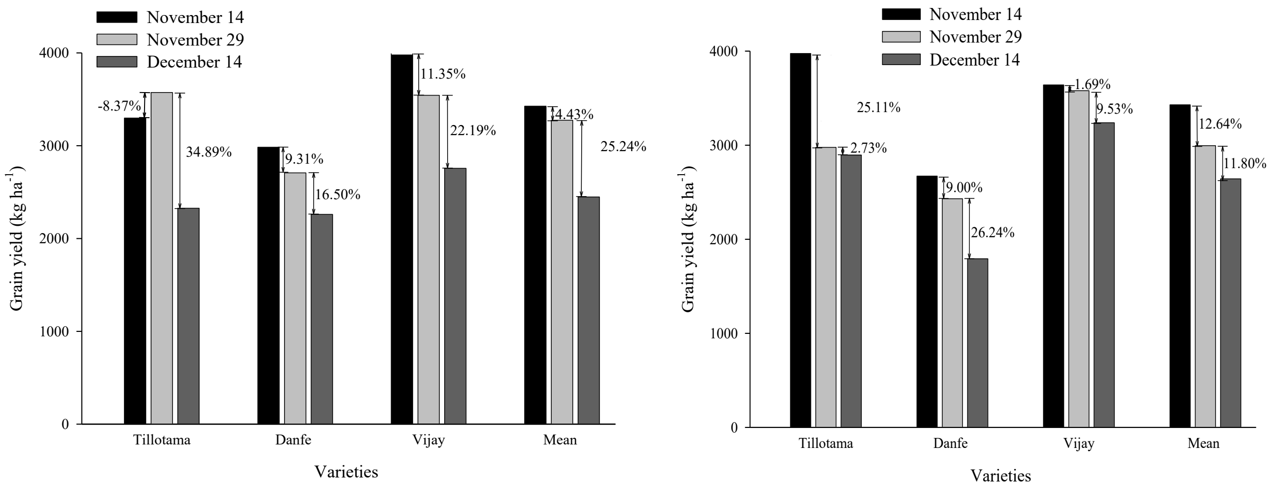
Among the two tillage practices comprising CA and conventional agriculture, no any significant difference was seen in yield (Table 1). However, Wheat sown on 14th November had the significantly higher yield (3427.15 kg ha^{-1}) followed by sowing on 29th November (3134.68 kg ha^{-1}) and 14th December (2544.78

kg ha^{-1}). Variety Vijay proved to be the highest yielder (3458.61 kg ha^{-1}) which was at par with Tillotama (3173.96 kg ha^{-1}). Variety Danfe was significantly lower for yield (2474.02 kg ha^{-1}) than both of the varieties. On an average grain yield reduction due to delay sowing by 15 days from November 14 was 8.53% and 15 days from November 29 was 18.82% (Figure 2).

Table 1. Yield attributes and grain yield as influenced by establishment methods, sowing dates and varieties of wheat in 2014-15 at AFU, Rampur, Chitwan, Nepal

Treatments	Number of effective tillers m^{-2}	Number of gains spike^{-1}	1000 grain weight (g)	Sterility percentage	Grain yield (kg ha^{-1})
Establishment methods					
CA	329.35	30.38	36.66	42.23	3049.02
ConA	326.88	28.98	38.71	41.17	3022.05
SEm (±)	7.86	0.81	0.83	1.36	25.00
LSD (=0.05)	ns	ns	ns	ns	ns
Sowing dates					
14th Nov	343.87	31.88	38.06	39.54	3427.15^{a}
29th Nov	330.45	30.57	38.02	43.44	3134.68^{b}
14th Dec	310.04	26.59	36.96	42.11	2544.78^{c}
SEm (±)	9.78	0.18	0.95	1.55	53.40
LSD (=0.05)	ns	0.70	ns	ns	209.8
Varieties					
Tillotama	344.15^{a}	32.51	34.59^{b}	38.51^{a}	3173.96^{b}
Danfe	332.63$_{a}$	27.45	34.85^{b}	43.44^{b}	2474.02^{c}
Vijay	307.58^{b}	29.07	43.60 ^{a}	42.46^{b}	3458.61^{a}
SEm (±)	14.13	0.98	1.34	1.09	103.10
LSD (=0.05)	25.16	2.87	3.90	3.18	301.00
CV, %	8.62	14.00	15.10	11.10	14.40
Grand Mean	328.12	29.68	37.68	41.70	3035.53

Note: CA, Conservation agriculture; ConA, conventional agriculture; ns, non-significance. Treatments means followed by the common letter (s) are not significantly different from each other based on DMRT at 5% level of significance



(a) (b)

Figure 1: Grain yield (kg ha^{-1}) and reduction in grain yield (%) as influenced by establishment sowing dates and varieties of wheat (a) under CA and (b) conventional agriculture in 2014-15 at AFU, Rampur, Chitwan, Nepal

Heat use efficiency

The heat use efficiency higher value for Vijay variety on all three dates of sowing followed by Tillotama and Danfe. The variety Vijay had the lowest coefficient of variation (%) of 13.01. Increasing temperature and incidence of drought associated with global warming are posing serious threats to food security in these days (Lobell et al., 2013). The more and consistent heat use efficiency on all three dates proving proved the variety Vijay was the most heat tolerant in the present context.

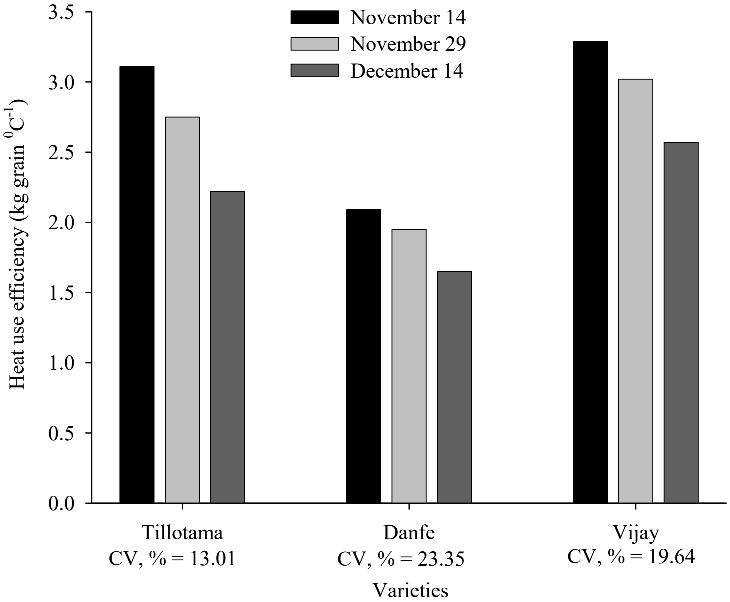


Figure 2: Heat use efficiency (kg grain $^0C^{-1}$) as influenced by wheat varieties and date of sowing in 2014-15 at AFU, Rampur, Chitwan, Nepal

Yield attributes and grain yield of rice

Effective tillers m^{-2} was significantly influenced by establishment methods, and nitrogen doses but not by the varieties. Significantly higher in CA (261.10 m^{-2}) than conventional agriculture (201.30 m^{-2}). Increase in nitrogen levels increased the effective tillers m^{-2} (Table 2). There was significantly more number of effective tillers m^{-2} in 180 kg N ha^{-1} (251.80) than 0 and 60 kg N ha^{-1} but at par with 120 kg N ha^{-1} (243.50). Lowest effective tillers were observed in control plot (205.90). The number of grains per panicle was significantly higher in conventional agriculture (137.70). Gorakhnath-509 had the statistically higher number of spikelet and grains per panicle (158.90) than Sabitri (101.60). The number of grains per panicle was found highest in 120 kg N ha^{-1} (136.10) which was at par with 180 (135.00) and 60 kg N ha^{-1} (129.60). Thousand grain weight was found significantly higher in conventional agriculture (17.80) than CA (17.67 g). Similarly, thousand grain weight of Gorakhnath-509 significantly lower (14.82 g) than Sabitri (20.65 g). The grains of Gorkhnath 509 was finer than the Sabitri which cause the lower thousand grain weight. Nitrogen levels had not influenced the thousand grain weight.

The average grain yield was 4436 kg ha^{-1}. The grain yield was significantly influenced by crop establishment methods and nitrogen levels but not by the varieties (Table 2). The grain yield under CA (4766 kg ha^{-1}) was significantly higher than conventional agriculture (4106 kg ha^{-1}). Both varieties had almost equal grain yield. The grain yield was increasing statistically up to 120 kg N ha^{-1} application (4769 kg ha^{-1}).

Table 2. Influence of establishment methods, varieties and nitrogen levels on Yield attributes and yield of rice during monsoon season at Rampur, Chitwan, Nepal, 2015

Treatment	Effective tillers m^{-2}	Grains per Panicle	Thousand grain weight (g)	Grain yield (kg ha^{-1})
Establishment method				
CA	261.10[a]	122.80[b]	17.67[b]	4766.00[a]
Con A	201.30[b]	137.70[a]	17.80[a]	4106.00[b]
SEm (±)	9.27	1.58	0.02	35.60
LSD (=0.05)	56.40	9.62	0.102	216.50
Varieties				
Gorakhnath-509	219.40	158.90[a]	14.82[b]	4438.00
Sabitri	242.90	101.60[b]	20.65[a]	4433.00
SEm (±)	8.85	5.82	0.26	172.80
LSD (=0.05)	ns	35.44	1.592	ns
Nitrogen levels (kg Nha^{-1})				
0	205.90[c]	120.10[b]	17.98	3686.00[c]
60	223.50[bc]	129.60[ab]	17.77	4308.00[b]
120	243.40[a]	136.10[a]	17.64	4769.00[a]
180	251.80[ab]	135.00[a]	17.55	4980.00[a]
SEm (±)	7.24	4.14	0.23	91.00
LSD (=0.05)	21.13	12.08	ns	265.70
CV, %	10.80	11.00	4.40	7.10
Grand mean	231.20	130.20	17.74	4436.00

Note: CA, Conservation agriculture; Con A, conventional agriculture; ns, non-significance; DAS, days after sowing. Treatments means followed by the common letter (s) are not significantly different from each other based on DMRT at 5% level of significance

Model parameterization

The adjustment of parameters so that simulated values were similar with observed values is known as calibration. Using the data obtained from the field experiment, genetic coefficients of both wheat (3 genotypes and) and rice (2 genotypes) under study were adjusted using CSM-CERES-Wheat and Rice model embodied under DSSAT ver. 4.6.

Rice	Wheat
P1: Time period (in ^{0}C above a base temperature of 9 ^{0}C) from seedling emergence P2O: Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate P2R: Extent to which phasic development leading to panicle initiation is delayed (in ^{0}C) for each hour increase in photoperiod above P_2O P5: The time period in (GDD ^{0}C) from the beginning of grain filling to physiological maturity with a base temperature of 9^{0}C G1: Potential spikelet number coefficient G2: Single grain weight (g) under ideal growing conditions G3: Tillering coefficient relative to IR64 cultivar under ideal conditions G4: Temperature tolerance coefficient (G4) PHINT: Interval between successive leaf tip appearances (^{0}C.d)	P1V: Days, the optimum vernalizing temperature required for vernalization P1D: Photoperiod response P5: Grain filling (excluding lag) phase duration G1: Kernel number per unit canopy weight at anthesis G: Standard kernel size under optimum conditions G3: Standard, non-stressed mature tiller wt (incl grain) (g dwt) PHINT: Interval between successive leaf tip appearances (^{0}C.d)

Wheat: The genetic coefficients for wheat genotypes were adjusted by running the models several times by trial and error methods (Table 4). The model calibration was accomplished by adjusting the proximity values between observed and simulated values on 75% dates of anthesis, and physiological maturity and adjustable grain yield. Calibration of wheat genotypes by changing the values of genetic coefficients (P1V, P1D, P5, G1, G2, G3, and PHINT) planted at 14th November. The genetic coefficients P1V, P1D, P5, G1, G2, G3, PHINT were 4, 32, 675, 18, 23, 5.0 and 80 respectively for Tillotama. For this variety, the simulated and observed grain yield was 3055 kg ha^{-1}and 3073 kg ha^{-1} respectively. The P1V, P1D, P5, G1, G2, G3, PHINT values for Danfe were 12, 55, 500, 17, 19, 2.0 and 113 respectively. Likewise, the same genetic coefficient values for Vijay were 8 (P1V), 16 (P1D), 610 (P5), 20 (G1), 27 (G2), 6.5 (G3) and 105 (PHINT). The simulated and observed grain yield calibrated for Danfe and Vijay were 2566 kg ha^{-1} and 2566 kg ha^{-1} and 3222 kg ha^{-1} and 3436 kg ha^{-1} respectively. The differences in the observed and simulated results obtained were found to be slightly over-estimated but within the range of 10% which normally is accepted thus obtained genetic coefficients were valid for validation and sensitivity analysis.

Rice: The genetic coefficient of both hybrid Gorakhnath 509 and improved variety Sabitri were calculated by observing yield, 75% anthesis and physiological maturity of 180 kg N ha^{-1} in CA. Finally, the genetic coefficients were observed as P1 (667.6), P2O (120.6), P2R (345.2), P5 (11.53), G1 (76.09), G2 (0.026), G3 (0.938), G4 (1.048) and PHINT (83.0) for Gorakhnath 509 and P1 (780.4), P2O (250.3), P2R (459.2), P5 (11.43), G1 (100.5), G2 (0.047), G3 (0.524), G4 (0.971) and PHINT (83.0) for Sabitri that have the nearest match between measured and simulated parameters. The simulated and observed grain yield for Gorkhnath 509 and Sabitri were 4485 and 4152, and 4676 and 4599 kg ha^{-1}, respectively, indicated the satisfactory for validation and sensitivity analysis.

Model validation

After calibration of the model, the above determined genetic coefficients of three varieties were used for the validation. Model validation was illustrated by the comparison of the model performance against data collected on days to anthesis and physiological maturity, tops weight at maturity, grain yield for all three varieties on all sowing dates for wheat. Model validation of rice was done by using the second best nitrogen levels (120 kg N ha^{-1}) of both establishment methods and varieties for phenological characters anthesis, physiological maturity, and grain yield. Model evaluation for development, yield, and time-course of growth were performed using RMSE and index of agreement (D-index) as suggested by Willmott et al. (1985). For all varieties, the model predicted the days to anthesis, days to physiological maturity accurately and grain yield and tops weight at maturity were fairly predicted.

Sensitivity analysis of sowing dates of wheat

Sensitivity analysis was done for studying the sensitivity of simulated yield, anthesis and physiological maturity for six sowing dates using CERES-Wheat. The response of wheat cultivars to sowing dates was different for each cultivar. Six different sowing dates from November 1 to December 24 were used to simulate the grain yield, anthesis days and days to physiological maturity which showed the difference in yield among the cultivars after selecting the treatments. Among the three varieties, only Vijay showed increasing yield by 10.09% up to December 4 sowing and reduction in yield thereafter. The simulated values revealed that with advancing in sowing date grain yield decreased for all the three varieties proving November 14 the optimum date of sowing for Tillotama and Danfe, whereas crop growth duration increased with advancing sowing date. The days to anthesis increased up to November 24 sowing and continue to decrease thereafter for all cultivars. The table revealed Vijay as the most promising varieties as it showed the least fluctuation in yield overall sowing dates.

Table 3. Sensitivity analysis of wheat cultivars with changes in sowing dates

Sowing dates	Varieties	Simulated grain yield (kg ha^{-1})	Percentage yield change	Anthesis days	Maturity days
Nov 1	Tillotama	2754	90.83	78	125
	Danfe	2372	92.44	93	127
	Vijay	3145	91.74	71	117
Nov 7	Tillotama	2861	94.36	81	124
	Danfe	2458	95.79	95	127
	Vijay	3279	95.65	74	117
Nov 14a	Tillotama	3032	100.00	83	123
	Danfe	2566	100.00	97	126
	Vijay	3428	100.00	77	117
Nov 24	Tillotama	3007	99.18	82	120
	Danfe	2464	96.02	95	122
	Vijay	3755	109.54	79	115
Dec 4	Tillotama	3004	99.08	74	114
	Danfe	2262	88.15	91	118
	Vijay	3774	110.09	77	110
Dec 24	Tillotama	2405	79.32	68	102
	Danfe	2000	77.94	81	108
	Vijay	3322	96.91	69	100

Note: a- base sowing date for sowing wheat

Sensitivity analysis of climate change scenarios on wheat

Sensitivity analysis of wheat cultivars with changes in temperature, solar radiation, and CO_2 concentration was done. The CSM-wheat model was run for sensitivity analysis to simulate the grain yield and growth duration over changing climate change parameters: maximum and minimum temperature, carbon dioxide (CO_2) concentration, and solar radiation. The maximum and minimum temperature were changed by 4^0C, the CO_2 concentration of 20 ppm and solar radiation by 1 MJ m^{-2} day^{-1} and simulated to create different climate scenarios. The simulation showed that change in maximum and minimum temperature by 4^0C additional temperature resulted in yield reduction with only 66.85%, 71.27% and 66.36% for Tillotama, Danfe, and Vijay respectively, whereas minimum and maximum temperature, when reduced by 4^0C resulted in yield increase by 14% and 22% for Tillotama and Vijay respectively. Increase in CO_2 concentration by 20 ppm showed the positive effect on yield when temperatures were decreased by 4^0C up to 25% for Vijay, but yield reduction was observed when CO_2 increased with increase in temperature parameters. Change in solar radiation by 1 MJ m^{-2} day^{-1} either addition or subtraction, both led to the severe decrease in grain yield and growth duration for all the cultivars. The decrease in temperature parameters and increase in CO_2 concentration along with solar radiation showed the increase in yield for all cultivars with highest for Vijay by 36.46%. However, decrease in radiation with other parameters remaining same caused increase in yield for Tillotama and Vijay by 6.89 and 13.73%, respectively, while decreasing the yield of Danfe despite the crop duration for all varieties were similar for both increased and decreased solar radiation scenarios.

Table 4. Sensitivity analysis of wheat cultivars with changes in temperature, solar radiation, and CO_2 concentration

Max temp (ºC)	Min temp (ºC)	CO_2 conc. (ppm)	Solar radiation (MJ m^{-2} day^{-1})	Treatments	Simulated yield (kg ha^{-1})	% yield change	Growth duration (days)
+0[a]	+0	330	+0	Tillotama	3032	100	123
				Danfe	2566	100	126
				Vijay	3428	100	117
+4	+4	330	+0	Tillotama	2027	66.85	106
				Danfe	1829	71.27	108
				Vijay	2275	66.36	99
-4	-4	330	+0	Tillotama	3472	114.51	137
				Danfe	2373	92.47	137
				Vijay	4215	122.95	132
+4	+4	+20	+0	Tillotama	2112	69.65	106
				Danfe	1857	72.36	108
				Vijay	2320	67.67	99
-4	-4	+20	+0	Tillotama	3525	116.25	137
				Danfe	2409	93.88	137
				Vijay	4287	125.05	132
+4	+4	+20	+1	Tillotama	2335	77.01	106
				Danfe	2020	78.72	108
				Vijay	2591	75.58	99
+4	+4	+20	-1	Tillotama	1880	62.00	106
				Danfe	1692	65.93	108
				Vijay	2044	59.62	99
-4	-4	+20	+1	Tillotama	3807	125.56	137
				Danfe	2582	100.62	137
				Vijay	4678	136.46	132
-4	-4	+20	-1	Tillotama	3241	106.89	137
				Danfe	2225	86.71	137
				Vijay	3899	113.73	132

Note: a-standard base

Sensitivity analysis of climate change scenarios on rice

Sensitivity analysis showed that increasing minimum and maximum temperature results in drastic reduction of yield whereas decreasing minimum and maximum temperature increase in yield except for conventional Sabitri which was vice-versa. Increase in temperature by 2^{0}C resulted in 71.36, 51.40, 46.91 and 121.67% yield of CA Gorakhnath, CA Sabitri, conventional Gorakhnath and conventional Sabitri respectively as compared to actual (Table 5). Whereas the decrease in temperature increase in yield of all cultivars except for conventional Sabitri. The decrease in temperature by 2^{0}C resulted in 151.51, 117.37, 100.72 and 98.17% yield of CA Gorakhnath, CA Sabitri and conventional Gorakhnath and conventional Sabitri respectively as compared to actual. The increase in CO_2 level (+20 ppm) with the similar change in temperature slightly influenced the yield of rice cultivars. Further, increase or decrease in solar radiation by 1 MJ m^{-2} day^{-1} with the increase in temperature and CO_2 concentration did not drastically affect the grain yield. Similar was observed in case of the decrease in temperature.

Table 5. Sensitivity analysis of rice cultivars with the changing temperature, solar radiation and CO_2 concentration

Minimum temperature	Maximum temperature	CO_2 concentration	Solar radiation	V	An	M	Y	% yield change
+0[a]	+0	+0	+0	A	95	120	3817	100.00
				B	112	144	4208	100.00
				C	83	109	4016	100.00
				D	100	133	3383	100.00
+2	+2	+0	+0	A	95	121	2724	71.36
				B	109	139	2163	51.40
				C	83	109	1884	46.91
				D	97	127	4116	121.67
-2	-2	+0	+0	A	96	123	5783	151.51
				B	117	154	4939	117.37
				C	86	114	4045	100.72
				D	107	147	3321	98.17
+2	+2	+20	+0	A	95	121	2753	72.12
				B	109	139	2227	52.92
				C	83	109	1936	48.21
				D	97	127	4179	123.53
-2	-2	+20	+0	A	96	123	5869	153.76
				B	117	154	5005	118.94
				C	86	114	4152	103.39
				D	107	147	3447	101.89
+2	+2	+20	+1	A	95	121	2651	69.45
				B	109	139	2110	50.14
				C	83	109	1648	41.04
				D	97	127	4095	121.05
+2	+2	+20	-1	A	95	121	2845	74.53
				B	109	139	2365	56.20
				C	83	109	2384	59.36
				D	97	127	4235	125.18
-2	-2	+20	+1	A	96	123	5618	147.18
				B	117	154	4791	113.85
				C	86	114	3396	84.56
				D	107	147	3237	95.68
-2	-2	+20	-1	A	96	123	5865	153.65
				B	119	156	5099	121.17
				C	86	114	4712	117.33
				D	107	147	3657	108.10

Note: [a] = Standard base, V= variety, An= anthesis date, M= Physiological maturity, Y= yield (kg ha^{-1}); A = CA, Gorakhnath 509 with 120 kg N ha^{-1}; B = CA, Sabitri with 120 kg N ha^{-1}; C = Conventional Agriculture - Gorakhnath 509 with 120 kg N ha^{-1}; D = Conventional Agriculture -Sabitri with 120 kg N ha^{-1}

The anthesis and maturity days were found influenced by the change in temperature. The increase in temperature showed the lower increase in anthesis and maturity days as compared to decrease in temperature.

DISCUSSION

Yield attributes and grain yield of wheat

The effective tillers m^{-2} was not affected significantly by crop establishment methods as for the first season the difference between conservational and conventional agriculture was not drastic. The first date of sowing (14th November) had produced the higher number of effective tillers m^{-2} followed by 2nd and 3rd date of sowing which is reported earlier too. This is due to longer vegetative period obtained by early sowing and it is well-established fact that early sowing produced more tillers. The delayed planting produced fewer tillers and tillers die between the start of stem extension and flowering with the last formed dying first which consequently resulted in less number of effective tillers m^{-2} on late sowing. Tillotama and Danfe produced the significantly higher number of tillers than Vijay. Bradley et al. (2008) mentioned that tillers survivals are significantly affected by varieties. The decreasing number of grains per ears with a delay in sowing date could be explained by the decreasing number of days from booting to ear emergence available for them due to change in weather conditions. As Bradley et al., (2008) mentioned the number of grains per spike is determined before flowering, the temperature plays the crucial role in prolonging the ear formation period. Fischer (2011) also reported that 10-15 days prior to anthesis is crucial for the grain number formation. The less number of days avail for grain number formation could also be evident by the significant difference in days to heading for the 3rd date of sowing than earlier sowing. The variation in the number of grains per spike for varieties is controlled by the genetic factors as Tillotama showed better performance than Danfe and Vijay. The thousand grain weight is not significant for the date of sowing and establishment methods. The thousand grain weight depends upon the number of days available for grain filling and varietal genetic makeup. The thousand grain weight is not significantly different though delayed sown wheat varieties get less number of grain filling days and that might be due to fewer numbers of the grains which nullified the effect. In case of varieties, Vijay produced grains with significantly higher thousand grain weight was due to genetic reasons. Moreover, Bradley et al. (2008) reported that a crop with sparse shoot density produce more grains per ear and heavier grains than thick crop which is evident in case of Vijay as it had the significantly lower number of effective tillers m^{-2} than two other varieties.

The grain yield had been higher for conventional agriculture, which might be attributed to the higher number of effective tillers m^{-2} and the higher number of grains per spikes. The effects of CA on crop yield were variable. In some instances, CA increased yield by improving soil fertility through soil and water conservation and sequestering organic carbon (Govaerts, Sayre, Lichter, Dendooven, & Deckers, 2007) but the effects are pronounced in the long term, in short-term immobilization in the CA system is consider-ability higher. As all the yield attributing characters as the number of effective tillers m^{-2}, the number of grains per spike and thousand grain weight is higher for earlier sowing at 14th November, it is obvious and logically correct to have significantly greater grain yield than sowing at 29th November followed by 14th December. The longer crop duration and the chance of escaping from terminal stress due to early sowing had been another reason for the significant variation in grain yield. The variation within the varieties is purely genetic which showed Vijay is high yielder followed by Tillotama and Danfe, which also reflected from the higher and consistent heat use efficiency of Vijay.

Yield attributes and yield of rice

In the present experiment, effective tillers m^{-2} were significantly higher in CA as compared to conventional agriculture. Hobbs, Singh, Giri, Lauren, & Duxbury (2002) recorded 150% higher number of panicles per unit area in DSR than TPR. Similarly, Gathala et al. (2013) recorded more number of effective tillers m^{-2} under no-till DSR compared with TPR. Higher numbers spikelets per panicle, grains per panicle and thousands grain weight were recorded in TPR as compared with DSR (Jaiswal & Singh, 2001). This was due to the close spacing causing higher plant population (Patil et al., 2007) which increases the mother plant causing less effect due to tiller mortality. Fageria (2014) reported that in the aerobic condition the effective tillers in the main culm is important than other secondary tillers. In CA seeds are shown at continuous in rows resulting more number of the main culm which is limiting in TPR due to the spacing of 20 cm by 20 cm. The number of grain per panicle was significantly higher in conventional agriculture as compared to CA. In general, DSR had more panicles per unit area but fewer spikelets per panicle, eventually, the fewer number of grains per panicle (Schnier, Dingkuhn, De Datta, Mengel, & Faronilo, 1990). It is due to the higher plant population causing intra plant completion for assimilates causing fewer number of grains formation per panicle.

Grains per panicle were also significantly influenced by varieties and nitrogen doses. Gorakhnath 509 was found to have higher grains per panicle and the nitrogen levels resulting the maximum number of grains per panicle in 180 kg N ha^{-1} which was significantly at par with 120 and 60 kg N ha^{-1} and minimum in control plots. The similar result was also obtained by Manzoor, Awan, Zahid, & Faiz (2006) and reported that grains per panicle were highest in 175 kg N ha^{-1} which was significantly at par with the application level from 125 to 225 kg N ha^{-1}. The similar result was obtained by Nawaz, Usman, & Cheema (2001). This might be due to the better nitrogen status of the plant during panicle growth period as nitrogen contributes in grains during the grain filling stage. Thousand grain weight was significantly different among varieties whereas the establishment methods and nitrogen levels did not influence it. Patil et al (2001) also found that the thousand grain weight was non-significant to the nitrogen levels. Sharma, Tripathi, & Singh (2005) had reported that establishment methods were non- significant to the thousand grains weight. The significant difference between varieties was due to their genotypic character as Gorakhnath 509 is a fine grain cultivar than Sabitri. According to Patil et al. (2001), all growth parameters, yield, yield associated attributes and N accumulation are significant to N levels at all three years of experiments in DSR, whereas a thousand grains weight were non-significant to N levels.

Grain yield was found significantly higher in CA as compared to conventional agriculture. It was due to the sum effect of growth and effective tillers. Timsina, Jat, & Majumdar (2010) also reported the significantly higher grain yield of rice in no-till DSR than TPR. The higher LAI and greater biomass in DSR were attributed to the increased number of tillers m^{-2} (Murthy & Murthy, 1984) which along with residue retention increased the yield in CA. Similarly, Zheng et al. (2014) reported that rice yield increases in CA by 4.1% in rice. Govaerts et al. (2007) supported the result as they also observed that CA increased yield by improving soil fertility through soil and water conservation and sequestering organic carbon. CA has found to be increased yield by increasing soil organic matter level and nutrient availability by utilizing previous crop residues enhanced water use efficiency due to crop residue and reducing evaporation loss, biochemical decomposition of organic crop residue at the soil surface (Cornell University, 2015). In the present experiment, Grain yield was found significantly higher in 180 kg N ha^{-1} which was statistically similar with 120 kg N ha^{-1} and lowest was observed in nitrogen control plot. Manzoor et al. (2006) also reported that 175 kg N per hectare produced maximum yield which was statistically similar with that obtained in 150, 200 and 225 kg ha^{-1} with lowest paddy yield in control plots. The increased nitrogen content of plant is closely associated with numbers of tillers, spikelets (Matsushima, 1976) and leaf area index which in turn increases the yield. Better establishment practice and nutrient management improved the yield of both hybrid and improved varieties.

Sensitivity analysis of wheat

Model sensitivity showed that earlier planting and late planting over the optimum date of planting both leads to the yield loss and November 14 as the best date of sowing which is due to the changes in cropping period, days to anthesis and maturity days. The delayed sowing caused less number of days especially reproductive phase resulting in less grain whereas climate and temperature also played the vital role. This could be seen in case of variety Vijay as the drop in yield is less which could be further due to less reduction in HUE than other varieties.

The sensitivity to climate change scenarios revealed the increase in both minimum and maximum temperature by 4^0C over the base scenario lead to drop of yield which was also reported by Amgain, Devkota, Timsina, & Singh (2006) while simulating the effect of climate change in rice and wheat in Punjab. Reduction in both minimum and maximum temperature and increase in CO_2 ppm showed the increase in yield which reveals the interactive effect of temperature and CO_2 concentration. Timsina, Adhikari, & KC (1997) also reported 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. At elevated CO_2, light intensity positively affects photosynthesis and increased temperature promotes photosynthesis as reported by Imai, & Murata (1979). The requirement of minimum temperature is important in wheat because the minimum vernalization requirement for wheat is completed only in the presence of low temperature. The growth duration was shortened (only 99 days) and yield was decreased with the increment in temperature whereas the decrease in temperature enhanced the duration of the crop. Imai (1988) reported that increasing temperatures reduced growth duration, and probably decreased photosynthesis, increased water use, and reduced water use efficiency. 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).

Sensitivity analysis of Rice

Change in temperature showed the main effect on grain yield. Increasing temperature by 2^0C showed decreased yield whereas increased yield under lowering temperature by 2^0C. Increasing temperature decreased yield and only yielded 71.36% whereas decreasing the temperature increased yield 51.51% as compared to the actual/observed yield. Increase in yield due to the decrease in minimum and maximum temperature by 2^0C is due to the reduction of respiration and increase in photosynthesis rate causing the increase in net accumulation rate which was also reported by Schlenker, & Roberts (2009). Pollen viability in rice declines as the maximum temperature exceeds 33^0C as well production decreases and above 40^0C metabolic processes ceases (Welch et al., 2010). Hatfield & Pruegar (2015) found that warm temperatures increased the rate of senescence during grain fill and reduced final grain yield. Grain yield declined by 10% for each 1^0C increase in growing-season minimum temperature (Peng et al., 2004). Increased CO_2 levels increased rice yields and reduction of rice yields due to high temperature in all season was observed by Karim, Ahmed, Hussain, & Rashid (1994). Singh, & Padila (1995) reported that the increased CO_2 concentration would reduce transpiration and N losses and increase water, N and radiation use efficiencies. Hendrey, & Kimball (1994) reported that higher CO_2 concentration increases growth and yield, mainly through their effect on the photosynthetic processes of the crop. Increased CO_2 concentrations and decreased temperature increased growth duration and yield while increased temperature shortened growth duration and reduced yield. Jin, Ge, Chen, & Fang (1995) observed that the direct effects of increased CO_2 concentration compensate the negative effect of increased temperature on rainfed rice. Solar radiation mainly influenced the hybrid Gorakhnath 509 in conventional agriculture which showed up to 18% variation in yield. The similar result was reported by Lamshal, Amgain, & Giri (2013).

CONCLUSION

To achieve the higher productivity in cereal crop production, climate change adaptation studies should be considered, especially for all commonly cultivated varieties/genotypes. The CSM-CERES-Rice and Wheat Model was well validated under the sub-tropical condition of central terai of Nepal has shown the immense scope of using this model as a tool for estimating yield gaps and study on different scenarios of climate changes. Wheat variety Vijay can be grown in CA with higher yield and can also be sown up to 1st week of December with very less yield decline in context with changing climatic variability. Results revealed that the yield was higher under CA than conventional agriculture. Increase in the minimum and maximum temperature would decrease the yield of both varieties in CA whereas decreased minimum and maximum temperature would increase the yield of both varieties in CA, but could have the negligible effect on conventional agriculture. For the wider application of models and using it for better decision support system, there is a real need of further testing and verification of model in large agro-ecological areas of Nepal.

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