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Multi-year Prediction of Wheat Yield under the Changing Climatic Scenarios in Central-west Terai using DSSAT Crop Model

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ABSTRACT

The central-west Terai region is one of the major production domains of wheat in Nepal; however, its yield over the past three decades has been greatly affected by climate anomalies such as fluctuating temperatures, decreased solar radiation and rainfall. NASA-POWER derived weather data of Taulihawa in Kapilbastu (27.55˚ N, 83.667˚ E) district in central Terai for the past 32–33 years (1984/85-2017/18) were purposively selected and downloaded and validated with recorded weather data (1985/86, 1995/96, 2005/06 and 2015/16) of Department of Hydrology and Meteorology (DHM). The trend analysis for grain yield of wheat yield in Kapilvastu was drawn with the historical data of maximum and minimum temperatures and rainfall. Positive correlations between grain yields and minimum temperature and rainfall each showed an acceptable coefficient of determinations (R^2). The Cropping system Model - Crop Environment Resource Synthesis (CSM-CERES)- Wheat model, embedded in Decision Support Systems for Agro-technology Transfer (DSSAT) ver 4.7 was used for multi-year predictions of wheat yields using both historically recorded and simulated climatic scenarios. Model simulated results closely agreed with the observed wheat yields recorded by the Ministry of Agriculture and Livestock Development (MoALD) in Nepal. The correlation coefficient of minimum temperature and wheat yield was 0.272 ($p<0.05$). The correlation between precipitation and observed and DSSAT simulated wheat yield were 0.379 ($p<0.01$). The multi-year predicted wheat yields using the historical weather data and by the use of the International Panel on Climate Change (IPCC, 2007) scenario embedded in DSSAT crop model showed that yield of wheat could be sustained with use of the current crop cultivars only for 2050 scenarios. Agro-climatic index, mainly temperature, was found to be more sensitive to wheat production in the Nepalese central-west Terai region. This study suggests for the development of new temperature and drought tolerant ready wheat cultivars to feed the increasingly growing Nepalese population.

Keywords: Agro-climatic indices, Central-west Terai, DSSAT 4.7 crop model, Multi-year prediction, Wheat yields

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INTRODUCTION

Rice (*Oryza sativa* L.) - wheat (*Triticum aestivum* L.) system, the practice of growing wheat after rice in an annual rotation is the leading cereal cropping system in the Indo-Gangetic plains and vital for the staple grain supply for about 8% of the world's population, making these systems critically important for global food security, livelihood and employment of millions of people in the region (Timsina et al 2022; Devkota et al 2021). Rice-wheat systems produce more than 30% of the rice and 42% of the wheat consumed in South Asia (CIMMYT 2015). It is also the dominant cropping system among other cereal cropping production systems in Terai region of Nepal and is important for food security. In Nepal, rice and wheat occupy 1.5 and 0.76 million ha, respectively and are grown mainly as rainfed crops in succession on more than 0.56 million ha which accounts 37% of the rice and 85% of wheat area (Amgain et al 2020; Marahatta and Amgain 2019; Devkota et al 2015a, 2016). Wheat alone contributes about 7.14% share in the agriculture gross domestic product (AGDP) of the country in Nepal (Poudel et al 2013; Devkota et al 2015b).

The highly intensive cereal-based cropping systems in Nepalese Terai are facing the sustainability problems due to fragile ecologies and mining of nutrients from soils due to increased dominance of cereals without inclusion of legumes in the cropping systems (Devkota et al 2018). Preliminary work in Nepal has shown large gaps (around 2.45 t/ha) between attainable and farmers' yield and is far below the average yield of South Asian countries (Devkota et al 2022; MoALD 2021) and climate change has been reported one of the reasons of it. One of the important strategies to increase cereal yields is to adapt temperature and drought stress tolerant crop varieties (Sapkota et al 2014; Devkota et al 2016). Kapilvastu district is contributing significantly in food security with higher production of wheat in central-west Terai in Nepal (Dhakal 2020), but their productivity is felt declining over the last three decades.

Climate change includes steadily increasing average temperature as well as increased frequency and magnitude of extreme weather events (Sapkota et al 2021; Bhatta and Aggrawal 2015). The inter-governmental panel on climate change (IPCC) has also projected that the global mean surface temperature is predicted to rise by 1.1–6.4 $^{\circ}$C by 2100 with the different amplitudes of temperatures and CO_2 for different scenarios of 2020, 2050 and 2080 (IPCC 2007, 2013). It has also been predicted that there will be increase in mean temperature by 0.4 to 2.0 $^{\circ}$C in monsoon and 1.1-4.5 $^{\circ}$C in winter by 2070 (IPCC 1996). The temperature in Nepal has also increased annually by an average of 0.04-0.06 $^{\circ}$C (Amgain 2011, 2013; MoE 2010). Increased temperature may decrease wheat potential yield more than the rice and posing a challenging threat in food security. It is also reported that the changing rainfall pattern and its distribution affect negatively on wheat yield because wheat cultivation is mostly rainfed, but more vulnerable to drought stress than other crops in Nepal (Amgain et al 2019, Amgain and Timsina 2004, 2005; Timsina and Humphreys 2006). It is also reported that research on farmers' field would be more vulnerable to climate change and, hence urge for innovative climate change research (Amgain et al 2018; Amgain 2015).

A range of technologies have been identified in recent years, which have the potential to increase resource use efficiency, reduce adverse environmental impacts, and increase crop productivity (Acharya et al 2021; Timsina et al 2021; Amgain 2015). The use of correlation co-efficient and regression equations, trend analysis and various crop models are used to know the impact of agro-climatic indices on the yield of rice, maize, wheat and chickpea in Nepal (Amgain and Dhakal 2019; Amgain et al 2019). It is assumed that evaluation and site-specific adaptation of these technologies can be assisted through crop simulation models. Among several crop models evolved, the Decision Support System for Agro-technology Transfer (DSSAT) is the pioneer one (Jones et al 1998; Kaur and Singh 2020) because it simulates growth, phenology, yield and development activities under different management practices and climate change scenarios. Cropping system model (CSM-CERES-Wheat) is a decision support tool used widely to evaluate and/or forecast the effects of environmental conditions, management practices, and different genotypes on rice and wheat growth, development and yield (Jones and Kiniry 1986; Timsina and Humphreys 2006). This model can identify the gaps between potential and on-station and on-farm yields, helps to evaluate management option and to determine likely environmental impacts. They can also be used to forecast yield prior to harvest and extrapolate the results conducted in one season or location to other seasons, locations or management (Hoogenboom et al 2010).

Several studies in this line have done separately as an on-station trials of various parts of the world and in Nepal (Bhandari et al 2021; Devkota et al 2022; Timsina et al 2021), but there is lack of study focusing the real impacts on agro-climatic indices on productivity of wheat and multi-year weather and yield prediction in central-west Terai conditions of Nepal. Therefore, this study was conducted to evaluate the multi-year prediction of agro-climatic scenarios on yield of wheat in Kapilvastu district of central-west Terai after to compare the agro-climatic indices and wheat yields for last 32-33 years.

MATERIALS AND METHODS

Location and weather details of the study area

Kapilvastu district as one of the major domains of wheat lies in the central-west Terai region in Lumbini Province of Nepal, The district was selected purposively for this study as it represents major wheat growing districts in the Terai region (Figure 1). The elevation of Kapilvastu varies from 93 meters to 1,491 meters above sea level with an area of 1,738 km^2 and a population of 571,936 (CBS 2013). The summer maximum temperature in Kapilvastu is 45˚C, whereas the minimum temperature during winter is near to freezing. The distribution of precipitation in central-west Terai also depends on the spatial location and time of the year wherein, about 20% rainfall perceives during winter (December–February).

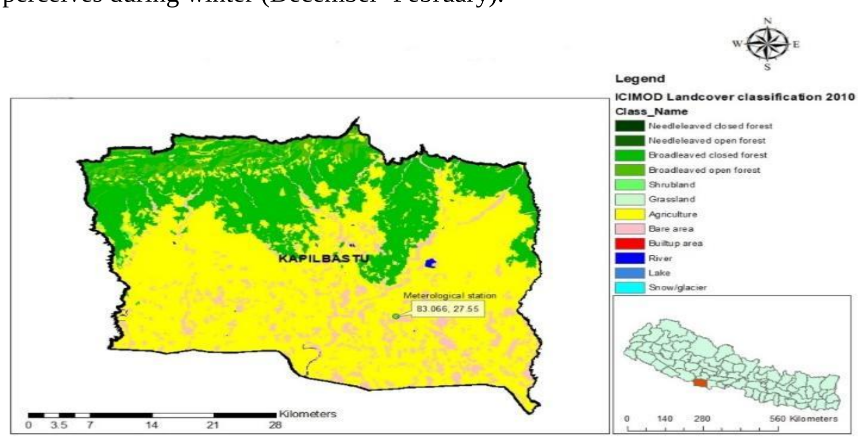


Figure 1. A map of Nepal showing study site, Kapilvastu district in central-west Terai

Collection of historical weather and crop yield data

This experiment was accomplished after the rigorous study of three approaches: i) validation of the Department of Hydrology and Meteorology (DHM) observed weather data with the data obtained from the NASA-POWER, ii) trend analysis between historical agro-climatic indices (temperature, solar radiation and precipitation), and wheat yields over Kapilvastu district, and, iii) testing the sensitivity of the CSM-CERES-Wheat (DSSAT ver 4.7) Model over the changing climatic scenarios and weather years in central-west Terai regions of Nepal. For this, the research primarily depended on secondary datasets that were obtained from several government departments and agencies.

Records of multi-year climatic database

The daily weather records including maximum and minimum air temperatures, solar radiation, and rainfall for last three decades (1984/85-2017/18) was downloaded from the National Aeronautics and Space Administration (NASA)/ Prediction of Worldwide Energy Resource Radiation (POWER) site (https://power.larc.nasa.gov/data-access-viewer/) at Taulihawa in Kapilvastu (27.55˚ N, 83.067˚ E) during winter. These data are required to run DSSAT model (Hoogenboom et al 2010). The NASA-POWER project at the NASA Langley Research Center provides daily data for main climatic variables on 0.5° latitude by 0.5° longitude grid cells for the entire globe. NASA-POWER data is mostly used in DSSAT model. Consequently, the data for maximum and minimum temperatures and rainfall were also taken from ground station provided by Department of Hydrology and Meteorology (DHM) for the further process in validation. The weather data (maximum and minimum temperature and precipitation) of 32-33 years (1984/85-2017/18) derived from the NASA-POWER was validated with the ground station data (observed data) provided by the DHM. The values of solar radiation data for various years were found to be missing in the DHM data repository which forced the researchers to download the NASA-POWER database.

Validation of multi-year weather data

On the data provided by DHM weather repository, there were a lot of missing data in the ground station (Taulihawa, Kapilvastu) and this obviously decided to use satellite data than the data provided by DHM. The DSSAT model accepts the NASA-POWER data that was validated with the ground station (Timsina 2011). Before using any satellite data, it is important to check how it relates to the observed data and can be used further for its significant use. For this we selected random 4 years (1985/86, 1995/96, 2005/06 and 2015/16) of wheat growing season as per the maximum availability of the daily records of weather variables at DHM ground station of Taulaihawa. These 4 years of weather records taken separately during wheat season limits within the range of 10% data of the multiple weather records of the 32-33 years and it was especially done to validate with the NASA-POWWR data. Due to lack of solar radiation data, we excluded it and taken only the temperature and precipitation for the validation of the data sources.

Records of agricultural database

The wheat yield data were obtained from the Ministry of Agriculture and Livestock Development (MoALD), Nepal. Some missing yield data were also collected from the International Center for Integrated Mountain Development (ICIMOD) agricultural atlas.

Trend analysis between historical weather data with the wheat yield

Trend analysis was done to see either climatic indices are increasing or decreasing and to see how wheat yield is related to different weather parameters. The trend line was plotted to determine the relationship between minimum and maximum temperature, rainfall and solar radiation and wheat yield. Similarly, with the yield predicted by the DSSAT model, a separate trend line was also drawn between the weather variables to show temporal variability. Correlation analysis deals with the association between two or more variables. The calculation of the correlation coefficient is performed using the equation, in which X represents the independent variable and Y represents the dependent variable.

$$\boldsymbol{r} = \frac{\sum(\boldsymbol{X} - \overline{\boldsymbol{X}})(\boldsymbol{Y} - \overline{\boldsymbol{Y}})}{\sqrt{\sum(\boldsymbol{X} - \overline{\boldsymbol{X}})^2(\boldsymbol{Y} - \overline{\boldsymbol{Y}})^2}}$$

Where, X and Y represent the sample mean of x and y, respectively.

Regression analysis is fundamental relationship between a dependent random variable and one or more independent random variables. The general form of the regression function is

$$Y = b_0 + b_1X_1 + b_2X_2 + \dots \dots \dots \dots \dots + b_kX_k + c$$

Where (b_0, b_1, b_2,…………b_k) are the regression coefficient, X and Y are two variables and c is the constant.

Calibration and validation of CSM-CERES- Wheat model

For the evaluation of CSM-CERES- Wheat, DSSAT ver 4.7 crop model was used in Kapilvastu condition. A properly calibrated and fairly validated model with the genetic co-efficient of wheat cultivar Gautam (Marasini 2016; Amgain et al 2019) was used for the further study the sensitivity of the model.

Prediction of wheat yield with changing agro-climatic scenarios

Simulation to different scenarios of climatic parameters was accomplished by comparing the growth and yield performance of wheat 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 wheat was accomplished while studying sensitivity analysis. It was done by changing their respective magnitude as mentioned in Table 1 to predict the growth and yield performance of wheat for 2020, 2050 and 2080 scenarios as advocated by IPCC (2007, 2013). The given scenarios were in the range of increasing of 2-4˚C temperatures, 420 to 570 ppm of CO_2 concentration and increase of 1MJ m^{-2} day^{-1} of solar radiation for the cereal crops, respectively (Abdul Haris et al 2010).

RESULTS

Evaluation of NASA POWER- derived and DHM observed weather data

The comparison between NASA-derived daily maximum, minimum temperature and rainfall and ground-measured data for the different four years (1985/86, 1995/96, 2005/06 and 2015/16) at Taulihawa Kapilvastu, Nepal (Figure 2, 3 and 4) showed that the maximum temperature for NASA data range from 13 °C to 43.24 °C, whereas the measured temperature ranged from 8.3 °C to 45 °C with hardly 10% limitation range. The corresponding NASA-derived and measured minimum temperature ranged from 2.41° C to 28.97 °C and 0°C to 32.6 °C, respectively.

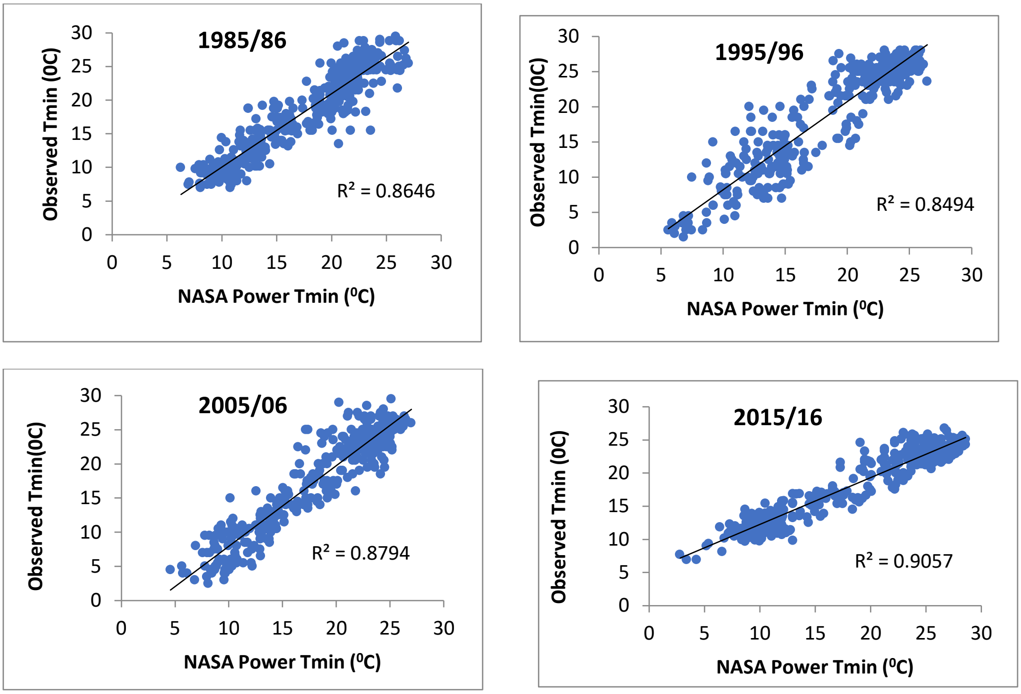
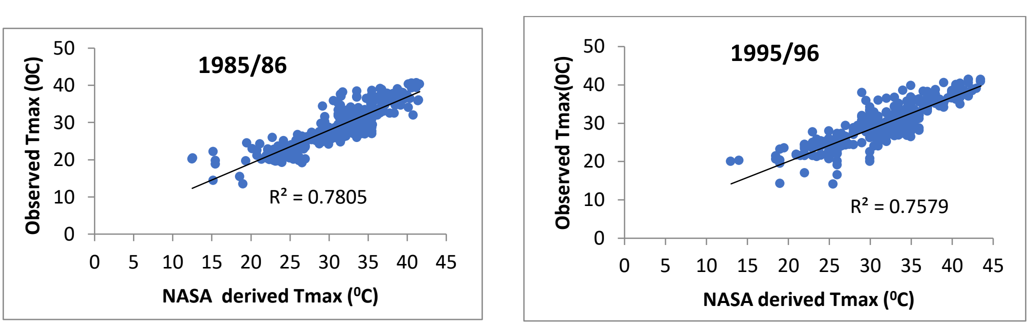


Figure 2. Comparison of NASA-derived and measured maximum temperature of four years (1985/86, 1995/96, 2005/06 and 2015/16) at Taulihawa, Kapilvastu, Nepal

The overall mean maximum temperature reflected in NASA data was 2 °C cooler than that given by the measured data; values of mean minimum temperature were almost the same for both source of data. Although mean daily rainfall was quite similar (2.96 vs 3.86 mm for NASA and measured data), there were large variations in individual daily rainfall (0 – 157.21 mm for NASA data; 0 – 298.5 mm for measured data). The coefficient of determination (R^2) values for maximum temperature for year 1986, 1996, 2006 and 2016 were 0.78, 0.75, 0.63 and 0.71, respectively. Similarly, R^2 values for minimum temperature were 0.86, 0.84, 0.87 and 0.90 for respective year. The R^2 values for the mentioned period show the satisfactory agreement between NASA-derived and ground measured data. For rainfall, R^2 values was least satisfactory, it was 0.21, 0.31, 0.29 and 0.30 for 1985/86, 1995/96, 2005/06 and 2015/16, respectively (Figure 3 and 4).



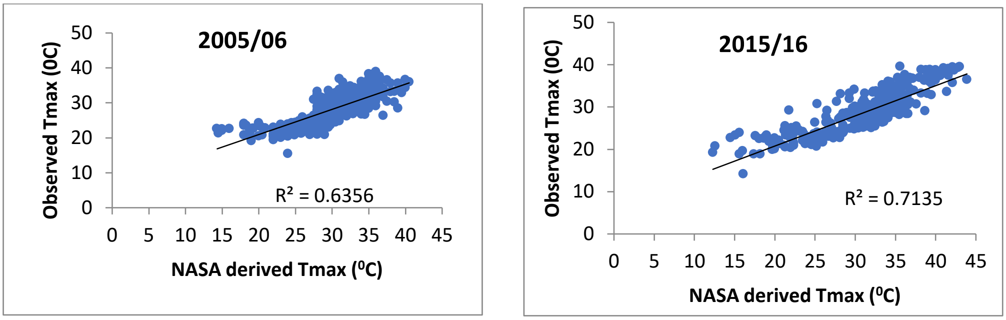


Figure 3. Comparison of NASA-derived and measured minimum temperature of four years (1985/86, 1995/96, 2005/06 and 2015/16) at Taulihawa, Kapilvastu, Nepal

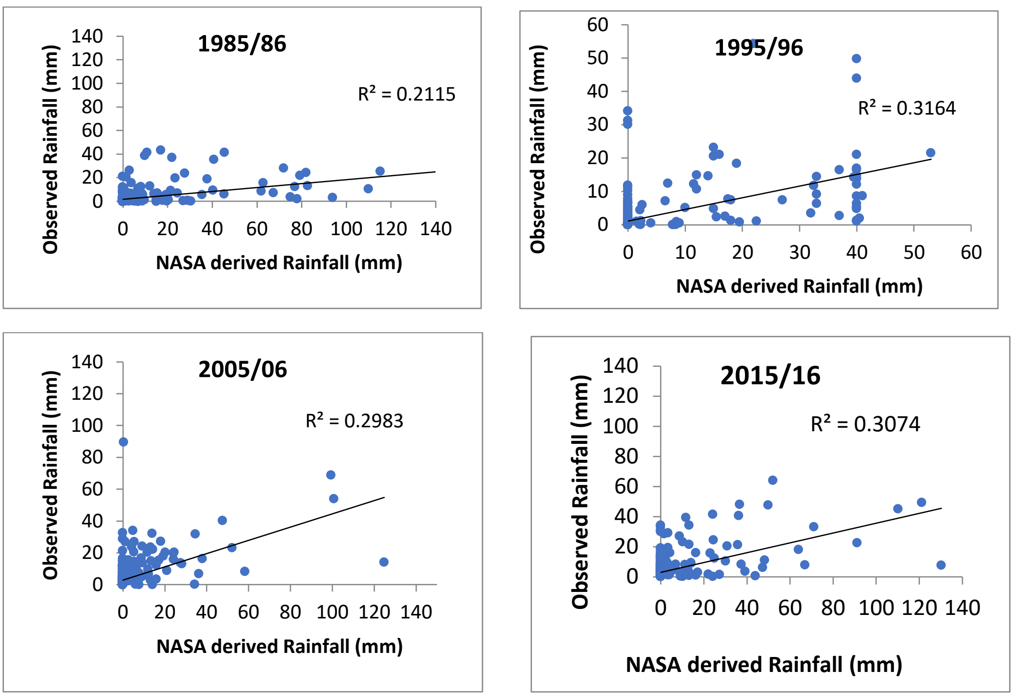


Figure 4. Comparison of NASA-derived and measured rainfall of four years (1985/86, 1995/96, 2005/06 and 2015/16) at Taulihawa, Kapilvastu, Nepal

Trend Analysis of historical agro-climatic indices (mean temperature, total rainfall and solar radiation) and wheat yield during wheat season in Kapilvastu

The time series of annual mean and mean temperature of wheat growing seasons including linear trends are depicted in Figure 5. Average temperature records from 32 years (1984-2016) shows decreasing trends at the Taulihawa, Kapilvastu district. Over the last 32 years the mean temperature decreased by 0.02˚C per year and the highest and the lowest values of mean temperature are 24.5 in 2002 and 22.4 in 2013, respectively. Similarly, the mean temperature at wheat growing seasons (October to April) of the 32 years also shows the decreasing trends. In this season mean temperatures decreases by 0.016˚C per year.

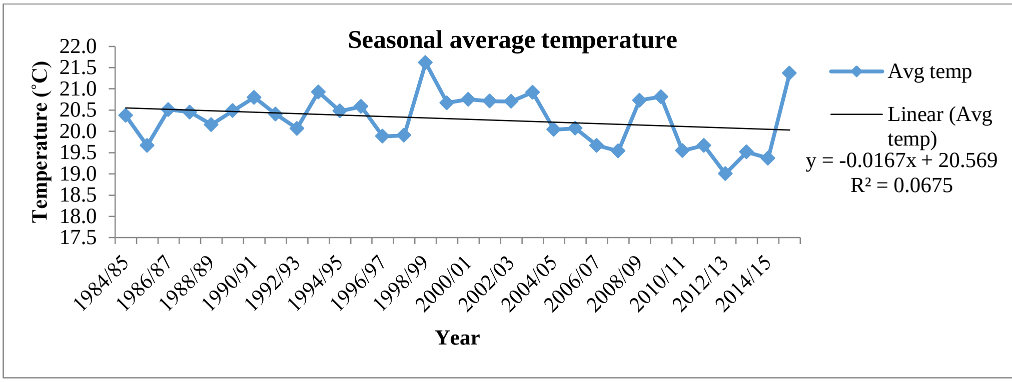


Figure 5. Average temperature of wheat growing seasons of Taulihawa, Kapilvastu of 32 years (1984/85 to 2017/18)

Both the annual and seasonal maximum temperature records from 32 years (1984-2016) shows decreasing trends. Over the last 32 years both annual and seasonal maximum temperatures are decreases by 0.049˚C per year and 0.047˚C per year, respectively. The minimum temperature of both annual and wheat growing season shows the increasing trends. The minimum annual and seasonal temperatures were increased by 0.007˚C per year and 0.013˚C per year, respectively. The mean annual precipitation and mean precipitation of wheat growing seasons (October to April) was found as 1065.15 mm and 115.4 mm, respectively. The precipitation of both annual and wheat growing season shows the increasing trends. The annual precipitation and seasonal precipitation were increased by 28.52 mm per year and 3.46mm per year, respectively. The time series of annual precipitation and precipitation of wheat growing seasons including linear trends were depicted in Figure 6.

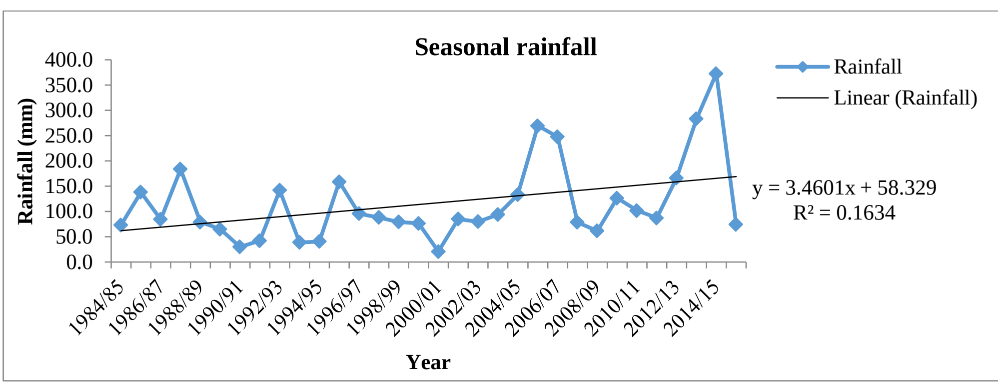


Figure 6. Seasonal minimum temperature of wheat growing seasons of Taulihawa, Kapilvastu of 32 years (1984/85 to 2017/18)

The time series of annual solar radiations and solar radiations of wheat growing seasons including linear trends were depicted in Figure 7. Both the annual and seasonal solar radiations records from 32 years (1984/85 -2017/18) shows decreasing trends. Over the last 32 years both annual and seasonal radiations were decreases by 0.034 MJ m^{-2} per year and 0.032 MJ m^{-2} per year, respectively.

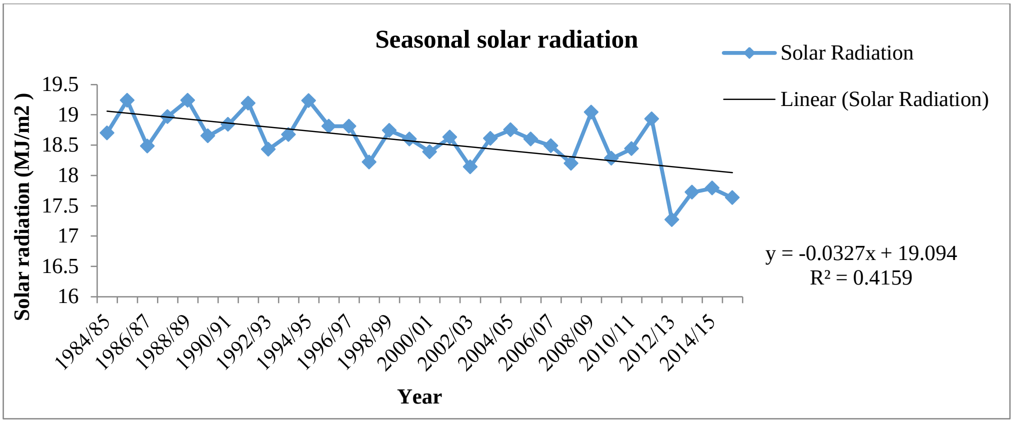


Figure 7. Seasonal solar Radiations of wheat growing seasons of Taulihawa, Kapilvastu of 32 years (1984/85 to 2017/18)

Impact of climatic indices on temperature, total rainfall, solar radiation and wheat yield

A relationship between wheat yield (both observed and DSSAT simulated) and temperature (both maximum and minimum) were shown in Figures 8-9. It is well noticed that the effect of wheat yield is more dependent in minimum temperature than maximum temperature. Wheat yields showed the negative correlation for the maximum temperature. The correlation between the maximum temperature and observed wheat yield and DSSAT simulated yields were -0.512 and -0.214, respectively resulting that the increase in maximum temperature has large negative impacts on net wheat yield. Similarly, correlations between the observed and simulated wheat yield and minimum temperature showed positive correlations; and values were 0.272 and 0.123, respectively.

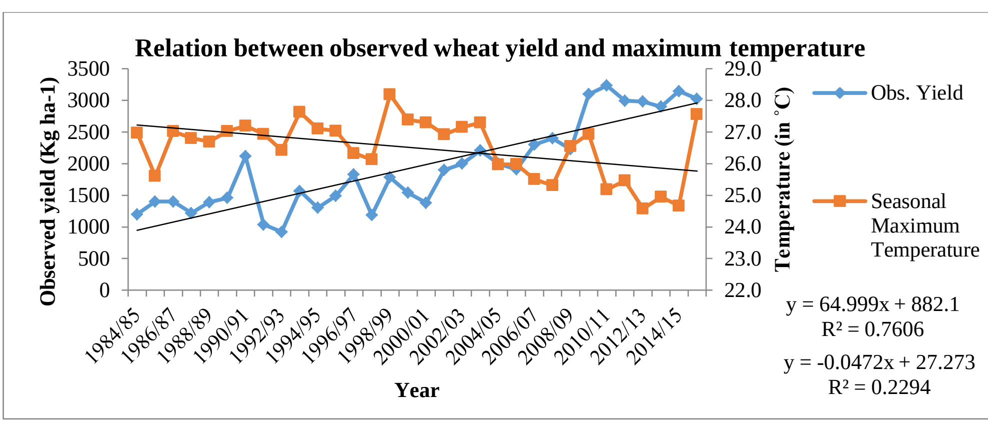


Figure 8. Relation between observed wheat yield and maximum temperature at Taulihawa, Kailvastu during 32 years

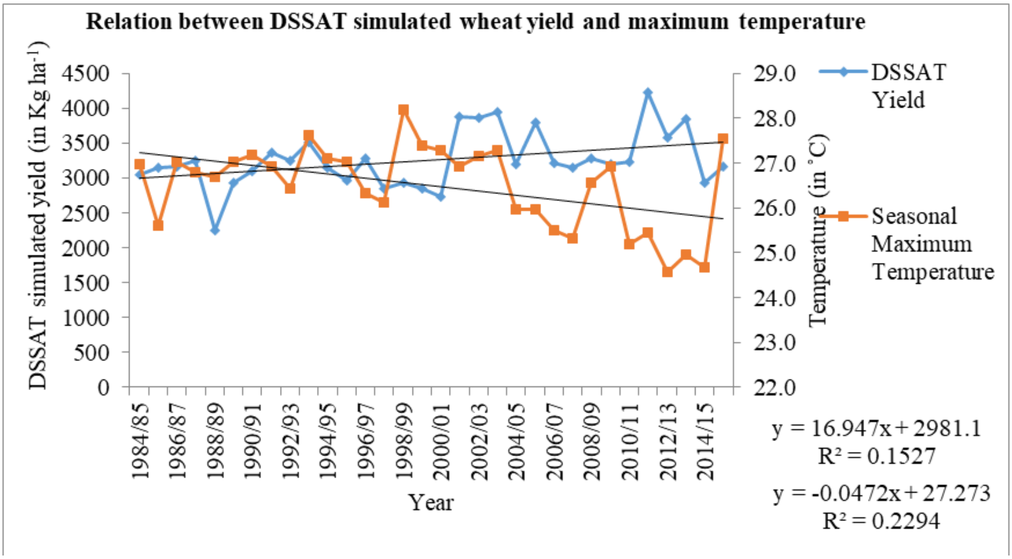


Figure 9. Relation between DSSAT simulated wheat yield and maximum temperature at Taulihawa, Kapilvastu

It was well noticed that the effect of wheat yield was depend on rainfall. Wheat yields showed the positive correlation for the rainfall. The observed yield showed the strong positive correlation in compare to the wheat yield from DSSAT simulation. The correlation between the rainfall and observed wheat yield and DSSAT simulated yields were 0.379 and 0.158. That means increases in rainfall had positive impacts on net wheat yield. A relationship between wheat yield (both observed and DSSAT simulated) and rainfall were shown in Figures 10 and 11.

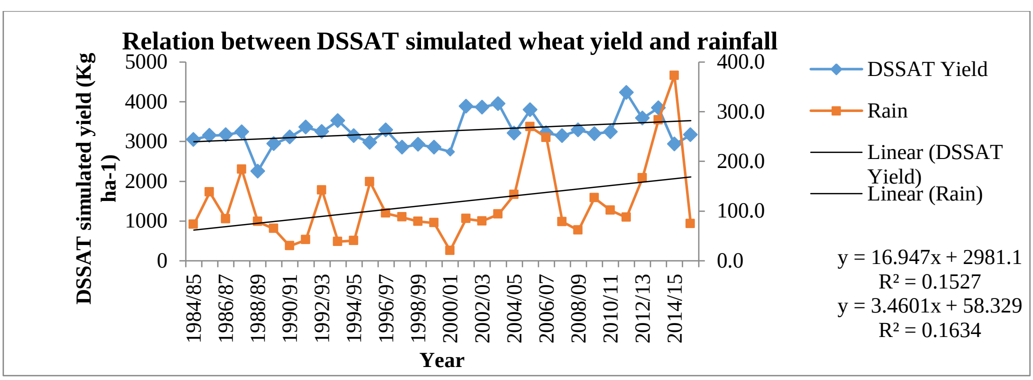


Figure 10. Relation between DSSAT simulated wheat yield and rainfall at Taulihawa, Kapilvastu

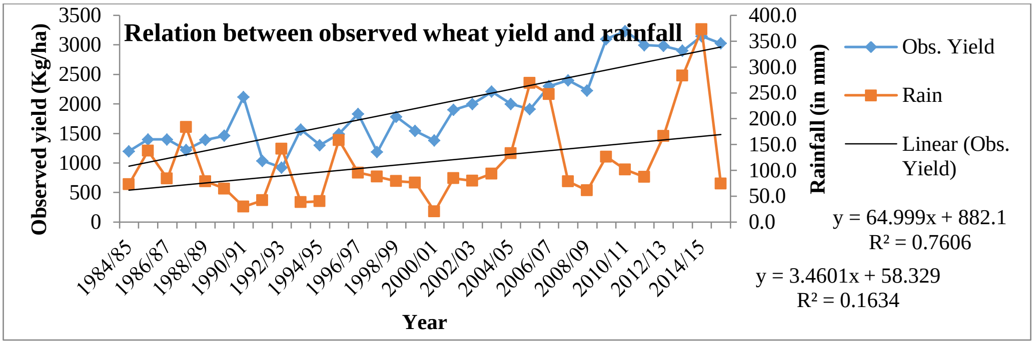


Figure 11. Relation between observed wheat yield and rainfall at Taulihawa, Kapilvastu

A relationship between wheat yield (both observed and DSSAT simulated) and solar radiation were shown in Figures 12 and 13. Wheat yields showed the negative correlation with the solar radiation. The observed yield showed the strong negative correlation in compare to the wheat yield from DSSAT simulation. The correlation between the solar radiation and observed wheat yield and DSSAT simulated yields were -0.587 and -0.176. That means increases in solar radiation had negative impacts on net wheat yield.

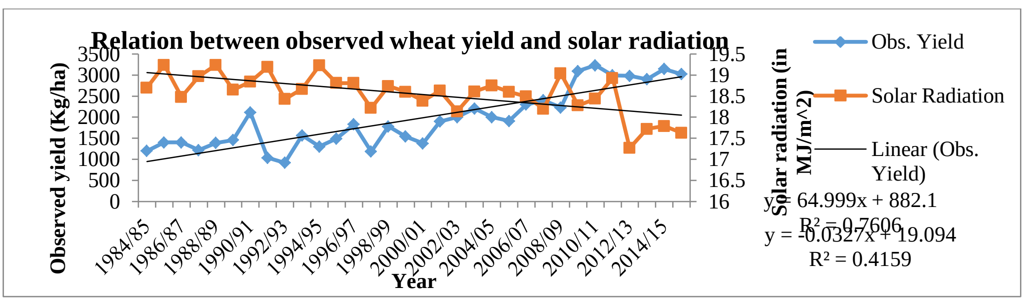


Figure 12. Relation between observed wheat yield and solar radiation at Taulihawa, Kapilvastu

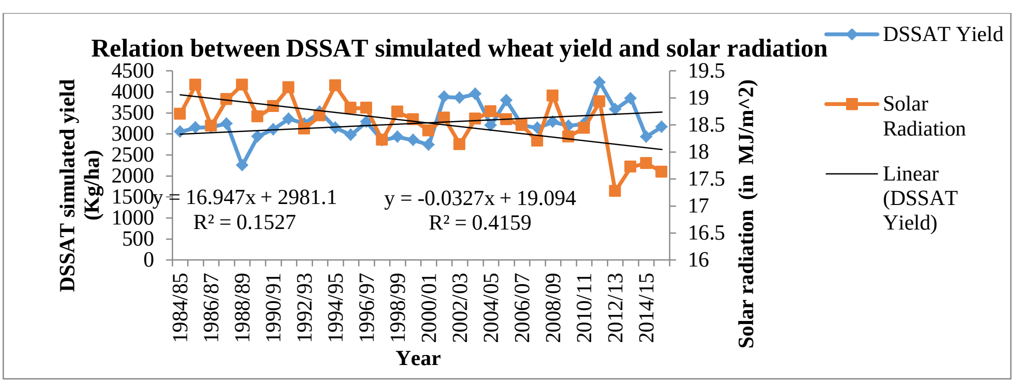


Figure 13. Relation between DSSAT simulated wheat yield and solar radiation at Taulihawa, Kapilvastu

Multi-year prediction of wheat yields as influenced by changing climatic scenarios (IPCC 2007)

Under increased temperature condition (along with elevated CO_2 and increased or decreased solar radiation), the yield of wheat cultivars was found decreased. Likewise, it was found to be increased in yield for decreased in maximum and minimum temperature by 4˚C (Table 1). Temperature primarily affected growth duration with lower temperature increasing the length of time that the crop could intercept radiation. The model was sensitive to various scenarios of climate change parameters (temperature, solar radiation and CO_2 concentrations). Change in maximum and minimum temperatures by 1˚C (+ 1˚C) and CO_2 concentrations 370 ppm (+0 ppm) with no change in solar radiation resulted increase in yield of WK-1204 by only 2 percent (Table 1). The maximum and minimum temperature was increased by 1˚C and CO_2 concentrations added 50 ppm (420 ppm) with change in solar radiation (+1 $MJm^{-2}day^{-1}$) resulted increase in yield by 6 %, which is the maximum increment in wheat due to climate change. The temperature increased further will decrease the wheat yield. The temperature increased by 2˚C the yield decreased by 8 percent, similarly increased in temperature by 3˚C and CO_2 concentration 470 (+50) ppm the yield will be minimum, declined by 15%. While the maximum increase in the maximum and minimum temperatures by 4˚ C along with 100 and 200 ppm CO_2 concentration showed the yield decline of 14 % than the standard model treatment (without changing the weather parameters). The existing wheat cultivar could not sustain the yield potential of the present level in future after 2020 and, hence it should be opined to adopt the climate change adaptation strategies over the long-run.

Table 1. Sensitivity analysis of wheat as according to the different climate change scenarios for 2020, 2050 and 2080

S. No	Max Temp (˚C)	Min Temp ˚C)	Solar radiation (MJ m^{-2} day^{-1})	CO_2 Conc. (ppm)	Simulated Yield (kg ha^{-1})	% yield change
1.[a]	+0	+0	+0	370	4471	100
2.	+1	+1	+0	370	4755	106.4
3.	+1	+1	+1	+50(420)	4582	102.5
4.	+2	+2	+1	+50(420)	4107	91.9
5.	+3	+3	+1	+100(470)	3797	84.9
6.	+3	+3	+1	+200(570)	3514	78.6
7.	+4	+4	+1	+200(570)	3261	72.94

Note: [1a]: Standard climatic conditions (model default), 2, 3 and 4: Climate change scenario 2020, 5 and 6:. Climate change scenario 2050 and 7: Climate change scenario 2080 (IPCC 2007)

DISCUSSION

Weather and yield trend analysis

The weather data of 32-33 years (1984/85-2017/18) derived from the NASA-POWER source was validated with the ground station data (observed data) provided by the DHM. Although the R^2 values were less than desired, the scatter diagram show similar trends and patterns, indicating a close relationship between NASA-derived and actual ground measured data, especially for temperature. Due to lack of solar radiation data, we could not validate it and we used the data derived from (NASA Power). To check the pattern of temperature, precipitation and solar radiation we read the trend analysis. We use annual data as well as the wheat growing season's data of temperature, precipitation and solar radiations. The patterns were almost same for annual and seasonal data. The annual mean temperature and maximum temperature were in decreasing trend. The mean and maximum temperatures were decreased by 0.02˚C per year and 0.049˚C per year, whereas the minimum temperature was increasing and increased by 0.007˚C.

Similarly, the precipitation was in increasing trend and solar radiation was in decreasing. The precipitation was increased by 28.52 mm per year and solar radiation was decreased by 0.034 MJ m^{-2} $year^{-1}$. Both observed yield and DSSAT simulation yield were used to see the relationship. Correlation coefficient and regression analysis was done individually with the climatic indices (max, min temperature, precipitation and solar radiations).

The results highlighted that the maximum temperature has negative correlation with the observed wheat yield and minimum temperature had positive correlation. The correlation coefficient of maximum and minimum temperature and wheat yield were -0.512 and 0.272, respectively, whereas with DSSAT simulated yields were -0.214 and 0.123, respectively. Similarly, the correlation between wheat yield and precipitation had positive and solar radiation had negative correlation. The correlation between precipitation and observed and DSSAT simulated yield were 0.379 and 0.158, respectively. The correlation between the solar radiation and observed wheat yield and DSSAT simulated yields were -0.587 and -0.176. The trend analysis on grain yields of rice was correlated over the historical records of maximum and minimum temperatures along with rainfall. A positive correlation was found with rainfall with well-formed regression equations as well as strong coefficient of determination (R^2 value of 0.71). However, the yield was found to be negatively correlated with the maximum temperature and minimum temperature.

DSSAT model and multi-year climate and wheat yield prediction

We used already calibrated and validated CSM-CERES-Wheat model, DSSAT ver. 4.7 to study the model simulation (Amgain et al., 2019). The determined genetic coefficients for wheat cultivar WK-1204 was 3 (P1V), 39 (P1D), 315 (P5), 40 (G1), 71 (G2), 0.9 (G3) and 64 (PHINT). By running sensitivity analysis, the model was found sensitive to weather years and various parameters of climate change. In the 1998/99, decrease in yield was observed. In the year 1984/85 and 1991/92 increased yields was found. The maximum yield was observed in the year 2005/06 as compared to the year 2015/16 (Dhakal 2020). Increase in minimum and maximum temperature by 4˚C decreased the wheat yield whereas; decrease of temperature by same amount increases the yield. Change in temperature (-4˚C), CO_2 concentration (+20 ppm) with reduction in solar radiation (MJ m^{-2} day^{-1}) resulted maximum increase in yield of wheat cultivar by 12%. Similarly change in temperature (+4˚C), CO_2 concentration (+20 ppm) with increase in solar radiation (MJ m^{-2} day^{-1}) resulted decrease in yield by 62%. DSSAT model was also used to multi-year prediction of wheat yield. The wheat yield was on decreasing on the future. By increasing 1˚C maximum and minimum temperature and CO_2 concentration 420 ppm (+50 ppm) with change in solar radiation (+ 1MJ m^{-2} day^{-1}) resulted maximum increase in yield of WK-1204 by 6%. After that the wheat yields was found decreasing. IPCC defined weather scenario suggested that the maximum increase in the maximum and minimum temperatures by 4˚C along with 100 and 200 ppm CO_2 concentration showed the yield decline up to 16 percent. Amgain et al (2006) reported that increase in minimum and maximum temperature by 4˚C over the base scenario decreased the wheat yield by 4%. Reduction of minimum and maximum temperature by 4˚C and increase in CO_2 by 20 ppm showed increase in yield (Amgain et al 2006, 2019). 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 et al 2016; Qureshi, Quersi and Iglesias 1994; Timsina et al 1997). At elevated CO_2, light intensity positively affects photosynthesis and increased temperature promotes both photosynthesis and leaf area. 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). Increased CO_2 concentrations would reduce transpiration and nutrient losses and increase water, nutrient and radiation use efficiencies and that might have increased yield under decreasing temperature. Similar result was also resulted by Marasini (2016) and Singh and Padilla (1995). An increase of temperature of the order of 3°C or more cancels out the beneficial effects of elevated CO_2 in all the maize cultivars under study (Amgain 2015).

CONCLUSIONS

We can safely use the NASA-POWER weather data for multi-year prediction of agro-climatic studies if the observed data are missing due to some technical reasons. Based on the historical weather details, the average temperature and solar radiation are increasing during summer and decreasing during winter in central-west Terai and there was a positive trend line of average temperature on wheat yield. The rainfall data as predicted by NASA-POWER could not find positive correlation with wheat yield. It could also be suggested that we would have to adopt the new climate change resilient wheat cultivars after 2050 scenarios of climate change as advocated by IPCC (2007, 2013). The extrapolative use of CSM-CERES- Wheat model embedded in DSSAT ver. 4.7 in large areas will be the best management decision tool in predicting the future yield gaps and knowing the factors of crop yield decline. For wider application of model 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 with multi-year seasonal, rotational and spatial analysis.

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AUTHORS' CONTRIBUTION

Devid Dhakal carried out the field experiment and write-up the manuscript. Lal Prasad Amgain supervised the experiment and helped in manuscript preparation. Laxmi Bhandari helped in writing manuscript.

CONFLICTS OF INTEREST

The authors have no any conflict of interest to disclose.

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