Multi-year Prediction of Rice Yield under the Changing Climatic Scenarios in Nepal Central Terai Using DSSAT Crop Model

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ABSTRACT

NASA-POWER derived weather data of Dumkauli in Nawalparasi (27.68° N, 84.13°E) district in the Nepal central Terai for the past 33-years (1984/85-2017/18) were purposively downloaded and validated with recorded weather data of Department of Hydrology and Meteorology (DHM). The trend analysis for grain yield of rice in Nawalparasi was drawn with the historical data of the maximum and minimum temperatures and rainfall. Positive correlations between grain yields and minimum temperature and rainfall each showed an acceptable coefficient of determination (R^2). The CSM-CERES-Rice embedded in DSSAT ver 4.7 was used for multi-year prediction of rice yield using both historically recorded and simulated climatic scenarios. The model simulated results closely agreed with the observed rice yield recorded by the Ministry of Agriculture and Livestock Development (MoALD) in Nepal. The correlation between precipitation and observed rice yield was 0.71 and the correlation between precipitation and observed and DSSAT simulated yield was 0.379. The multi-year predicted rice yield using historical weather data and the DSSAT rice model showed that rice yield could be sustained with the use of the current crop cultivars only for the upcoming few years. The climate index, mainly the rainfall index, was found to be more sensitive to rice production in the Nepal central Terai region. This study suggests for the development of new climate change ready rice cultivars to feed the increasingly growing Nepalese population.

Keywords: agro-climatic indices, DSSAT 4.7 crop model, Multi-year prediction, Nepal central Terai, Rice yield

सारांश

नासा-पावरबाट रेकर्ड गरिएको दुम्कौली, नवलपरासी केन्द्रको ३३ वर्ष अवधि (१९८४/८५-२०१७/१८) सम्मको दैनिक हावापानी रेकर्डलाई अध्ययनार्थ छनौट गरी डाटा खिचिएको र जल तथा मौसम विभागबाट रेकर्ड गरिएको उक्त केन्द्रको यथार्थ मौसमका कारकतत्वहरुसंग प्रमाणिकरण गरी यस अध्ययनको शुरु गरियो । धान बालीको उत्पादकत्व तथा हावापानी कारक परिसूचकका तत्वहरु वीच वहाव लाईन खिची हेर्दा धान बालीमा धनात्मक समता पाईयो । DSSAT-४.७ बाली मोडललाई धानमा उत्पादकत्वलाई फरक पार्ने हावापानी परिवर्तनका कारक तत्वहरुसंग समन्वय गरी हेर्दा पनि यो रेखात्मक चित्र धनात्मक नै भेटीयो । विश्व हावापानी अध्ययन केन्द्र (IPCC, 2007) वमोजिम हावापानी परिवर्तनका परिसूचकहरु जस्तै: तापक्रम, सूर्यको किरणको तिब्रता तथा कार्वनडाइअकसाइडको मात्र हुन सक्ने प्रध्येपित नतिजा अनुसारमा फेरबदलहुने सन् २०२०, २०४० र २०८० सम्म परिवर्तित हावापानी सूचकहरुमा हाल विकाश गरिएका धानका जातहरुले अरुका केहि वर्षमात्र उत्पादकत्व कायम राख्न सक्ने तथा अव छिट्टै नै विषम हावापानी सहन गर्न सक्ने नयाँ जातहरुको विकास गर्न र यस वाली मोडेललाई राम्रोसंग प्रयोग गर्न सक्दा नेपालको मध्य तराइमा धानको उत्पादकत्व बृद्धि गर्न सकिने देखिएको छ ।

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 and Connor 2001, Timsina et al. 2022, Devkota et al 2021). In South Asia, rice-wheat systems produce more than 30% of the rice and 42% of the wheat consumed (CIMMYT 2015). It is also the dominant cropping system among other cereal cropping production system in Terai region of Nepal and is important for food security (Timsina and Connor 2001). In Nepal, rice occupies 1.5 Million ha and is 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 (Marahatta and Amgain 2019, Devkota et al 2015, 2016). Rice alone contributes nearly 20% to the agriculture gross domestic products (AGDP), more than 50% of food grains, and 50% of the total caloric requirements of the people (ABPSD 2013/14, FAOSTAT 2021).

The highly intensive cereal-based cropping systems in Nepalese Terai are facing the sustainability problems due to fragile ecologies and 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 1.5 t/ha) between rice yields in farmers' fields (<3.0 t/ha) and in research stations (around 1.5 t/ha) (Amgain et al 2021, Fischer et al 2009, Devkota et al 2021). Globally, it has been agreed that one of the important ways to increase cereal yields is to adapt the climate change adaptation strategies against the weather anomalies created due to increasing greenhouse gas emissions (Sapkota et al 2014, Devkota et al 2016). Nawalaparasi being one of the main districts in contributing about 5.44% of total harvesting area of rice (Adhikari 2020), but the productivity is felt declining over the last three decades and henceforth, its yield over last three decades along with the anomalies of agro-climatic indices like fluctuating maximum and minimum temperatures, solar radiation and rainfall have been studied.

Climate change includes gradually 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 $1.1–6.4^0$C by 2100 with the different amplitudes of temperatures and CO_2 for different scenarios of 2020, 2050 and 2080 (IPCC 2007, 2013). There will be increase in mean temperature by 0.4 to 2.0 $^{°}$C in monsoon and 1.1- 4.5 $^{°}$C in winter by 2070 (IPCC 1996). The temperature in Nepal has also increased by 0.04 – 0.06 °C annually on an average (Amgain 2013, MoE 2010). Increased temperature may decrease rice potential yield up to 7.4% per degree increment of temperature. Changing rainfall pattern and distribution is negatively affecting paddy production in Nepal because it relies on ample water supply and thus are more vulnerable to drought stress than other crops (Timsina and Humphreys 2006a, 2006b) and research on farmers' field would be more vulnerable to climate change and, hence urge for innovative research.

Globally, a range of technologies has been identified in recent years, which have the potential to increase resource use efficiently, reduce adverse environmental impacts, and increase crop productivity (Acharya et al 2021, Timsina et al 2021, 2022). It is assumed that evaluation and site-specific adaptation of these technologies can be assisted through crop simulation models. 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, wheat, maize and chickpea in Nepal (Amgain and Dhakal 2019). Among several crop models evolved, the Decision Support System for Agro-technology Transfer (DSSAT) is pioneer one (Timsina et al 1995, 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-Rice) is a decision support tool used widely to evaluate and/or forecast the effects of environmental conditions, management practices, and different genotypes on rice growth, development and yield (Jones and Kiniry 1986, Timsina and Humphreys 2006a, 2006b). This model can also 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).

Climate components like temperature, solar radiation, rainfall, relative humidity and wind velocity independently or in combination, can influence crop growth and productivity of rice. Several studies have done separately in on-station of various parts of the world and in Nepal (Bhandari et al 2021, Devkota et al 2022,Timsina et al 2021, 2022), but there is lack of study focusing the real impacts on agro-climatic indices on productivity of rice and multi-year weather and yield prediction in central Terai conditions of Nepal and, therefore this study was proposed, executed and accomplished to evaluate the multi-year prediction of agro-climatic scenarios on yield of rice in Nawalparasi district of central Terai after comparison of the agro-climatic indices with it's yield for last 32-33 years.

MATERIALS AND METHODS

Location and weather details of the study area
Nawalparasai district lying in central Terai region of Nepal being the major domains of rice was selected purposively to study this multi-year prediction of rice yield. The elevation of Nawalparasi varies from 300 meters to 2000 meters above sea level with the area of 2162 km^2 and a population of 643,508 (CBS 2013). The average annual temperature in Nawalparasi is 24.3 °C with the total annual precipitation of about 2248 mm, approaching about 80% contribution from the monsoon. The distribution of precipitation in central Terai also depends on the spatial location and time of the year wherein, about 20% rainfall perceives during winter (December–February).

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

Records of multi-year climatic database
As per the demand of daily weather records of maximum and minimum temperature, solar radiation, and rainfall to run DSSAT model (Hoogenboom et al 2010), the multiple years of historical weather records of 32-33 years (1984/85-2017/18) was downloaded via the internet 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 Dumkauli in Nawalparasi (27.68˚ N, 84.13˚E) during monsoon. 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 (Dumkauli, Nawalparasi) 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 or not. For this we selected random 4 years (1986, 1996, 2006 and 2016)

for rice as per the maximum availability of the daily records of weather variables at DHM ground station of Dumkauli, Nawalparasi. These 4 years of weather records taken for rice 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 at the station we excluded the validation of this variable.

Records of agricultural database
The rice yield data were obtained from the Ministry of Agricultural Development, 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 rice yields
Trend analysis was done to see either climatic indices are increasing or decreasing and to see how rice yields are related to different weather parameters. The trend line was plotted to determine the relationship between minimum temperature, maximum temperature, rainfall and solar radiation of the 32-33 years (1984-2016) along with the rice 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.

$$r = \frac{\sum_i (x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_i (x_i - \overline{x})^2}\sqrt{\sum_i (y_i - \overline{y})^2}}$$

Where,
r = Pearson correlation coefficient
xi= x variable, yi= y variable
$\overline{x}$ = Mean of x variable
$\overline{y}$ = Mean of y variable

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

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

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 DSSAT CSM-CERES-Rice and Wheat models
For the evaluation of DSSAT CSM-CERES-Rice model, DSSAT ver 4.7 crop model was used under Dumakuli, Nawalparasi condition. A properly calibrated and fairly validated model with the genetic co-efficients of rice cultivar Sukkha-5 (Dhakal 2016, Amgain et al. 2019) was used to study the sensitivity of the models

## Multi-year prediction of rice yields with changing agro-climatic scenarios
Simulation to different scenarios of climatic parameters was accomplished by comparing the growth and yield performance of rice genotypes for various weather years. The proportionate increase or decrease in maximum and minimum temperature, solar radiation and increase of CO_2 concentration on the input file (File-X) of rice was done by changing the respective magnitude to predict the growth and yield performance for 2020, 2050 and 2080 scenarios as advocated by IPCC (2013). The scenarios given are in the range of increase of 2-4°C temperatures, of 420 to 570 ppm of CO_2 concentration (Abdul Haris 2010).

RESULTS

### Evaluation of NASA POWER- derived and DHM observed weather data
Rice season in Nawalparasi

The NASA-derived daily maximum and minimum temperature and rainfall and ground measured data for 32-33 years at Dumkauli of Nawalparasi validated well (**Figure** 1-3).
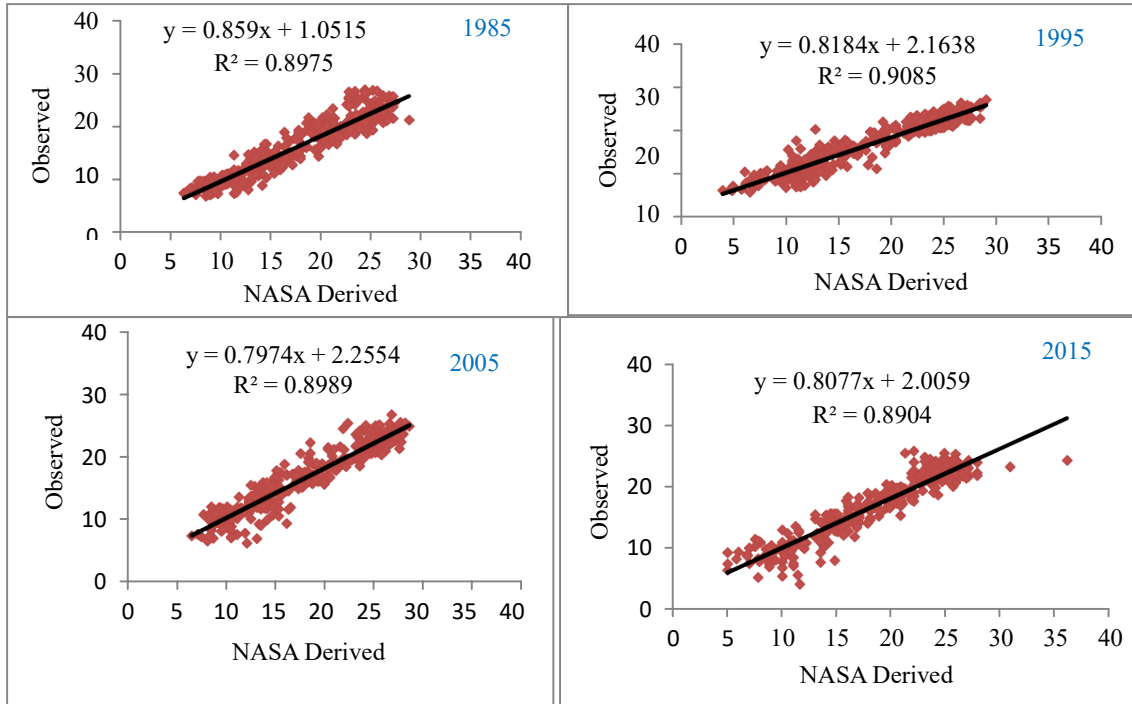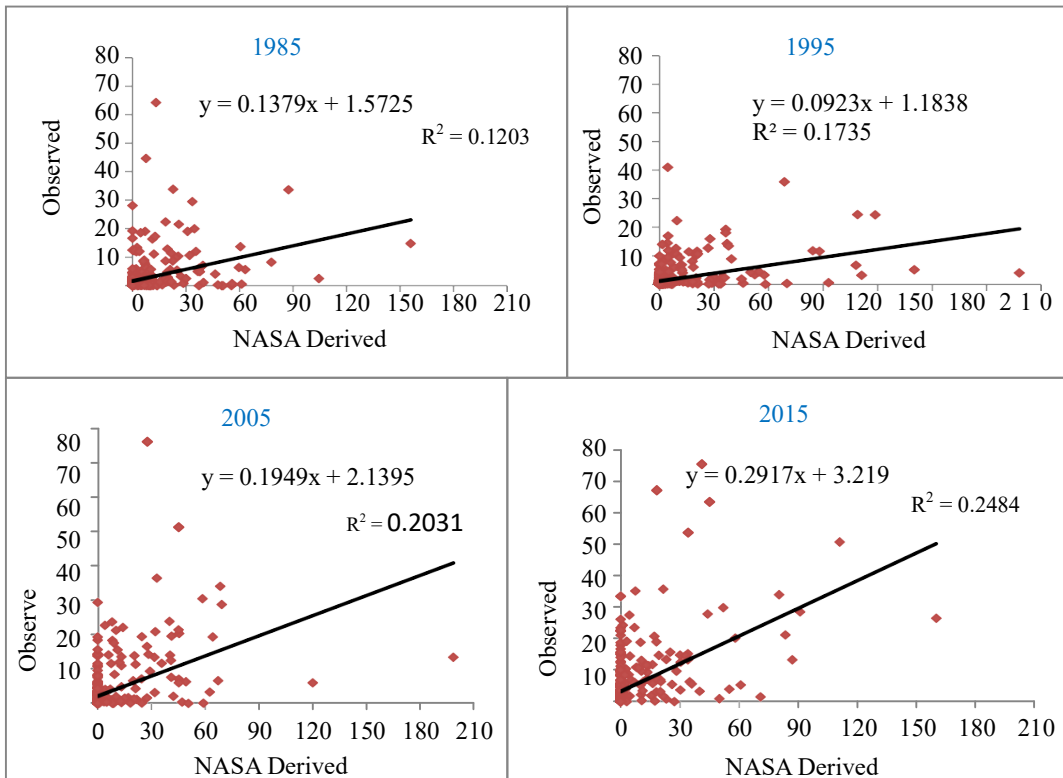

Figure 1. **Validity testing of NASA-derived and ground observed minimum temperature data of 4 consecutive years during rice season at Dumkaluli, Nawalparasi**

There was a good agreement between temperature estimated by NASA and those obtained from Department of Hydrology and Meteorology (DHM). However, measured daily maximum and minimum temperatures were slightly higher than NASA-derived temperatures. Similarly, there were minor discrepancies between the measured and the NASA-derived daily rainfall. The maximum temperature for the NASA-data ranged from 11.09°c to 41.4°C, whereas the measured temperature ranged during rice season varies from 9°c to 43.3°C. The corresponding NASA-derived and measured minimum temperature ranged from 0.86°C to 27.29°C and 3.6°C to 36°C, respectively. The co-efficient of determination (R^2) values for maximum temperature during rice season for the year 1985, 1995, 2005 and 2015 were 0.72, 0.80, 0.79 and 0.64, respectively. Similarly, the values for minimum temperature were 0.89, 0.90, 0.89 and 0.89 during the experimentation period. When we have seen the rainfall, the R^2 values was the least satisfactory as it was 0.12, 0.17, 0.20 and 0.24 for the year 1985, 1995, 2005 and 2015, respectively.
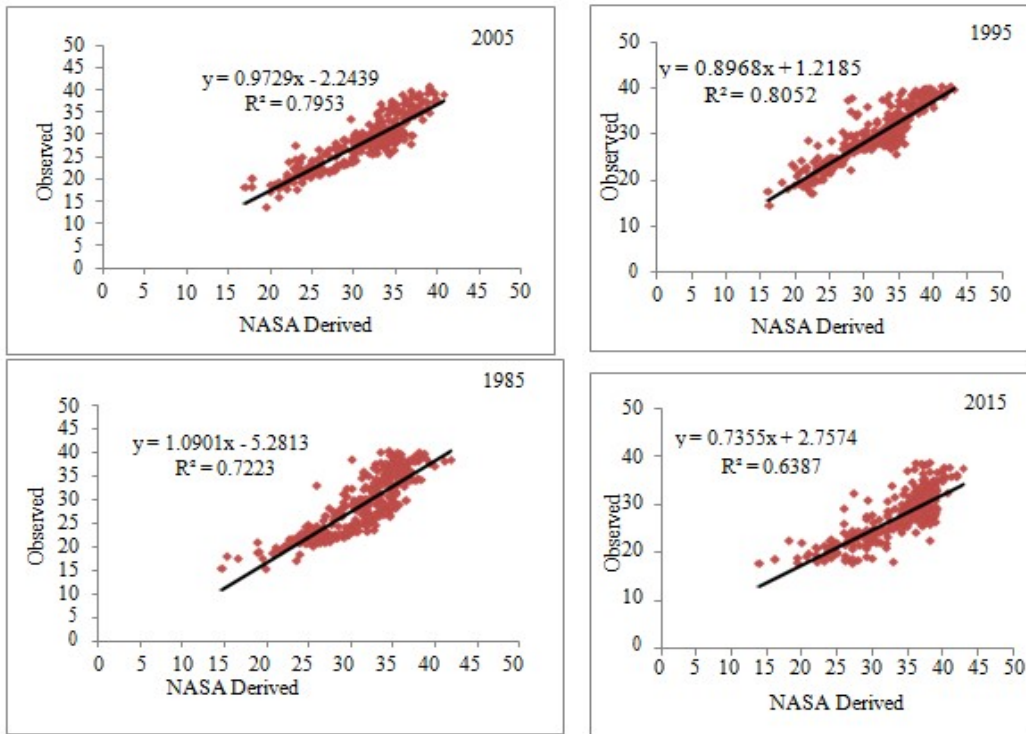
Figure 2. Validity testing of NASA-derived and ground observed maximum temperature of 4 consecutive yearsduring rice season in Dumakauli, Nawalparasi

Figure 3. Validity testing of NASA-derived and ground observed total rainfall data of 4consecutive years during rice season at Dumkaluli, Nawalparasi

**Trend Analysis of historical agro-climatic indices and rice yield**
Analysis of mean temperature, total rainfall and solar radiation during the rice growing season
Average temperature records from 1985-2017 shows decreasing trends at Dumkauli of Nawalparasi district. Over the last 32-33 years the mean temperature decreases by 0.21°C per year and the highest and the lowest values of mean temperature are 23.15 in 1999 and 21.7 in 2012, respectively. Similarly, the mean temperature at rice growing seasons (Jun to Nov) of the 33 years also shows the decreasing trends. The time series of annual mean and mean temperature of rice growing seasons including linear trends are depicted in **Figures** 4. Both the annual and seasonal maximum temperature records from 1985 -2017 shows decreasing trends. Over the last 33 years both annual and seasonal maximum temperatures are decreases by 0.43°C per year and 0.35°C per year, respectively. The minimum temperature of both annual and rice growing months 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 time series of precipitation of rice growing months including linear trends were depicted in **Figure** 5. The mean annual precipitation and mean precipitation of rice growing months (June to November) was found to be 991 mm and 864 mm, respectively. The precipitation of both annual and rice growing months shows the increasing trends. The annual precipitation and seasonal precipitation were increased by 34.32mm per year and 28.41mm per year, respectively. The time series of annual solar radiations and solar radiations of rice growing months including linear trends were depicted in **Figure** 6. Both the annual and seasonal solar radiations records from 1985 -2017 also shows decreasing trends. Over the last 32 years both annual and seasonal radiations were decreases by 0.28 MJ/m²per year and 0.008 MJ/m² per year, respectively.
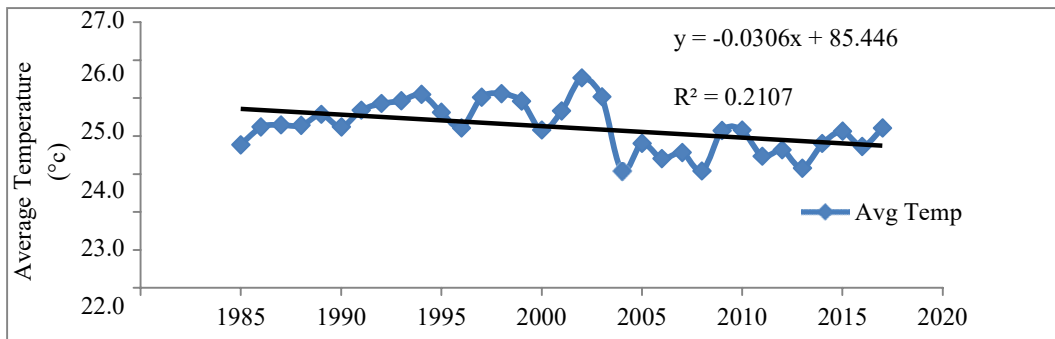
Figure 4. Trends of average temperatures during rice growing months (June-November) in Dumkauli, Nawalparasi for 33years (1985 to 2017)
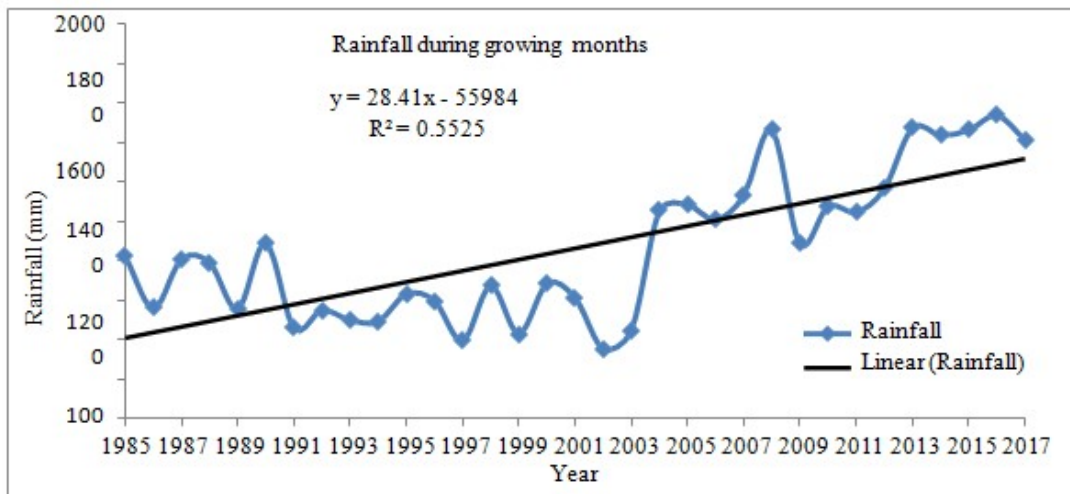
Figure 5. Trends of annual precipitation during rice growing months of Dumkauli, Nawalparasi for 33 years (1985 to2017)

94
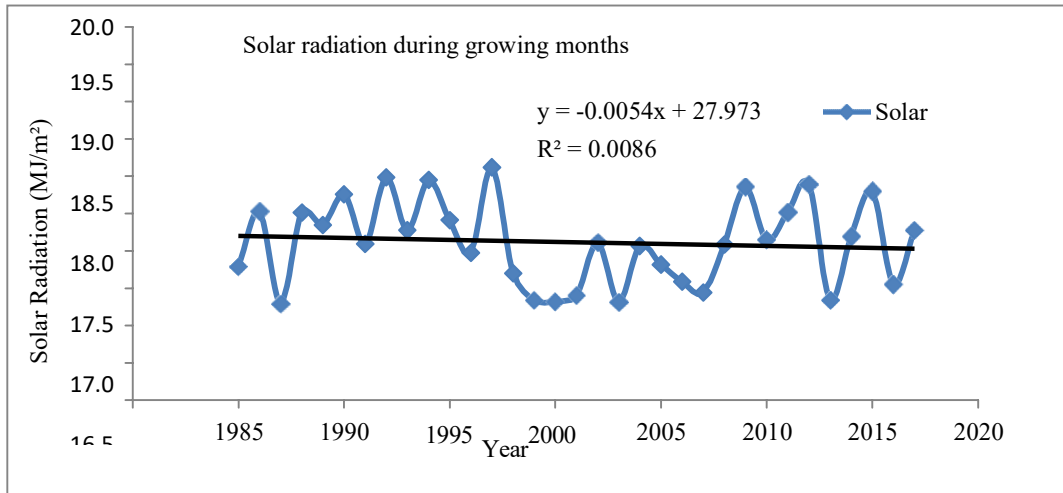
Figure 6. T r e n d s o f a nnual solar radiation during rice growing months of Dumkauli, Nawalparasi of 33 years (1985 to 2017).

Impact of agro-climatic indices on rice yield
*Due to variability in temperature, total rainfall and solar radiation*

The relationships between maximum and minimum temperature and rice observed yields was analyzed and the relationship between rice yield (observed) and temperature (both maximum and minimum) were shown in **Figure** 7. It is well noticed that the effect of rice yield is more dependent in minimum temperature than maximum temperature. Rice yields showed the negative correlation for the maximum temperature. The correlation between the maximum temperature and observed rice yield and was found to be -0.56. That means increase in maximum temperature has large negative impacts on net rice yield. Similarly, correlations between the observed rice yield and minimum temperature also showed negative correlation and was found to be -0.11.

A relationship between rice yield (observed) and rainfall is shown in **Figure** 8. It was well noticed that the effect of rice yield depends on rainfall. Rice yields showed the strong positive correlation for the rainfall. The correlation between the rainfall and observed rice yield was found to be 0.71. That mean increment in rainfall had positive impacts on net rice yield. It was well noticed that the rice yield was depend on solar radiation. Rice yields showed the positive correlation with the solar radiation. The observed yield showed the strong positive correlation. The correlation between the solar radiation and observed rice yield was found to be 0.05. That mean increment in solar radiation had positive impacts on net rice yield and production.
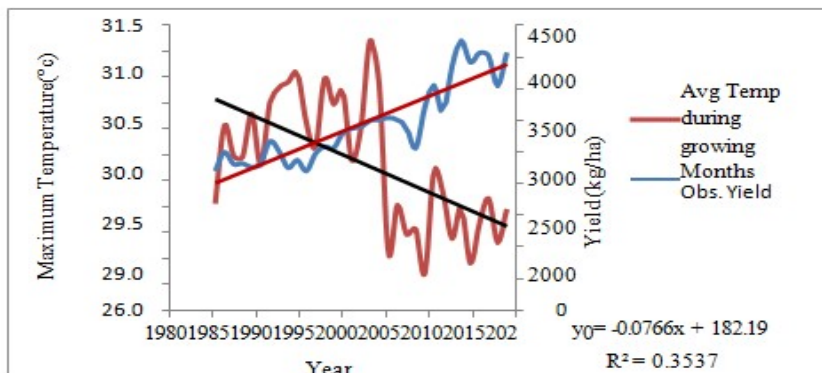
Figure 7. Relation between observed rice yield and maximum temperature during 1980 to 2020 in Dumkauli, Nawalparasi

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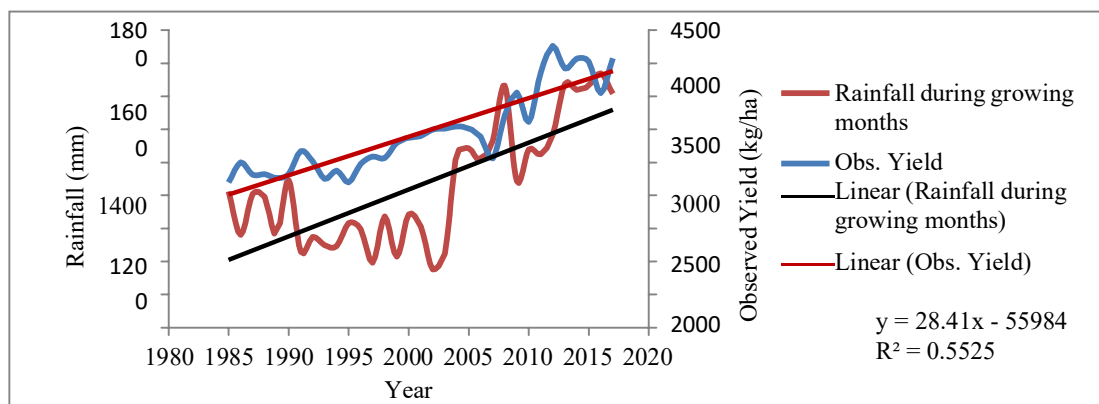
Figure 8. Relation between observed rice yield and rainfall during 1980 to 2020 in Dumkauli, Nawalparasi

Multi-year prediction of rice yield as influenced by changing climatic scenarios (IPCC 2007)

CERES-Rice model was sensitive to various scenarios of climate change parameters (temperature, solar radiation and CO_2 concentrations). Change in maximum and minimum temperatures upto 2°C (+2°C) and CO_2 concentrations upto 420 ppm (+50 ppm) with change in solar radiation (+1MJ m^{-2} day^{-1}) resulted declination in yield of Sukkha-5 (**Table** 1).

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

SN	Max Temp (°C)	Min temp (°C)	CO_2 conc. (ppm)	Solar radiation (MJm^{-2}day^{-1})	Simulated yield (kg ha^{-1})	% yield change
2	+0[a]	+0	370	+0	4999	100
2	+1	+1	370	+0	4081	81
3	+1	+1	+50	+1	3776	75
4	+2	+2	+50	+1	3119	62
5	+3	+3	+100	+1	2980	60
6	+3	+3	+200	+1	2934	59
7	+4	+4	+200	+1	1908	38

Note: a: 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).

The maximum increase in the maximum and minimum temperatures by 4°C along with 100 ppm CO_2 concentration showed the yield increment of 85% and 200 ppm concentration showed the yield decrement at about 41 percent with this cultivar the standard model treatment (without changing the weather parameters). The existing varieties of rice 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 or mitigation strategies over the long-run.

DISCUSSION

The weather data (temperature, precipitation and solar radiation) of 32 years (1985-2017) derived from the NASA-POWER 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 cannot validate it and we used the data derived from (NASA Power). Agro climatic indices such as temperature, precipitation and solar radiation are analyzed by trend analysis. We use annual data as well as the rice growing month 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 in decreasing trend, whereas the minimum temperature was also in decreasing trend. Similarly, the precipitation was in increasing trend and solar radiation was in decreasing. Correlation coefficient and regression analysis is done

individually with the climatic indices (max, min temperature, precipitation and solar radiations). Maximum temperature has negative correlation with the observed rice yield and minimum temperature also had negative correlation. The correlation coefficient of maximum and minimum temperature and rice yield are -0.56 and -0.11, respectively. Similarly, the correlation between rice yield and precipitation along with solar radiation had positive correlation. The correlation between precipitation and observed rice yield were 0.71 and 0.05, respectively. Similar results were also marked by Pariyar et al (2021) when testing rice yield with weather years in Pokhara, Nepal.

For the evaluation of CSM-CERES-Rice model, DSSAT ver 4.7 was used at Dumakuli, Nawalparasi condition. Model calibration was done for rice cultivar named as Sukkha-5. The genetic coefficients for Sukkha-5 were 560 (P1), 160 (P2R), 440 (P5), 12 (P20), 94 (G1), 0.040 (G2), 0.98 (G3), 1.0 (G4). This model was tested and validated (Dhakal 2016) by using the above mentioned genetic coefficients of the respective cultivar. By running sensitivity analysis, the model was found sensitive to weather years and various parameters of climate change. The simulated yield for Sukkha-5 was reduced by 11% in 2005. In the year 1995, Sukkha-5 produced 17% less yield than standard. The model was also sensitive to climate change parameters (temperature, solar radiation and CO_2 concentration). Change in temperature, CO_2 concentration and with change in solar radiation resulted almost decrement in yield of Sukkha-5.

From the various field studies, it could be said that the most important limiting factor for rice production is drought and it is becoming a big and severe problem in many regions of the world. It is also found that the yield trend is positive with respect to rainfall and it is obvious though we are in search of drought resistant cultivar of rice. Cropping Systems model CERES-Rice embedded in Decision Support System for Agro-technology Transform (DSSAT) ver 4.7 model was used to study the multi-year prediction of rice yield over the recorded and simulated climatic scenarios. The data set to run the CSM-CERES-Rice model taken from the well predicted and validated crop model Sukkha-5 cultivar of rice and was well used in Terai condition of sandy-clay loam soil, resembling the production domain of the project sites. The simulation results using DSSAT model over the 30 years of weather data were found to be very closely agreeing with the observed data of the rice yield recorded from the Ministry of Agriculture and Livestock Development in Nepal. The multi-year prediction of the weather years was also done after following IPCC (2007) scenario using environmental modification section of the DSSAT ver 4.7 models. Further, DSSAT version was also used to forecast the yield by filtering /extracting the grid of Lumbini Province in Nepal and result showed that the rice yields for few years can only be sustained by using the present crop varieties and urged for the development of climate change ready crop varieties to feed the increasingly growing population. Similar result was also noticed in Chitwan by Lamsal and Amgain (2010). Agro-climatic indices mainly rainfall was found to be more sensitive for rice production in central Terai including Nawalparasi district, Nepal. 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 Bhusal et al (2009), Singh and Padilla (1995) in the case of yield. Although the R^2 values were generally less than desired, the scattered diagrams showed similar trends and patterns indicating a close relationship between NASA-derived and actual ground measured weather records especially for temperatures and precipitation for the site as earlier mentioned by Timsina et al (2004), Timsina (2011) in Bangladesh. 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.

CONCLUSIONS

The agro-climatic indices bounded huge yield gaps of rice in central Terai regions of Nepal could be empirically quantified by the use of regression and correlation studies and use of trend analysis, and it could also be bridged by the proper use of decision support tools like DSSAT 4.7 version of crop model. 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, it is well established that the average temperature and solar radiation are increasing during summer and decreasing during winter in central Terai and there is positive trend line of average temperature on rice yields. The rainfall data as predicted by NASA-POWER could not find positively correlation with rice crop yield. After looking the

crop yield data of last 32-33 years of rice yield in Nawalparasi district in central Terai of Nepal. The multi-year prediction of agro-climatic factors could fairly forecast the yield and that could be sustained only for few more years. It could also be suggested that we would have to adopt the new climate change resilient rice cultivars after 2040 scenarios of climate change as advocated by IPCC (2007). The extrapolative use of CSM-CERES- Rice 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 models in large agro- ecological areas of Nepal with multi-year seasonal, rotational and spatial analysis.

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