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Research Article

Impact of Climate Change on Sugarcane Productivity in the Southern Part of Nepal Using DSSAT-CANEGRO Model

Ravi Prasad Chaudhary[1], Jawed Alam[2], Mukti Nath Jha[3], Yam Kumar Rai[4], Manoj Kumar Joshi[5], Jagat Bandhu Adhikari[6], Sujan Khadka[7], Anjay Kumar Mishra[8]

[1]Land & Water Engineering, [2,4]Associate Professor, [7]Agricultural Engineer, Department of Agricultural Engineering, IOE Purwanchal Campus, Tribhuvan University, Nepal.
[3]Senoir Technical Officer, [5]Technical Officer, National Agricultural Engineering Research Center, Nepal Agricultural Research Council (NARC), khumaltar, Nepal.
[6]Scientist, National Sugarcane Research Program, Jeetpur-Simra, Bara.
[8]Professor, Kathmandu College of Management, Kathmandu, Nepal.
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I N F O

Corresponding Author:
Mukti Nath Jha, National Agricultural Engineering Research Center, Nepal Agricultural Research Council (NARC), khumaltar, Nepal.
E-mail Id:
muktinath2043@gmail.com
Orcid Id:
https://orcid.org/0000-0003-2577-5147
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A B S T R A C T

The research on impact of climate change in variety specific sugarcane cultivation in southern part of Nepal revealed realistic assessment on forecasting impact of climate change in sugarcane production as well as their successful adaptation strategic for agricultural management and future planning. The objective of this research is to describe climatic sensitivities of sugarcane; assessment on their yield simulation using DSSAT-CANEGRO model of five distinct sugarcane varieties that was cultivated in NSRP; and to calibrate and validate the simulated & observed and adaptation strategic for early, mid and late cultivars; and. The model created four years distinct simulated yields in which datasets was calibrated for consecutive two fiscal years (2018-19 and 2019-20) and validated with consecutive two fiscal years' (2020-21 and 2021-22). The sugarcane varieties (Co 86032, Co 0118, BO 120, CoSe 98255, CoS 08272) showed correlation coefficient of 0.5983, 0.889, 0.8713, and 0.7591. The sensitivity analysis on yield has been simulated with wide range of weather parameters with its values in two stage of sugarcane crop: germination and growth development. The climate modification has been done with DSSAT model as individual as well as combined form with weather parameters Tmin (±1 to ±3˚C), Tmax (±1 to ±3˚C), solar radiation Tmax (±1 to ±3 MJ/m2/day), and default CO2 concentration of 380 ppm to 500 ppm and 720 ppm scenario. The studied disclosed that with decrease in weather parameters value; the simulation yield of sugarcane decreases with decrease in parameters value and with increase in Tmax, Tmin, Solar radiation; the simulated yield increases but very slight effect of CO2 increase in yield except Co-86032 & CoSe-98255 in both stages.

Keywords: DSSAT-CANEGRO, Sugarcane, Climate change, Simulation, Nepal

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Introduction

Sugarcane (Saccharum officinarum) is major contributor, and economically significant globally cultivable high sucrose content crops, making it valuable source of sugar for various industries.[1] The evolution of sugar into nutritious and plentiful plant of today look a long time and is now widely assumed that the natural home of sugarcane, is the Polynesian islands of the south pacific where it is believed to have existed as long as 2000 BC.[2]

FAO (2021) statistic represent the global production of sugar crops increased marginally between 2020 and 2021 and Sugarcane is the primary source of sugar crop, cultivation has been reported to be 26.9 million hectares, with an average yield of 70.9 tons/hectare (t/ha).[3] Global production of the crop is of ~1.9 billion tons, compared 270 million tonnes in 2021 for sugar beet. It is also considered the main source for sugar production and crop for energy production, as well as for byproducts like ethanol and fibers in the world .[4] Sugarcane, the largest crop commodity with respect to total production, is grown in about 100 countries all over the world to meet the sugar needs. The area under cultivation has been reported to be 26.9 million hectares, with an average yield of 70.9 tons/hectare (t/ha). Srivastava and Rai (2012).[5] in his research let out that Sugarcane is a climatic sensitive crop: therefore, its spatial distribution on the globe is restricted as per the suitability of various climatic parameters and in almost nation, it is cultivated in tropical and sub-tropical regions with a plentiful supply of water for a continuous period of more than 6–7 months each year, either from natural rainfall or through irrigation. About 80%of global sugarcane produced from sugarcane are cultivated in 120 countries with approximately 27 million ha and average production is 1.8-2 billion tons per year.[6] According to MoALD (2021) [7], Sugarcane is the 3rd major commercial cash crop cultivated in Nepal and contributing 1.2% AGDP in country's agricultural and economy sector by types of commodities. Also, Nepal ranks 41st in sugarcane production with (2.93 million tons), 35th in harvested area (64,483 ha) and 67th in sugarcane yield (45.4 t/ha) [8]. However, when it comes to commercial production, the focus is primarily on only 14 districts just after the establishment of Morang Sugar Mill Limited in 1947 A.D. The overall production and the area of cultivation of sugarcane have been decreasing gradually since 2015/16 according to the statistical report of MoALD (2022) which shows a huge trade deficit in the sugarcane industry. Moreover, so far out of the 31 industries in existence, only 10 sugar mills are in operation.[8]

Fischer et al. (2005) researched that agriculture is the most vulnerable economic sector through such changes and for the past 30 years' numerous studies have attempted to estimate the effect of changing climate on crop yields and their production.[9] According to climate scientists, Global surface mean temperatures had increased from 0.55 to 0.67°C in the last century and are project to rise from 1.1 to 2.9°C (low emission) or 2.0 to 5.4°C (high emission) by 2100 relative to 1980–1999, depending on GHG emission level, region, and geographic location (Herring). Climatic parameter like temperature causes to reduces global yields of major crops in four independent average estimate studied by found reducing in global yields of sugarcane by 6.0%, rice by 3.2%, maize by 7.4%, and soybean by 3.1%. But,[10] Oliveira et (al.) in their research of sugarcane plants found on at 15°C growing were very slow, with few and short internodes and few leaves.[11] The leaf area per plant increased over time and was highest at 27°C. The leaf area per shoot biomass was constant over time, but twice as high at 15°C as at 45°C and 2.5 higher than at 27°C. Crop simulation models have been a key tool in assessing the effect of future climate change [12] and many agricultural risks of future climate change assessments have been carried out using crop models for specific locations, agricultural regions.[13] Global agricultural scientists in 18 countries measured the potential changes in crop growth and water use using compatible crop models and consistent climate change scenarios.[14] DSSAT has been in used globally by more than 25,000 researchers, educators, consultants, extension agents, growers, and policy and decision makers in 187 countries worldwide over 30 years for study the potential climate forecast, addressing real world problems and issues for improving on-farm and precision management, regional assessment of considering weather, genetics, soil and crop management practices.[15]

Singels et al.(2010) in research report of the DSSAT CANEGRO is a key model in decision support tool for research and management of sugarcane production and many climate change,[16] described model main features and its accuracy of simulating biomass, cane and sucrose yields globally, and enlighten the potential applications in sugarcane research and management. Over 42 crops simulation can be comprises with the Decision Support System for Agro-technology Transfer (DSSAT) software application program (as of Version 4.8.2) as well as tools to facilitate effective use of the models.[15] Pandey et al. (2020) in their research found that Nepalese sugarcane production contributes less than 1% among SAARC countries and ranks 41st position among global sugarcane production status.[17] The growth rate of sugar cane production in Nepal has been impressive, with an average annual rate of 6.11%. This indicates the increasing importance of sugar cane cultivation in the country's agricultural landscape. In 2021, sugar cane production for Nepal was 3.18 million tons. Sugar cane production of Nepal increased from 244,820 tons in 1972 to 3.18 million tons in 2021 growing at an average annual rate of 6.11%.

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Study Area

The experimental site for the research activities was carried out at the National Sugarcane Research Program, Jeetpur-simra sub-metropolitan city in Bara district which is located in 27°06’88” N latitude and 84°57’07” E longitude as shown in Figure 1 The topographic region variation ranges from 80 to 95 m, and climate is hot & humid in summer season and cool in winter. Research center extended to 20 hectares but only 14 hectares was cropping areas performed for sugarcane cultivation, that is located in Southern part of Nepal, Madhesh province; about 9,661 square kilometer having 574,360 hectares (17.75%) of cultivable sugarcane land despite having 6.5% of total agriculture of Nepal (joshi). The southern part has fertile agricultural plain land which is known as Terai. Madhesh province lies between coordinates approximately (26-27) °N and (84-87) °E and the region has low-lying areas in the south with elevations less than 100 m.

Chaudhary and Subedi (2019) in their research “Chure-Tarai Madhesh Landscape, Nepal From Biodiversity Research Perspective” revealed that South part of Nepal has limited water resources due to vast water systems that drain south into India and it has mean annual precipitation of the region varies from 1400-2000 millimeter (mm) [18]. other climatic parameters as average maximum temperature is found to be between (28.20 – 31.8) 0C and the average minimum between (15.8 – 20.4) ºC. About 80% of the country’s 28 million inhabitants (2019) live in rural areas. Small-scale, subsistence agriculture is a mainstay of Nepal’s economy, employing 69% of the country’s workforce in 2015. Despite this, agriculture contributed only 25% (Worldbank) to GDP in 2019, compared to a 60% contribution from the service sector. Nepal’s varied topography and social vulnerability make the country particularly susceptible to geological and climate-related disaster.[19]

Sugarcane cultivation Status in Nepalese Agriculture

Agriculture is the major sector of Nepalese economy [7]. It provides employment opportunities to approximately 66 percent of the total population and it contributes about 23.9 percent in the GDP of FY 2020/21 [20]. According to statistical information on Nepalese Agriculture (2020/2021), Nepal has cultivated land 3091,000 hectares in which 62,567 ha is cultivated with sugarcane and 1.2% contribution in agricultural commodities on agriculture GDP in FY 2022/23. The major cash crops cultivated areas with their production of last three years are presented in Table 1.

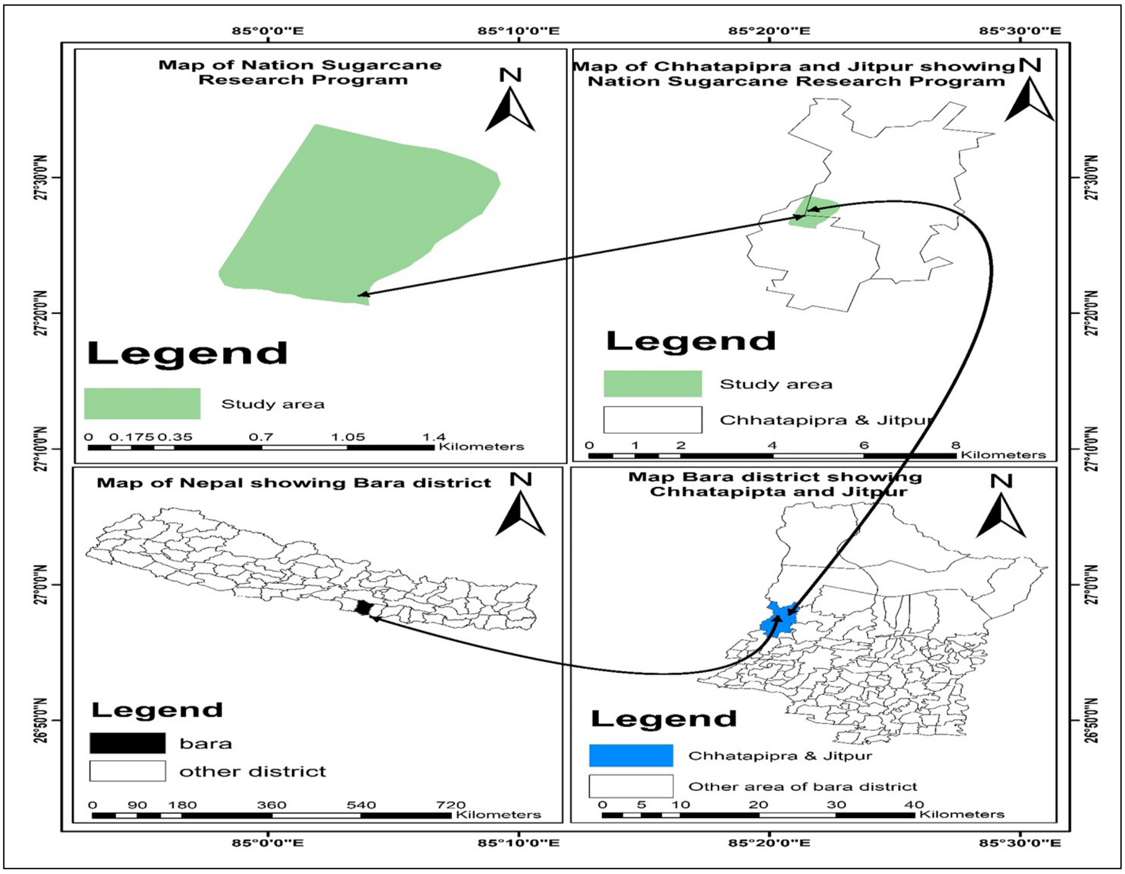

Figure1.Study Area: Bara District, Madhesh Province

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Table 1.Major cash crops production with areas for 3 consecutive years

Crops	2018/19		2019/20		2020/21	
	Area	Production	Area	Production	Area	Production
Oilseeds	260,307	280,530	258,141	278,325	259,101	287,038
Potato	193,997	3,112,947	188,098	3,131,830	198,788	3,325,231
Sugarcane	71,625	3,557,934	68,565	3,400,176	64,354	3,183,943
Jute	7,285	10,585	7,555	10,165	7,415	10,451
Cotton	97	99	135	140	142	147

Here Area in Hectare, Production in MT.

The table of major cash crops shows that lead contribution in Nepalese agriculture is oilseeds with average 259,183 ha in areas and 281,964 MT. The 3rd major cash crop as sugarcane cultivation as in area with average 68,181 ha in decreasing way with average producing 3,380,864 MT throughout the country.

Material & Experimental Methods

The overall research methodology framework of the study is presented in flow diagram as shown in figure 2 As presented in figure, methodology flowchart is sectioned into academics and model experiment steps each having three components i.e. identification of problems, to be review literature to set objective & field experiment, crop model and analysis of adaptation measure respectively. The second steps of component for field experiments were conducted in National sugarcane research program on five distinct variety of sugarcane during four consecutive years. The DSSAT-CANEGRO model was used in yield simulation with five cultivar treatments. Climate change scenarios were implemented in the DSSAT model, and outcomes were analyzed to compare climate change impacts. The research considered the historical data from (1991 - 2020), experimental period (2018 - 2021) climatic data to assess the baseline crop yield, calibration and validation of the model and future (2020 - 2039 and 2040 - 2059) climatic data is used for sugarcane yield prediction. Sugarcane yields in future was estimated for both RCP 4.5 and RCP 8.5 scenarios for the period 2020- 2039 and 2040-2059. In the last component, scenarios were run by changing the sowing date to analyze early, mid & late planting impact on yield.

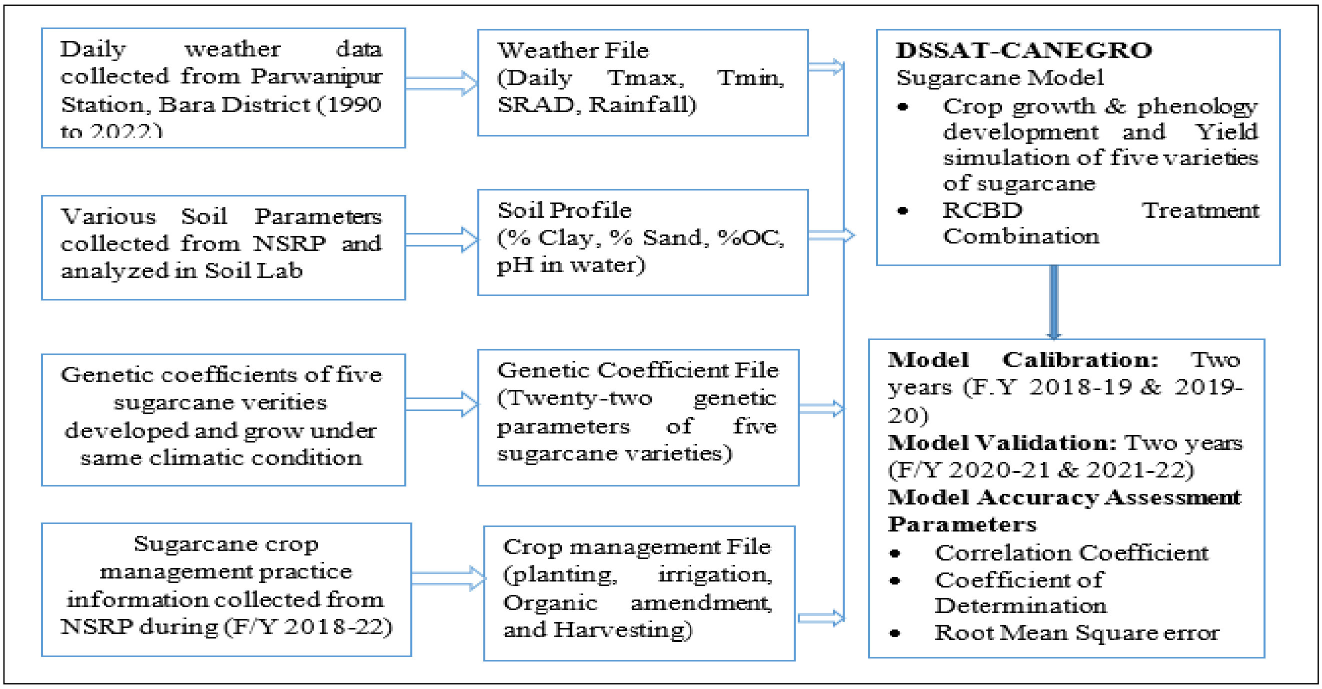

Figure 2.Flowchart for identification of problems, review literature to set objective & field experiment, crop model and analysis of adaptation measure respectively

Source: (Verma et al. 2023) [21]

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The DSSAT-CANEGRO Model

The DSSAT-CANEGRO model where modified to modular structure which link plant growth dynamics to the other modules in the DSSAT CSM during its development. Jones and Singels (2018) concluded that the model interface variables are specifically designed to link modules that describe growth, development stages and yield for individual's sugarcane varieties. For Crop simulation large numbers of data and information related to field to be organized in proper ways in relevant modules i.e. S Build, X Build are incorporated.[22]

Soil Profile Data

Soil data (SBuild.exe) file is an essential tool for creating and modifying soil profile properties required to simulate crops in DSSAT. SBuild can be used to edit or add profiles via a user-selected soil file (Soil. Sol or *.sol), which contains data on the soil profile properties. These files include soil depth information, pH water, Organic contents, nitrogen, phosphorus and root sections etc. of the crop models. The soil samples collected from experimental field is computed in laboratory with vertical profile soil of top to bottom (0-20,21-40, 41-60, 61-80, 81-100, and 101-120 cm). the soil depth containing soil parameters is as shown in Table 2. The overall soil particle determines the soil texture of experimental field.

Weather Data (Weatherman)

WeatherMan is a user-oriented tool for importing, analyzing, and exporting daily weather data for use in crop simulation modeling and other activities. Daily weather data from Parwanipur weather station (0911) in 27.07894N & 84.9327E provide maximum temperature(˚C), minimum temperature(˚C), solar radiation(MJ/m2/day) and rainfall (mm) for 32 years' data since 1990 to 2022(AD). The data commonly used as input to mathematical in simulation models of agricultural or ecological systems may or may not be complete, contains errors, and are often in an inconvenient format. Even though the data assumed to be complete, reliable raw data from weather station.[23]

The daily weather files(WTR.DIR) with any column format (including the DSSAT v4.8 files) and convert the data to desirable units. Data are checked and flagged for possible errors on import. The WeatherMan program is designed to simplify or automate many of the repetitive tasks associated with preparing raw weather data for use by a crop model and can also be used to provide quantitative analysis of weather data. WeatherMan has the ability to check for errors on import, and fill in missing or suspicious values on export and can also generate complete sets of weather data comprising solar radiation, maximum and minimum temperature, rainfall, and photo synthetically active radiation.

Crop Management Data

Crop simulation models rely on large amounts of data and information. The crop management data (XBuild.exe) is one of them which was designed to provide more effective tools to access all of the functionality of crop model. The XBuild is developer tool for creating a new FILEX which is simple in structure that simply leads by the users to fill the required fields on the screen and then save to the file. Smith et al.(2023) after use revealed that XBuild program provides a menu-driven interface for describing experiments in terms of fields, soil analysis, treatments, environments (soil and weather), crop management and simulation options as necessary input data and alert for incorrect entries [24]. Users allows to specify any combination of management options for simulation of several crops for purpose of validation (comparison with observed data), seasonal analysis, crop rotations, and spatial analysis that are available in DSSAT. XBuild allows users to select the options from the interface of the DSSAT folder structure, which designates the locations of all programs and data files used in DSSAT.

Experimental file

Creating Experimental File(FileX) referred to as FILEX, documents the inputs to the models for each "experiment" to be simulated. The file contains details of experimental (field characteristics, soil analysis, initial soil water and inorganic nitrogen conditions, seedbed preparation and planting geometrics, irrigation and water management, fertilizer management, organic residue application, chemical applications, tillage operation, environment modifications, harvest management, simulation controls and treatment combination). In our research, treatment was conducted on varieties specific sugarcane. To accommodate the different possibilities, the minimum required information for the simulation is Planting details such as Cultivar, their emergence days, plants heights, No. of tillers, their yields to simulation model (Table 3).

Table 2.Soil Parameters showing different parameters

Depth (cm)	Clay (%)	Silt (%)	Saturate Water content	Organic Carbons (%)	pH in Water	Bulk Density (g/cm2)	Hydraulic Conduct (cm/hr.)	Root growth factor (0-1)
0-20	12	52.1	0.556	1.0	6	1.4	1.62	0.99
21-40	25.4	41.8	0.471	0.85	6.9	1.42	1.32	0.95

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41-60	28.8	39.7	0.461	0.65	6.9	1.43	0.63	0.54
61-80	29.3	38.9	0.455	0.46	6.9	1.45	0.25	0.44
81-100	28.8	38.6	0.452	0.41	7	1.45	0.23	0.24
101-120	28.6	38.6	0.421	0.37	7	1.55	0.23	0.11

Table 3.Experimental Data for 5 Sugarcane Varieties

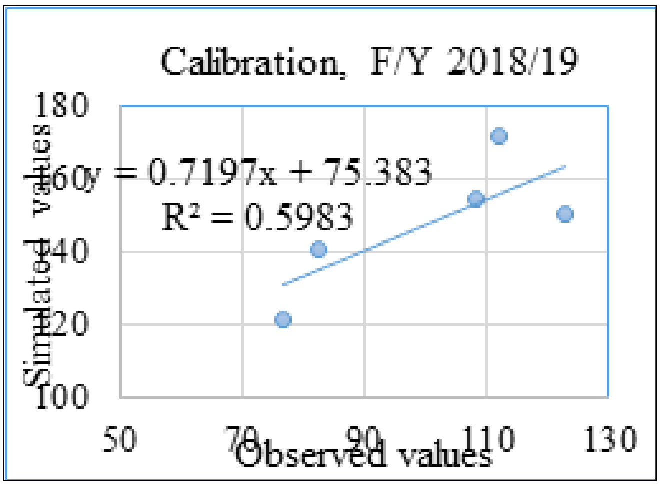
Treatment	Emergence (Days)	Harvest (Days)	Canopy height (m)	Tillers no.at maturity	Fresh cane yield(t/ha)
CoS-86032	25	330	3.38	7.4	125.93
BO-110	42	360	2.54	13.11	76.19
Co-92270	28	320	2.68	9.92	69.82
CoS-08279	25	295	2.45	9.62	90.44
CoP-2061	35	360	2.69	11.55	122.96

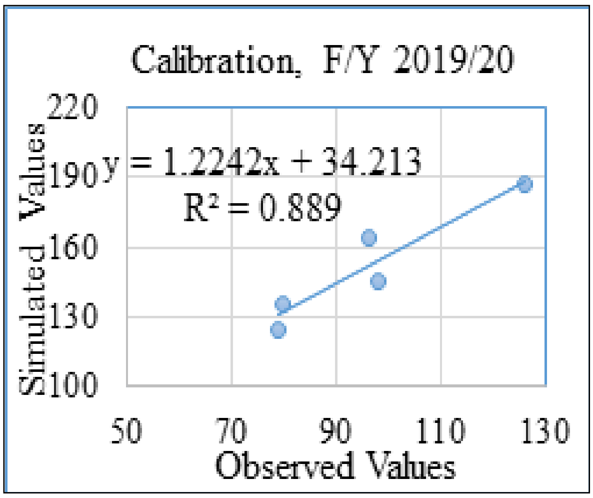
Result

The research study analyzed the climate change scenarios and management practices of sugarcane crop cultivation using DSSAT-CANEGRO Model in National Sugarcane Research Program, Bara district, Southern region of Nepal. The germination, growth and development stage of Sugarcane crop was simulated using CANEGRO model during autumn season with different varieties. Field observations were done in NSRP from 2018-2022 AD and analyzed to obtain the morphological parameters. The response of the crop in different irrigation intervals dates and fertilizer application rates were noted. In this research, the results describe how climate variables will impact the crop production and yield in the future.

Calibration & Validation of DSSAT-CANEGRO V4.8 Model

To calibrate model, two F/Y 2018/19 & F/Y 2019/20 field performed with sugarcane cultivation in National Sugarcane research program, jeetpur-simra. The growth, development & yield is recorded for each varieties of sugarcane and studied with yield simulation to fix genetic coefficients of cultivars. Thereafter, the model is run for two years of F/Y 2020/21 & F/Y 2021/22 in actual field crop management, soil, weather condition, & genetic coefficient values. To validate the performance of model, the first step is to compare the simulated yield developed by the DSSAT-CANEGRO model with the field observed yield obtained from different sugarcane variety. The simulated fresh cane yield may be less, more or equal to observed yield of each variety; are studied comparatively and plotted with scatted plot area graph as shown figure 3 below to measure the R2 for assessment accuracy. The R2 value for calibration are R2=0.598 & R2=0.8879 similarly R2 values for validation are 0.871 & 0.759.





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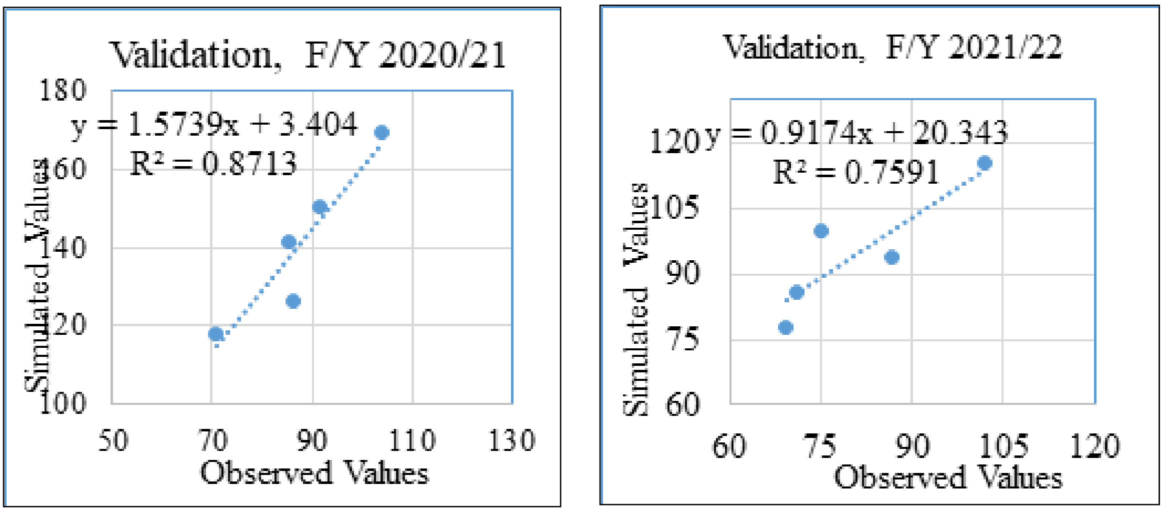


Figure 3.Calibration & Validation of DSSAT-CANEGRO V4.8 Model

3- Callibration and Validation Result which is acceptable value of R2 according to research paper entitled Calibration and validation study of sugarcane (DSSAT CANEGRO v4.6) model over north Indian region accept R2 in range of 0.57 to 0.77 is accepted.[25]

Model Accuracy Assessment

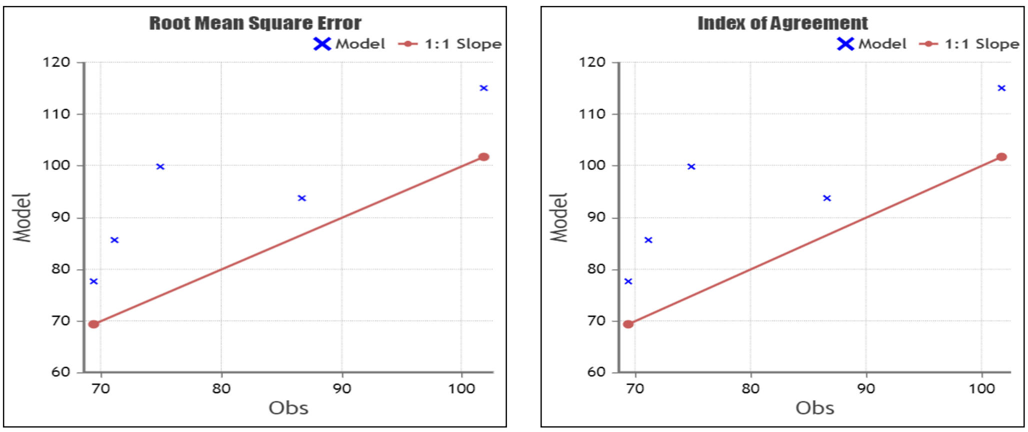
The model accuracy in the performance and precision assessment for DSSAT-CANEGRO model, we obtained different statistical indicators (figure 4), such as coefficient of determinant (R2), Pearson's correlation coefficient(R), Willmott index of agreement(D), Root mean square error (RMSE), Mean absolute percent error (MAPE), and Normalized root mean square error (nRMSE) and Mean bias error (MBE) are used for the accuracy assessment of model results. and above mentioned statistical parameters (D, R, R2, RMSE, MAPE, nRMSE and BME) few are calculated and presented in Table 4.

Sensitivity Analysis with Weather Parameters in Germination Stage

The climate change scenario simulated for maximum temperature (±1 to ±3 ˚C), minimum temperature (±1 to ±3˚C), solar radiation (±1 to ±3MJ/m2/day), and (500ppm, 720 ppm) against present CO2 concentration of default 380 ppm. The table on specific variety sugarcane simulated effect with climate change as an individual as well as their combined parameters of climate are according to complexity of climate pattern are in Table 4.

Table 4.Statistical Indicators of Accuracy Assessment Parameters

F/Y	R^2	R	RMSE	nRMSE	MAPE (%)
2018/19	0.598	0.773	48.612	0.484	49.3
2019/20	0.889	0.943	56.31	0.588	59.19
2020/21	0.8713	0.933	54.36	0.621	61.4
2021/22	0.759	0.871	15.072	0.187	17.4



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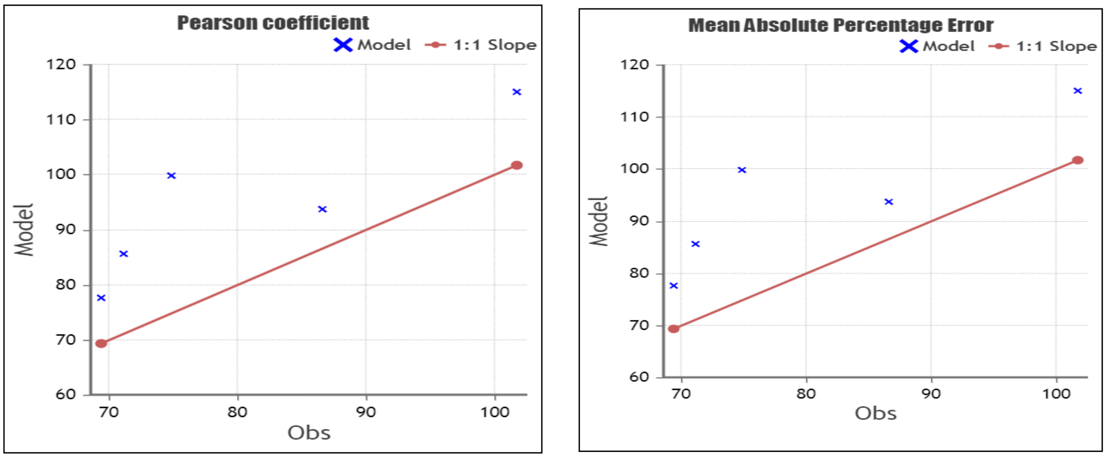

Figure 4.Sensivity Analysis

Effect of Tmax on Yield

The DSSAT CANEGRO model was simulated during germination stage (0-45days) after 17 days of planting stage under incremental values of climatic change pattern Tmax in range of (±1 to ±3) whose outcome shows gradual decrement in yield 109.90 to 108.8 t/ha from base value of 111.70 t/ha (-2.60 to -1.61 % of base yield) for Co-86032. But we observed opposite response to other varieties, either increment or decrement to certain range in Tmax simulated yield increases. For variety Co-0118, the yield slightly increases in the range of (0.97-1.95) %, for BO-120 (0.13-1.04%) of the base simulated yield. Similarly, for variety CoSe-98255 and CoS-08272, the yield gradual decreasing with decrease in Tmax in the range of (-1 to -3) ˚C up to 2.94%, we have noticed an incremental pattern in simulated yield to 1.57% for CoSe 98255 and to 1.71% in CoS-08272.Thus, the results in germination stage is more sensitive to support to increase in yield to maximum variety except Co-86032 (Fig 5).

Effect of Tmin on Yield

The increase in the range of (+1 to +3 ˚C) shows same gradual increment in the yield range 2.07% for Co-0118, 1.04% for BO-120, 1.37% for CoSe-98255 and 1.61% for CoSe-08272% from base yield except Co-86032 which showed nearly constant in even with increase Tmin. We have also noticed that with decrease in range (-1 to -3) ˚C, the yield decreases to base yield for Co-86032 i.e. 82.1 t/ha, small decrement to BO-120 i.e. 0.78% and 1.47% in -1 ˚C, 2.94 in 2˚C and 5.09% in 3 ˚C which shows huge decrease for CoSe-98255 variety sugarcane. Similar decrement characteristic in yield for CoS-08272 that ranges to 0%,0.96% and 2.25% respectively. Here, the obtained data conclude CoSe-98255 variety sugarcane as more sensitive to Tmin (figure 6).

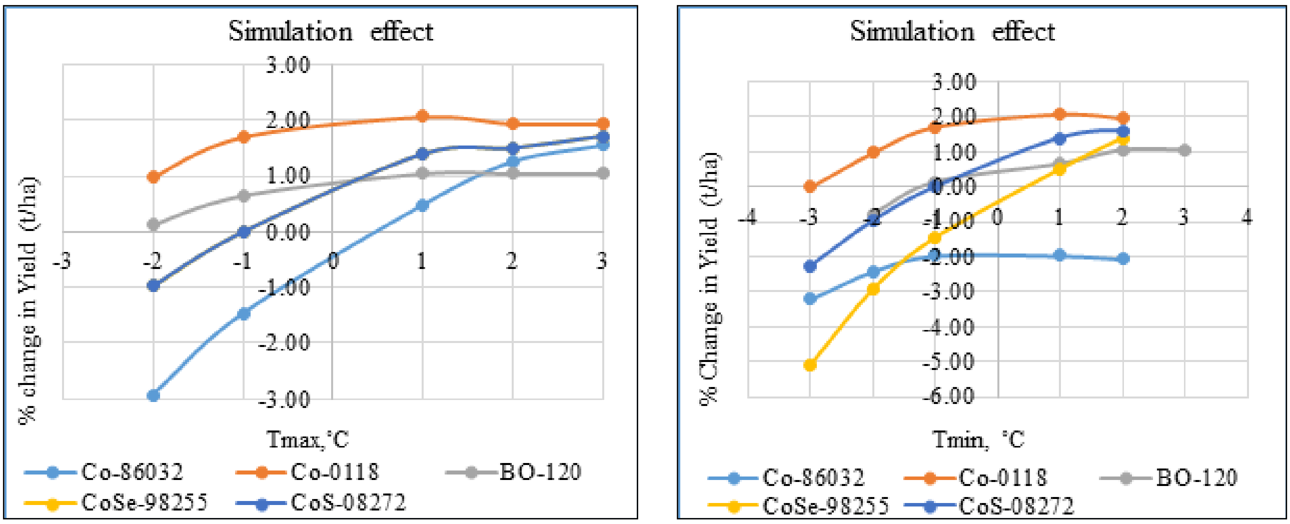

Figure 5.Simulation Effect of Tmax on yield

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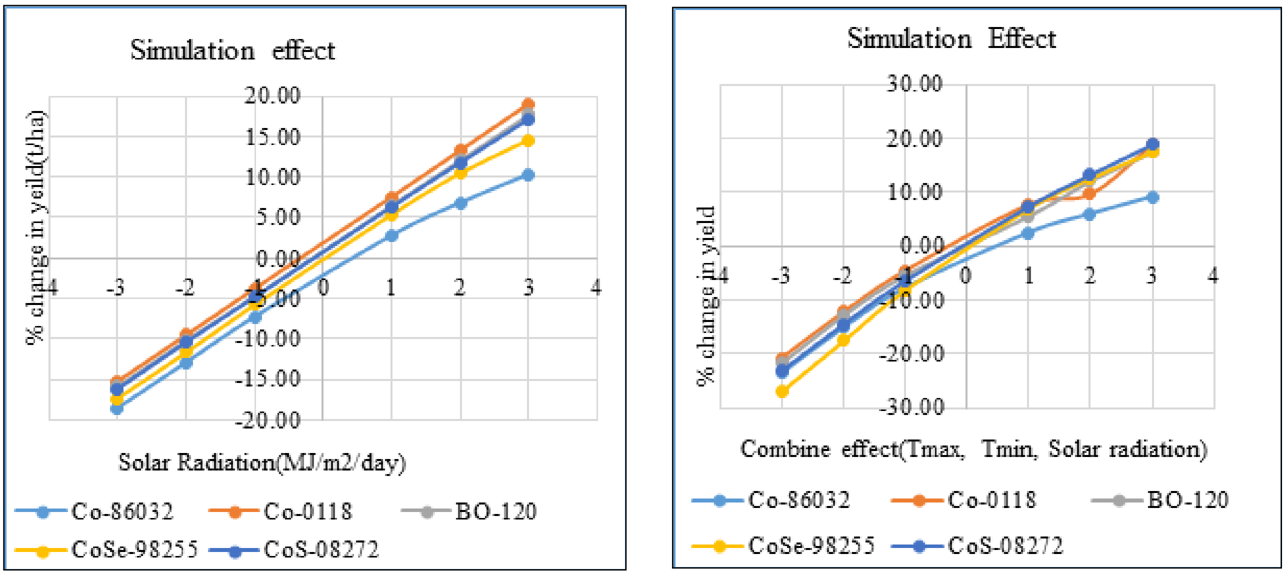

Figure 6.Simulation Effect of Tmin on yield

Effect Solar Radiation on Yield

All variety showed positive increment sign to solar radiation on increasing from 1 to 3 MJ/m2/day. For Co-86032 showed a yield increment (+2.78%, 6.80% and 10.30% from base yield), (+7.55%, 13.28% and 19% for Co-0118), (6.52%, 12.13% and 17.73% for BO-120), (+5.39%, 10.48% and 14.59% for CoSe-98255) and (6.32%, 11.78% and 17.13% for CoS-08272) respectively. Also with decrease in values of climate parameters from (-1 to -3) MJ/m2/day reverse trend was noticed. The decreased in yield is up to -18.53% for Co-86032, -15.23% for Co-0118, -15.91% for BO-120, 17.34% for CoSe-98255 and -16.16% for CoS-08272 from base yield value. The maximum increment in yield was reported +19% for Co-0118 whereas as the maximum reduction in yield was -18.53% for variety Co-86032 from base yield at ±3MJ/m2/day. The results indicate that all sugarcane varieties are directly proportional sensitivity to solar radiation effect, but Among these Co-0118 is more sensible than others.

Effect of CO2 Concentration

Many research studies result unexpected increases in sugarcane (C4) yields under elevated CO2, but CO2 effect on yield was not significant after the variance analysis was confined to yields on two earlier harvests sugarcane [26]. The effect on increasing co2 concentration level from default 380ppm value to 500ppm and 720ppm in CANEGRO model simulation showed -1.61% and -1.70% decrease in yield for Co-86032 and -0.20% for CoSe-98255 variety whereas constant increase of +1.71% increase in yield for Co-0118, +0.91% for BO-120 and +0.75% for CoS-08272. Thus, there is slight effect on increasing CO2 concentration level on these variety of sugarcane mentioned above.

Combine Effect of Tmax and Tmin

Both Tmax and Tmin temperatures during cropping period are changed in the range of (±1 to ±3) ˚C to all variety of sugarcane and theirs simulated yield are compared with base yield. The CANEGRO model on increasing both parameters to same level CoSe-98255 was noticed +2.94% increase in yield followed by +2.56%, +2.25%, +0.39% for Co-0118, CoS-08272 and BO-120 respectively whereas Co-86032 showed reverse result to -2.69% yield. Similarly, on decreasing combine parameters result significant decrease trend to all variety. CoSe-98255 indicates the most sensitive with result -12.05% decrease in yield from base yield. The other variety of sugarcane obtained as -9.74%, -7.52%, -7.04% reduction in yield by -3˚C decrease in Tmax and Tmin for CoS-08272, Co-86032, BO-120 and CO-0118 respectively.

Combine Effect of Tmax, Tmin, And Solar Radiation on Yield

Maximum (Tmax), minimum temperature (Tmin) and solar radiation are inserted simultaneously in the range of (±1 to ±3) values and their simulated yield is studied with base yield as shown above table 5. On increasing these parameters approximate twice time yield with each increase in Parameter. The increment is directly proportional to all variety though the most sensitive cultivar CO-0118 yield, was simulated with +18.76%. The variety CoSe-08272, CoSe-98255, BO-120 and Co-86032 followed accordingly to +18.74%, 17.47%, 17.43% and +9.04% respectively. Also with reducing the parameters, the maximum reduction was observed at -3 value. The yield is reduced by -27.03% for CoS-98255, is most sensitive variety and all other variety reduced by -23.55% for Co-86032, -23.23% for CoS-08272, -21.77% for BO-120 and the least by -20.83% for Co-0118 of the base yield. The yield is drastically decreasing at -2 and -3 values.

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Table 5.Simulated Yield Result

Tmax(˚C), Tmin(˚C) and Solar radiation(MJ/m2/day)										
-	Co-86032	-	Co-0118	-	BO-120	-	CoSe-98255	-	CoS-08272	-
Para-Meters	Simulated (t/ha)	% change	Simulated (t/ha)	% change	Simulated (t/ha)	% change	Simulated (t/ha)	% change	Simulated (t/ha)	% change
3	121.8	9.04	97.5	18.76	90.1	17.47	119.9	17.43	110.9	18.74
2	118.3	5.91	90	9.62	86	12.13	115	12.63	105.7	13.17
1	114.4	2.42	88.4	7.67	81	5.61	109.2	6.95	100.2	7.28
-1	103	-7.79	78.3	-4.63	72.5	-5.48	93.7	-8.23	87.3	-6.53
-2	94.8	-15.13	72	-12.30	66.8	-12.91	84.1	-17.63	79.8	-14.56
-3	85.4	-23.55	65	-20.83	60	-21.77	74.5	-27.03	71.7	-23.23

Sensitivity Analysis with weather parameters in Growth Development Stage

Climate change effect on yield in growth development stage

The climate change scenario simulated for maximum temperature (±1 to ±3 ˚C), minimum temperature (±1 to ±3˚C), solar radiation (±1 to ±3MJ/m2/day), and (500ppm, 720 ppm) against present CO_2 concentration of default 380 ppm. The table 6 on specific variety sugarcane simulated effect with climate change as an individual as well as their combined parameters of climate are according to complexity of climate pattern.

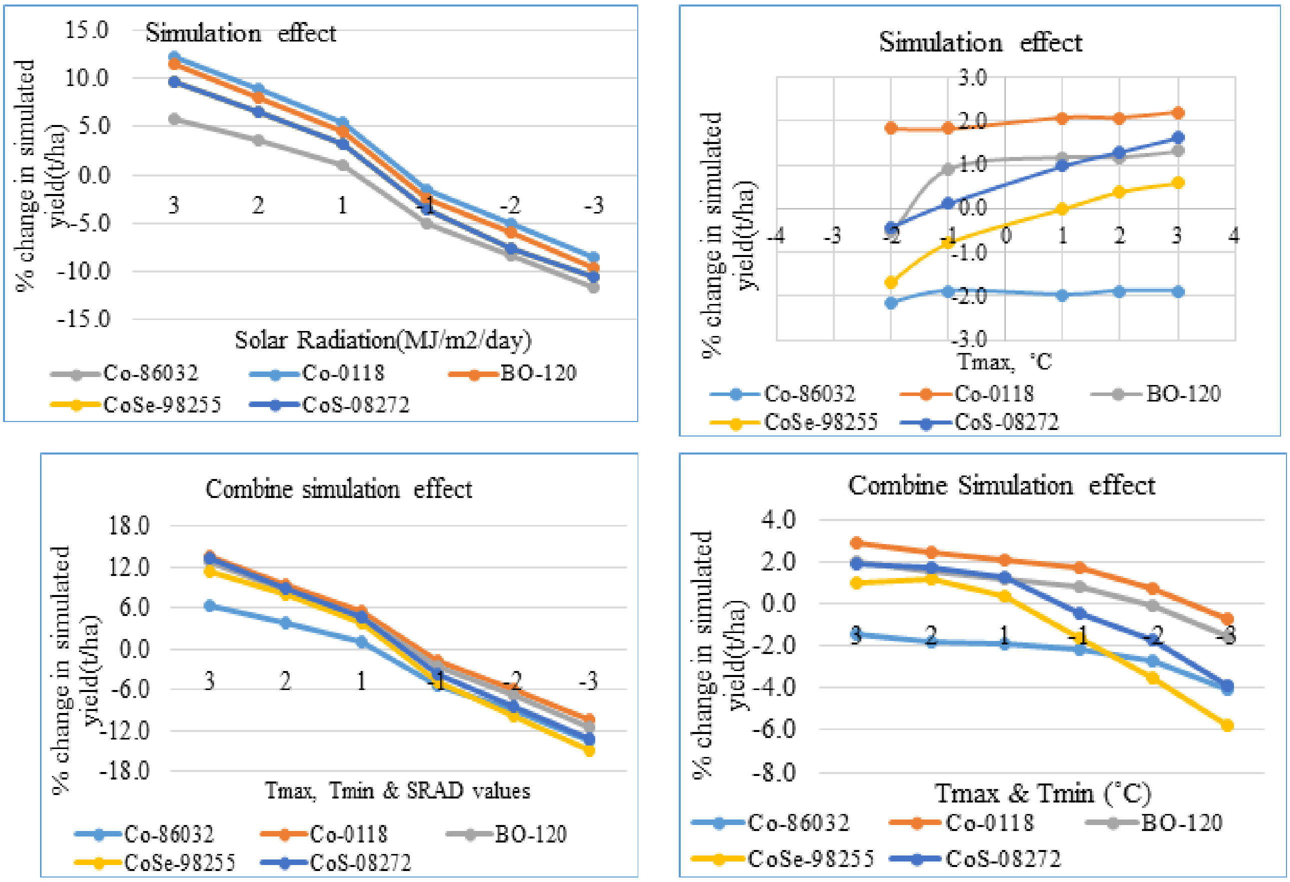

Figure 7.Climate Change Impact

Table 6.Impact of change in Max.Temp,Min.Temp and Solar Radiation

Tmax(˚C), Tmin(˚C) and Solar radiation (MJ/m2/day)										
Co-86032				Co-0118	BO-120		CoSe-98255		CoS-08272	
S.Y (t/ ha)	111.7		82.1		76.7		102.1		93.4	
Parame- ters	S.Y (t/ha	% change	S.Y (t/ ha)	% change	S.Y (t/ha)	% Change	S.Y (t/ha)	% change	S.Y (t/ha)	% change
+3	118.8	6.36	93.2	13.52	86.4	12.65	113.8	11.46	105.7	13.17
+2	115.8	3.67	89.8	9.38	83.2	8.47	110.2	7.93	101.7	8.89
+1	112.8	0.98	86.7	5.60	80.3	4.69	106.1	3.92	97.8	4.71
-1	105.8	-5.28	80.7	-1.71	74.6	-2.74	97.2	-4.80	89.8	-3.85
-2	101.6	-9.04	77.3	-5.85	71.5	-6.78	92.1	-9.79	85.6	-8.35
-3	96.8	-13.34	73.5	-10.48	67.9	-11.47	86.8	-14.99	81	-13.28

Evaluation of Agronomic Adaptation Measures

Effect on simulation yields with shifting planting date of sugarcane

The table 6 presented below shows the variation on yield with shifting planting to harvesting date of distinct cultivar and it is found that planting 15 days earlier than field observed i.e., shifting planting date from mid Nov to Nov; there will both increase & decrease in simulation yield for certain cultivar. Co-0118 and CoS-08272 increased their simulation yield by 1.22% & 5.67% while Co-86032, Bo-120 & CoSe-98255 decreased about 1.5% as shown in figure 7. On 15 days late planting from mid Nov to early Dec., similar behavior was found. To check more, on shifting both early and late of 30 days, all varieties showed increase in simulation yield as more sunshine hours may enhance in simulation yields (Table 7).

Again on 45 days early planting; there is drastically decrease in simulation yields in all cultivar's. With this values, we could conclude early, mid and late variety of sugarcanes and best management practice of sugarcane cultivation. In our research, Mid Oct. is best time for planting the sugarcane.

Figure 8 Relationship between simulated yield and planting dates (15,30 & 45 Days for future under 4.5& 8.5 RCP scenario)

For calibration in F/Y 2018/19 and 2019/20, the R2 is 0.598 and 0.889 for different sugarcane cultivars. Similarly, R2 values were found for the financial year 2020/21 as 0.871, and 0.759 for 2021/22 during validation. Pearson's Correlation coefficient (R) represents the relationship between two quantitative variables and the values varies from − 1 to + 1, is a measure of the degree of model prediction error. In this study, R values between simulated and observed sugarcane yield were found as 0.773 (F/Y 2018/19), 0.943 (2019/20), 0.933(2020/21) and as 0.871 (2021/22) for different variety. Further, the performance of the models was also evaluated by statistical parameters RMSE, nRMSE and MAPE.

RMSE and nRMSE is the square root of the variance of the residuals that indicates the absolute fit of the model to the data how close the observed data points are to the model's simulated values. The calculation is obtained using agricultural and metrological software online by inserting yearly simulated and observed yield in distinguish financial year, RMSE value was found to be 48.612, 56.31, 54.36 and 15.07, also nRMSE as 0.484, 0.588, 0.621 and 0.187 from F/Y 2018/19 and so on respectively. The Mean absolute percentage error (MAPE) is one of the most commonly used KPIs (key performance indicator) to measure forecast accuracy.

It is the sum of the individual absolute errors divided by the demand (each period separately) that measures the deviation (in terms of %) from the actual data. In this study, very low MAPE values 17.4% was observed in F/Y 2021/22. The ranges values between 49.3 % for 2018/19, 59.1% for 2019/20, and 61.4% for 2020/21.

CANEGRO simulated variety-wise sugarcane yield of distinguish financial year was carried out for National Sugarcane Research Program Jeetpur-Simra. In 2020/19 and 2020/21 the simulation yield was found to be relatively good accuracy, representing the highest R (0.943, 0.933) and R2 (0.871, 0.889). The sugarcane yield simulation in 2020/21 was found to be lowest errors (RMSE = 15.072% and MAPE = 17.4 %), as compared to the other financial year. The recommendations should be incorporated in agriculture act from Mishra, A.K. Nepal, A., & Aithal, P.S.,2022: Chaudhary KK, Mishra AK,2021: Mishra SK, Shrestha S, Jha SK. et al.,2023: Mishra S, Shrestha S, Mishra A, Jha M, Joshi M, C B, Chaudhary D, Sahani S.,2023 and Mishra, 2024 also.[27-31]

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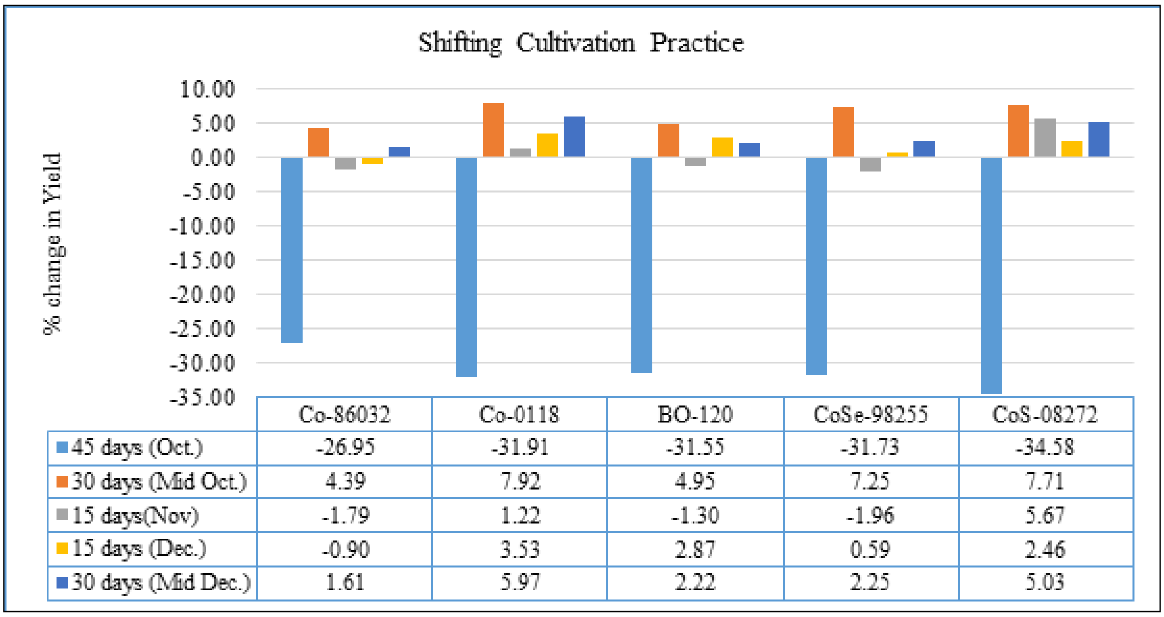
Table 7.Estimation simulated yield (t/ha) change for baseline with 15, 30 & 45 days early/late planting through DSSAT model simulation

Cultivars	Early plant			Field observed	Late Planting	
	45 days (Oct.)	30 days (Mid Oct.)	15days (Nov)	(Mid Nov)	15 days (Dec.)	30 days (Mid Dec.)
Co-86032	81.6	116.6	109.7	111.7	110.7	113.5
Co-0118	55.9	88.6	83.1	82.1	85	87
BO-120	52.5	80.5	75.7	76.7	78.9	78.4
CoSe-98255	69.7	109.5	100.1	102.1	102.7	104.4
CoS-08272	61.1	100.6	98.7	93.4	95.7	98.1



	Co-86032	Co-0118	BO-120	CoSe-98255	CoS-08272
45 days (Oct.)	-26.95	-31.91	-31.55	-31.73	-34.58
30 days (Mid Oct.)	4.39	7.92	4.95	7.25	7.71
15 days(Nov)	-1.79	1.22	-1.30	-1.96	5.67
15 days (Dec.)	-0.90	3.53	2.87	0.59	2.46
30 days (Mid Dec.)	1.61	5.97	2.22	2.25	5.03

Figure 8.Shifting Cultivation Practices

Conclusion & Recommendation

The research study investigated the future climate effect on sugarcane crop cultivation and identification of possible adaptation measure using these experimental observations which was carried out in National sugarcane research program jeetpur-simra, located southern part of Nepal. DSSAT- CANEGRO model was able to simulate the distinct cultivar of sugarcane yield under 9 different irrigation intervals and crop management practices. The model was successfully calibrated and validated the simulated yields to field observed yields for past years from 2018 to 2022 under distinct yearly weather file and soil file. Climatic, environmental, and genetic factors affect the yield of sugarcane crop as well as their management practices that are followed in the field. Further, possible adaptation measure on sugarcane cultivation was done for better future yield and to differentiate the early, mid as well as late variety of sugarcane and their future yields were uncertain with the change in climate variables that were expected to happen. Hence, this research was undertaken to understand the effects of climate change in sugarcane cultivar and management practices on sugarcane yield along with the expected changes in the future.

Field experiments data were conducted at National sugarcane research program, jeetpur-simra in sugarcane variety during three consecutive four financial years from 2018 to 2022. The experiment was laid out in Randomized Complete Block Design (RCBD) and was replicated four times, along with all other recommended necessary agronomic practices. Field observations were recorded on different traits viz: days of anthesis, days of physiological maturity, tillers count, plant height and diameter at different developmental stages of the crop, fresh cane yield, biomass and straw yield. These data were statistically analyzed through coefficient of determination(r2) and correlation coefficient (r) to analyze the correlation of different simulation yields of different treatments of sugarcane cultivation. Five sugarcane cultivars with same combination of irrigation interval and fertilizers dose were tested to observed field crops yields.

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Five sugarcane cultivar i.e. Co-86032, Co-0118, Bo-120, CoSe-98255 and CoS-08272 is applied in DSSAT-CANEGRO for gene-based application. The CANEGRO model simulated showed the highest producing yield for variety Co-86032 i.e. 111.70 t/ha whereas variety BO-120 produced the lowest yield similar crop management practices in an experimental field. Therefore, in sequence the varieties Co-86032, CoSe-98255, CoS-08272, Co-0118 and BO-120 are recommended for high cane yield producing sugarcane industries.

The yield simulation of F/Y 2019/20 model presented the highest correlation coefficient r (0.943) with r2 (0.889), RMSE value of 56.31 and 59.19% MAPE. In model F/Y 2021/22, there is minimum yield percentage error as compared to others. The result disclosed that the model has highest accuracy in calculated parameters. Since the model is run based on cultivar treatment, the 22 genetic parameters of sugarcane cultivars were calculated with coefficient of determination r2(0.946) in average simulation and observation of yield of last five financial years. The genetic potential of a crop variety plays crucial role in determination the yield. Some variety showed high yield whereas others had lower simulation.

Sensitivity analysis had also been performed in field site duration in two stage of sugarcane cultivation on cultivars to understand the characteristic of yield fluctuation with effect of weathers parameters climate variability. The DSSAT- CANEGRO model was simulated with for similar weather parameters (solar radiation, Tmax, Tmin, CO2 and Rainfall) as well as their combinations parameters. For this research study, the parameters were considered to be ±3 value increment or decrement to parameters value for simulation either single or in combination ways. The germination stage study indicated that with (+1 ˚C to +3 ˚C) increment in Tmax parameters to cultivars, the simulation yield increased by 1 to 2 % except Co-86032 so on development stage. And on decrement (-1 ˚C to -3˚C), simulated yield decreased and by up to -3% in cultivar CoSe-98255. Similarly, for Tmin on increasing parameters values, the simulated yield increased to 1.95% and on decrement the value, the simulated yield decreased up to -5.09% in CoSe-98255.Also the result of yield simulation in solar radiation with increment of (+1 to +3 MJ/m2/day), there is rapid increment in cultivar Co-0118 up to 19% and on decreasing from (-1 to -3 MJ/m2/day) from daily solar radiation, the simulated yield decreased and maximum for Co-86032 which was -18.53%. Whereas on increment of CO2 concentration from default value 380 ppm to 500 & 720 ppm, the simulated yield remains constant due to tiny crop and small leaf area. On combine effect of Tmax & Tmin, similar behavior for all cultivars but only value of decrement or increment in simulated yield was more. The combine effect (solar radiation, Tmax, Tmin) is highly sensitive and huge change in percentage value of simulated yield. The production showed more in Co-0118, CoS-08272 and CoSe-98255 cultivar which was close to 18.76% but CoSe-98255 showed 27.03% decreased in yield on decrement of (-3) from base values.

In the development stage, the simulation model was run with similar weather parameters to evaluate the % change in yield on increment and decrement. The output was only changed but effect seemed to be lower than germination stage. In overall, the research work highlighted that the simulated sugarcane yield model is directly proportional to weather parameters to almost varieties & came in conclusion that effect of climate change sensitivity to solar radiation is maximum than maximum temperature, minimum temperature, rainfall and CO2 concentration levels.

Future Recommendation

1. There is huge scope on research study with climate change effect on various variety & cultivar of sugarcane with modern adopted management practices on crop cultivation.
2. There is a scope to compare various other crop models at the farm level to get the better performance.
3. The metrological data and instrument to record be in good condition so that input weather file result excellent simulation for crop model.
4. As far possible maximum field management practices may be considering in the model to check the effect on crop simulation yield under distinct climate scenarios.
5. climate change scenario linkage to future simulation yield and their adaptation measure in research study may be conducted for smart agriculture.

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References

1. Khan, Muhammad Tahir, Nighat Seema, Imtiaz Ahmed Khan, and Shafquat Yasmine. 2016. "THE GREEN FUELS: EVALUATION, PERSPECTIVES, AND POTENTIAL OF SUGARCANE AS AN ENERGY SOURCE." Environmental Research Journal 10 (4).
2. Hannah, Tony, and Donald Spence. 1996. The International Sugar Trade. Elsevier.
3. FAO. 2021. "FAOSTAT ANALYTICAL BRIEF 60 Agricultural Production Statistics 2000-2021 FAOSTAT Analytical

Brief 60 FAOSTAT CROPS AND LIVESTOCK PRODUCTION INTRODUCTION." Agricultural Production Statistics 2000-2021 60: 1–17.

4. Morais, Lizz Kezzy de, Marcelo Sfeir de Aguiar, Paulo de Albuquerque e Silva, Tassiano Maxuell Marinho Câmara, Danilo Eduardo Cursi, Antônio Ribeiro Fernandes Júnior, Roberto Giacomini Chapola, Monalisa Sampaio Carneiro, and João Carlos Bespalhok Filho. 2015. "Breeding of Sugarcane." Industrial Crops: Breeding for Bioenergy and Bioproducts, 29–42.
5. Srivastava, Ashok K, and Mahendra K Rai. 2012. "Sugarcane Production: Impact of Climate Change and Its Mitigation." Biodiversitas Journal of Biological Diversity 13 (4).
6. Food, World. 2022. World Food and Agriculture – Statistical Yearbook 2022. World Food and Agriculture – Statistical Yearbook 2022. https://doi.org/10.4060/cc2211en.
7. MoALD, 2021. 2021. "Statistical Information On Nepalese Agriculture (2077/78)." Publicatons of the Nepal in Data Portal 73: 274. https://nepalindata.com/resource/statistical-information-nepalese-agriculture-207374-201617/.
8. Neupane, Prem Raj, Tek Narayan Maraseni, and Michael Köhl. 2017. "The Sugarcane Industry in Nepal: Opportunities and Challenges." Environmental Development 24: 86–98.
9. Fischer, Günther, Mahendra Shah, Francesco N. Tubiello, and Harrij Van Velhuizen. 2005. "Socio-Economic and Climate Change Impacts on Agriculture: An Integrated Assessment, 1990–2080." Philosophical Transactions of the Royal Society B: Biological Sciences 360 (1463): 2067–83.
10. Zhao, Chuang, Bing Liu, Shilong Piao, Xuhui Wang, David B Lobell, Yao Huang, Mengtian Huang, Yitong Yao, Simona Bassu, and Philippe Ciais. 2017. "Temperature Increase Reduces Global Yields of Major Crops in Four Independent Estimates." Proceedings of the National Academy of Sciences 114 (35): 9326–31.
11. Oliveira, J C M, L C Timm, T T Tominaga, F A M Cassaro, K Reichardt, O O S Bacchi, D Dourado-Neto, and G M de S Câmara. 2001. "Soil Temperature in a Sugar-Cane Crop as a Function of the Management System." Plant and Soil 230: 61–66.
12. Asseng, S, Y Zhu, B Basso, T Wilson, and D Cammarano. 2014. "Simulation Modeling: Applications in Cropping Systems."
13. Rosenzweig, Cynthia, Joshua Elliott, Delphine Deryng, Alex C Ruane, Christoph Müller, Almut Arneth, Kenneth J Boote, Christian Folberth, Michael Glotter, and Nikolay Khabarov. 2014. "Assessing Agricultural Risks of Climate Change in the 21st Century in a Global Gridded Crop Model Intercomparison." Proceedings of the National Academy of Sciences 111 (9): 3268–73.
14. Rosenzweig, C, and A Iglesias. 1998. "The Use of Crop Models for International Climate Change Impact Assessment." Understanding Options for Agricultural Production, 267–92.
15. Jones, J. W., G. Hoogenboom, C. H. Porter, K. J. Boote, W. D. Batchelor, L. A. Hunt, P. W. Wilkens, U. Singh, A. J. Gijsman, and J. T. Ritchie. 2003. The DSSAT Cropping System Model. European Journal of Agronomy. Vol. 18. https://doi.org/10.1016/S1161-0301(02)00107-7.
16. Singels, A, M R Jones, C H Porter, M A Smit, G Kingston, F Marin, S Chinorumba, A Jintrawet, C Suguitani, and M van den Berg. 2010. "The DSSAT4. 5 Canegro Model: A Useful Decision Support Tool for Research and Management of Sugarcane Production." In Proceedings of the International Society of Sugar Cane Technologists. Vol. 27.
17. Pandey, Amita, Diwas Raj Bista, Thaneshwar Bhandari, Hari Krishna Panta, and Sudip Devkota. 2020. "Profitability and Resource-Use Efficiency of Sugarcane Production in Nawalparasi West District, Nepal." Cogent Food & Agriculture 6 (1): 1857592.
18. Chaudhary, Ram P, and Chandra K Subedi. 2019. "CHURE-TARAI Madhesh Landscape, Nepal from Biodiversity Research Perspective." Plant Arch 19: 351–59
19. Neupane, Jaya Lal. 2022. "Dynamics of Hydro-Power Development in Nepal: Water-Energy-Food Security Prospect.
20. Lewis, W. Arthur. 2013. "Economic Survey." Economic Survey 3. https://doi.org/10.4324/9781315016702.
21. Verma, Amit Kumar, Pradeep Kumar Garg, K. S.Hari Prasad, and Vinay Kumar Dadhwal. 2023. "Variety-Specific Sugarcane Yield Simulations and Climate Change Impacts on Sugarcane Yield Using DSSAT-CSM-CANEGRO Model." Agricultural Water Management 275 (July 2022): 108034. https://doi.org/10.1016/j.agwat.2022.108034.
22. Jones, Matthew R, and Abraham Singels. 2018. "Refining the Canegro Model for Improved Simulation of Climate Change Impacts on Sugarcane." European Journal of Agronomy 100: 76–86.
23. Pickering, N B, James W Hansen, J W Jones, C M Wells, V K Chan, and D C Godwin. 1994. "WeatherMan: A Utility for Managing and Generating Daily Weather Data." Agronomy Journal 86 (2): 332–37.
24. Smith, Hunter D, Chris H Wilson, Stuart J Rymph, Erick R S Santos, and Kenneth J Boote. 2023. "Adapting the CROPGRO Perennial Forage Model to Predict Growth and Development of Pensacola Bahiagrass." Field Crops Research 302: 109095.
25. Bhengra, A. H., M. K. Yadav, Chandrabhan Patel, P. K. Singh, K. K. Singh, and R. S. Singh. 2016. "Calibration and Validation Study of Sugarcane (DSSAT-CANEGRO

V4.6.1) Model over North Indian Region." Journal of Agrometeorology 18 (2): 234–39.
26. Stokes, Chris J, N Geoff Inman-Bamber, Y L Everingham, and Justin Sexton. 2016. "Measuring and Modelling CO2 Effects on Sugarcane." Environmental Modelling & Software 78: 68–78.
27. Mishra, A.K. Nepal, A., & Aithal, P.S. (August2022). Industry 4.0 Concept for Nepal -Operating Virtual Farming Industry. PP- 31-35, Proceedings on Future Trends in ICCTand its Applications in IT, Management andEducation, Editors: Dr. Krishna Prasad, K.,Dr. P. S. Aithal, & Dr. A. Jayanthiladevi,ISBN: 978-81-949961-8-7, DOI: https://doi.org/10.5281/zenodo.7215189
28. Chaudhary KK, Mishra AK. Impact of Agricultureon Economic Development of Nepal usingStatistical Model. J Adv Res Alt Energ Env Eco2021; 8(2): 1-3
29. Mishra SK, Shrestha S, Jha SK. et al. Design andTesting of Power Tiller Driven 2-Rows ReducedTillage Maize Planter. J Adv Res Prod Ind Engg2023; 10(2): 1-10
30. Mishra S, Shrestha S, Mishra A, Jha M, Joshi M, C B, Chaudhary D, Sahani S. Performance Evaluation of Tractor driven Round Baler in Residue Management. JBMIS [Internet]. 31Dec.2023 [cited 6Jun.2024];10(2):26-0. Available from: https://qtanalytics.in/journals/index.php/JBMIS/article/view/3086
31. Mishra, A. K. (2024). GovernmentInvestment in Agriculture and PolicyRecommendations . SP Swag: Sudur-Pashchim Wisdom of AcademicGentry Journal, 1(1), 1-10.https://doi.org/10.5281/zenodo.11056826

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