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# Impact of climate change on maize yield in the maize growing region of Nigeria

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## Abstract

*Crop production is amongst the many delicate occupations that would be affected by weather fluctuations. We assess the conceivable effects of climate change on maize production in Nigeria. DSSAT crop simulation model was employed for this study to predict the maize yield in the northern maize producing areas until 2039, using projected weather data and current management practices. Increased in temperature, carbon-dioxide and variation in rainfall pattern throughout the growing period were found to affect the maize yields. The results presented that maize yield, during 2016 – 2039, compared to the base-values are projected to decrease by 10.8%, 6.8% and 8.1% largely caused by temperature increase, $CO_2$ and decrease in rainfall respectively. The results point out that maize yield could be more negatively affected by the temperature increase due to climate change.*

**Keywords:** Climate change, Maize, Weather, Temperature.

## Introduction

The most common staple crops throughout West Africa were cereals maize in particularly, Millet and sorghum are widely grown as well; most rural households engage in subsistence agriculture. However, due to rapid growing population in the region, increase in maize production is required. Several factors including anthropogenic and natural are influencing food production in the region. Future changes would impact agriculture due to complex interactions amongst several weather elements that were related to crop production system. The atmospheric conditions contributed to major roles, which dominated both local and regional crop production practices[1]. Climate change that source in $CO_2$ absorption and the subsequent changes in atmospheric temperature and rainfall patterns can considerably affect the crop yield. Most critical to global food security is the extreme resilience on crop to climate change in the coming years of the events.

The variation in pattern of precipitation and temperature can decrease crop productivity through different mechanisms of crop physiology due to relationships between crop development and temperature[2]. The plants biological growth and development depends on temperature rise to higher level before decreasing[3]. Hence, it is understood that crops nurture more rapidly in warmer situation whereas, yield can declined with potential temperature decline to certain threshold of the plant[4], especially in semi-arid regions where the limiting growth factor is water[5]. Variability in precipitation can reduce soil moisture availability and decrease growing season to rainfed crops in many regions, and could resulted to water stress which consequently decrease in crop productivity. Climate change impact in sub-Saharan Africa has been approach by different defined projects on cereal crop and defined their detrimental impacts[6]. The prediction in decrease of cereals (maize, millet, sorghum) by 15% in the mid-century[3], would be largely due to changes in future weather elements "temperature and precipitation". With temperature raise by 1$^{o}$C would cause yield reduction by about 65% of maize area harvesting in some regions[7]. Average yield decline was projected in most areas because of reduce in the crop growing season rain in most part of sub-Saharan Africa with consequences of 30% coupling with average yield losses of 3 – 20% projected to future loss[6]. Analysing impact of climate change on agriculture productivity[8], estimated cereals average median yield loss in a review published studies to be 13 – 18% in some parts of the north and southern regions of West Africa, respectively. However in a process based crop model[9], has appropriately examine how agriculture crops responded to ecological changes[10,4,5].

This study focus is on maize producing areas of Nigeria, to fill the knowledge gap on feature climate change effects on yield. The (DSSAT-CSM) is the mostly prefer plant biological based simulation crop growth model, it was used for maize simulation and employed model calibration in projecting future maize yields for proper understanding of the relationship of weather variables on yields.

## Materials and methods

**DSSAT crop model explanation:** The crop model works by incorporating different modules of; crop genotype, weather information, soil data, and crop management. CEREZ Maize is responsible for maize simulation in DSSAT[11,12]. The crop simulation model, simulates crop growth and yield of a uniform crop grown on land under simulated management with modifications in soil water content, carbon, and nitrogen. The model structure as describe by Jones[13] and Porter[14].

In this study version 4.6 was used, the model was upgraded from the previous version and can simulate several crops: maize, barley, millet, sorghum, rice, and wheat. The CEREZ module simulates plants growth cycle and is separated into several development phases, which are comparable amongst other crops: germination, emergence, end of juvenile, flora induction, flowering, start of grain-fill and physical maturity. Their rate of growth is mainly controlled by thermal time, which is a computer based on daily weather elements specifically maximum and minimum temperature.

The thermal time requirements on or after one stage to other are well-defined as user inputs and assumption regarding intermediate growth stage or the genetic cultivar specific inputs. The CERES module daily plant growth rate for maize crop is defined by optimum temperature and extreme temperature above which the growth does not occurs. Photoperiod, day length sensitivity also depends on cultivar, although, water stress and nutrient stress has no effect. Growth rate per day is work out by converting the daily trapped photo synthetically active radiation.

**Model calibration:** Model is mostly standardised for reasons includes is reducing error of the elements compared, ‘observed and simulated’ data and to determine the parameters of the model for its intending determination. In a regional study of climatic changes effect, within a larger geographical area and limited data access for assessments, the calibration is mostly limited to applying results from crops trials farms, agricultural experimental stations and the most common crop varieties produced within the study region. In this study we purposely use the maize variety AG-KADUNA which is the most popular variety of maize in the region, the maize experimental data set and crop management data information’s was obtained from[15]. Maize yield performance were needed for the calibration to enable lessen the “root mean square error (RMSE)” of both observed and simulated maize yields, such as seeds-emergence-date, flowering-date, physical maturity-date, amount of yield harvested and dry-weight product harvest date.

**Model testing:** model assessment would include several other model output comparisons with observed data for determination of its suitability for a future purpose. Though, the resultants are the records of the precision of the output for specific forecasts in particular region or an environment, an environment which is given suitable consideration to potential inaccuracies in input variables or assessment of the input data, specifically for the model validity with “root mean square error” (RMSE), “normalized root mean square error” (nRMSE) and “coefficient of residual mass” (CRM) was applied to evaluation of the error.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(S_i - M_i)^2}{n}} \tag{1}$$

$$nRMSE = \frac{RMSE}{\overline{M}} * 100 \tag{2}$$

$$CRM = \frac{\sum_{I=1}^{n} M - \sum_{i=1}^{n} S_i}{\sum_{i=1}^{n} S_i} \tag{3}$$

Where: $S_i$ is simulated value, $M_i$ is observed value, $n$ is number of observations over years, and $\overline{M}$ is calculate average of the observed values[16,17].

## Results and discussion

**Model validation:** Crop model application assumption indicated specifically that the model simulates the processes happening in the farming system[18]. The validation of the procedure was done by relating daily observed weather data of maximum and minimum temperature, precipitation and solar radiation that was gotten from institute of agricultural research (IAR, Zaria) for time period of 1992 – 2014 years. The output of simulated yields was compared with the observed yields in the rainfed seasons.

The validated results indicates that, the crop system model simulated yield were diverse around (361.1kg/ha) from the observed yield. The results presented that model has simulated realistic maize yield with nRMSE = 7.95% and the result of the CRM, presented that many of the simulated values remained larger than the observed values. The average simulated yield were slightly higher with (about 1.3%) over the actual yield.

**Effects of the predicted changes on maize yield:** for this study we consider the effect of weather variables of temperature, rainfall and $CO_2$ on maize yield, the study applied these variables that were predicted for the time periods of 2016 – 2039. The results for the predicted changes in yield for each climate variable are shown in Figure 1 – 3.

This study results shows the impacts of temperature; rainfall and $CO_2$ in maize growing region of Nigeria and predicted yield for the period of 2016-2039. The study area is considered as regions whose major annually subsistence farming were maize cultivation, the study region has the capability of producing maize for vast majority of the population within the context of the nation. The prediction is shown in Figure 1-3.

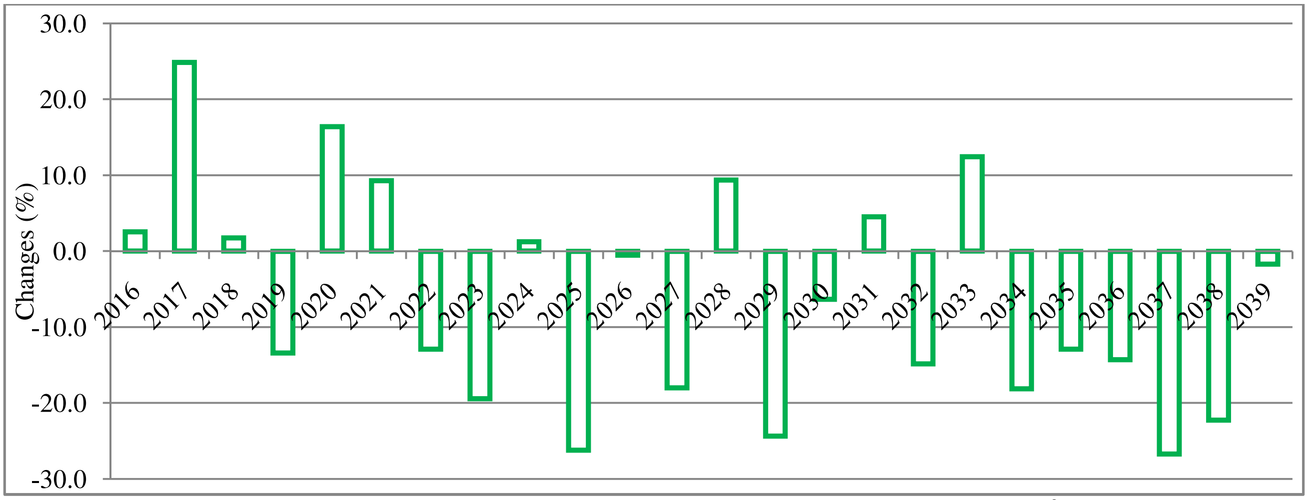


**Figure-1:** Percentage changes of maize yield for the region when temperature, $CO_2$ (+ 2.0$^o$C/$CO_2$ = 389).

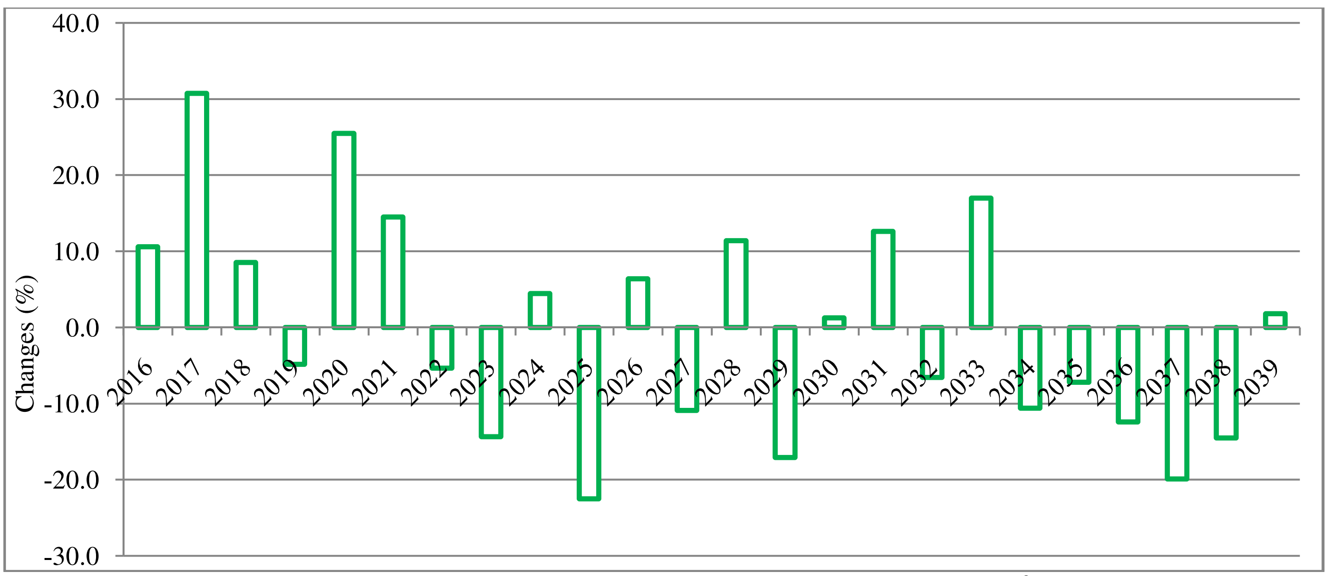


**Figure-2:** Percentage changes of maize yield for the region when temperature, $CO_2$ (+2.0$^o$C/$CO_2$ (1.5%) = 584).

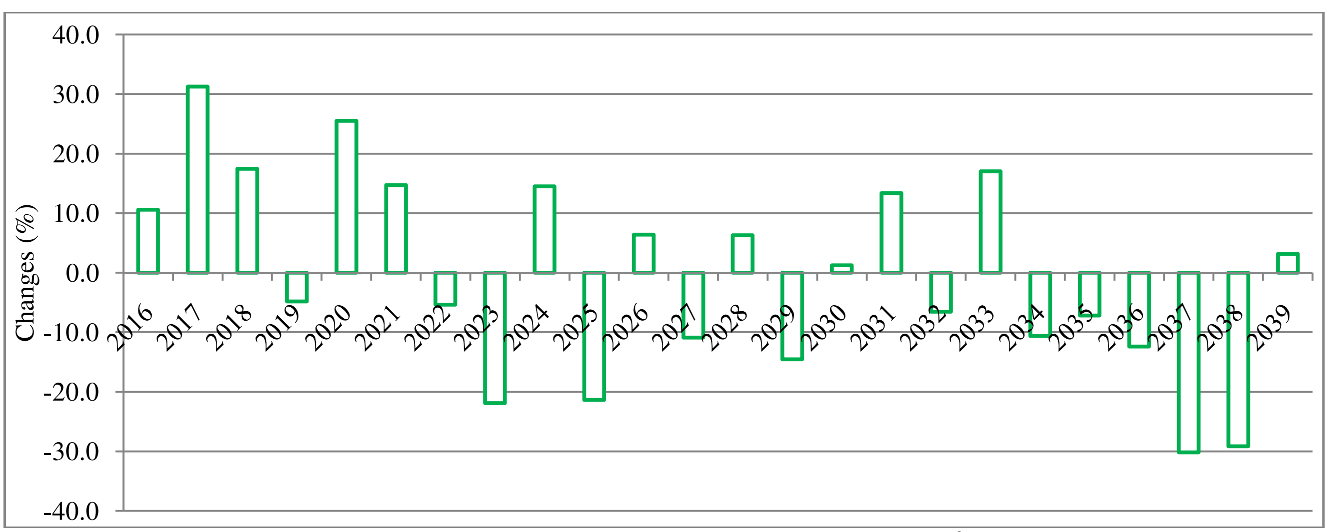


**Figure-3:** % changes of maize yield for the region when temp, rainfall and $CO_2$ (+2.0$^o$C/$CO_2$ (1.5%) = 584/ -11mm).

For more accurate prediction results, the model was run separately for each year, and then the average was taken to get yield variation for each year run. Stating that, only temperature, rainfall and carbon dioxide were considered as the major climatic factors. Other factors which include soil, technology, management practice and other weather inputs, were consider to be constant. The predictions were contributed using the default fixed absorption of atmospheric $CO_2$ of 389ppm (as the default value in DSSAT).

The yield predicted results for maize growing region of Nigeria; indicated reduction in maize crop yield during the years of the seasons until 2039. During the seasonal, the temperature and carbon dioxide were predictable to rise with approximately 0.02$^{o}$C and rainfall decreases by -0.35mm per year respectively while carbon dioxide level increased by 1.5% from the current atmospheric level. The yield of the years is projected to drop by overall average of 8.5% over the next 24 years. However, rainfall will decrease by -11mm during the 2016-2039 while temperature increases by 2.0$^{o}$C within the same period. The results indicate that maize would be additional affected negatively by the change in weather when temperature rises without the carbon level increasing; the yield decline drastically in most of the years and consequently when its being tested with carbon level increase in the atmosphere the yields increases over the earlier effects of temperature. We knew that rainfall controls the phenological development of plants and the analysis results for the trends indicated a very slight yields reduction in some years with significant less effect. The carbon effect signifies that, the increased carbon level in atmosphere by 1.5% increase is beneficial to crop yield especially maize crop which belongs to C4 Plants, however in some areas in certain years (e.g. 2017, 2020, and 2031) indicated a prediction for substantial yield increase in the region. The variability in maize yield was basically due to changes on the weather elements of temperature, carbon dioxide and rainfall in definite time period of plant physical development; conversely it depends mainly on planting date.

The sensitivity of Maize yield through the seasons fluctuates after each year estimate to another, though for most of the estimates, the all-out loss in yield predicted would occurs during the years of 2025, 2029, 2034, 2037 and 2038, respectively when temperature level raise to (2.0$^{0}$C) with normal carbon and no decrease in rainfall. The yields fluctuations varied from one location to different climates conditions, with slightly high yield reductions predicted for the study region.

The predicted results with temperature increase at default constant carbon level with no water stress, shows a high reduction in yield for the farming years of the seasons (Figure–1). This raising temperature would affect the yields in so many years of the periods (2019, 2023, 2025, 2027, 2029, 2032, 2034, 2037 and 2038) respectively. Comparing the feature yield to our base value for the estimate, the yield would be expected to decrease by 10.7% respectively.

The prediction results for temperature increase and 1.5% raising in carbon level is shown in Figure-2, the prediction indicated reduction in yield for the projected period until 2039, some of the years that shows variation and reduction were (2023, 2025, 2027, 2029, 2037 and 2038) respectively, even though the reduction is not as much like in temperature raise. Within the period the temperature rises by 0.02$^{o}$C per year, while the carbon level rises by 1.5% from the constant current level of 389ppm to 584ppm until 2039. Also within the prediction period of (2016-2039) the temperature will raise by 2.0$^{o}$C and carbon to 584ppm, respectively. Comparing with our estimated base value in the study area, the maize yield would be anticipated to decrease by 6.8% respectively.

The model predicted results for reduction of rainfall are being estimated, in Figure-3. We presented the results for temperature increase, raising carbon level and rainfall reduction. The prediction indicated yield fluctuation for some years and reduction in yields for some other years within the predicted years of (2023, 2027, 2029, 2037 and 2038) were the years predicted to have yields decline. Furthermore, the projected results indicate a slight increase in yields for some years (2017, 2020, 2024, 2030 and 2031).

However the rainfall may decreased by -11mm over the years up till 2039 period, while at the same time, the minimum and maximum temperature will be increasing by 0.02$^{o}$C per year and increase by 2.0$^{o}$C, in addition to 1.5% increase in carbon level all during the periods of 2016-2039. Consequently, as results of the enlisted variable effects above, the yield is expected to decrease by 8.1%during the years of the prediction until 2039.

## Conclusion

The future predicted yields results indicated that temperature increase during the growing periods of the maize have a consequences on the yield, the yield show high percentage of 10.7% decline, confirming from the finding indicated that when all the weather variables impacted on the crop, the cumulative average effects would be 8.5% of the yield, these would be lost due to impact of the weather change. Though there were significant uncertainty on the predicted weather elements, DSSAT crop model simulated results, suggested that if feature climate change impact resulted to significant pattern of changes in temperature rise, decrease in precipitation and rise in carbon dioxide level, then, impacts of the changes might in turn results in significant changes in maize yield.

The highest effect from the finding indicated that changes in temperature has more devastating effects on yield than other climatic variables, also escalating temperature would results in shorter growing seasons, which means shorter maturing of the crop and consequence reduced maize yields in the region. This highly impacted variable can be mitigated through adjustment of planting dates so that the crop can be done well in the shift of the season and increased maize yield in the study region.

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