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Research Article

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Modeling Climate Change Effects on Sweet potato and Okra Yield in Edo State, South Southern Nigeria

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Abstract The climate study aims to evaluate the projected effects of changes in climate on sweet potato (*Abelmoschus esculentus L.*) and okra (*Ipomoea batatas*) yields for the time slices of 2049-2069 (the 2050s) and 2070-2100 (2080s) relative to the referenced period 1977-2100 (2080s) relative to the referenced period 1977-2005 under the median and worst-case emission scenarios: representative concentration pathways (RCP 4.5 and RCP 8.5) using statistical downscaled climate datasets from an ensemble of three (3) general circulation models (GCMs) over Edo State, south southern Nigeria. The baseline yield analysis showed that sweet potato (SP) yield decreased with an average of 0.2 ton/ha, while okra (OKR) yield increased by 0.03 ton/ha from 1977-to 2007. Hence, this period corresponded to an annual mean temperature increase of 0.02ºC. The outcome of the climate analyses showed that the CCCMA model indicated the highest decrease in SP yield of 22.5% (1.3 ton/ha) and 27.7 % (1.66 tons/ha), while NOAA projected the lowest decrease of 15.2% (0.85 ton/ha) and 18.6% (1.04 tons/ha) for the 2050s and 2080 in comparison with the baseline. Hence, the projected climate has a slight effect on OKR yield compared to SP. The projection showed that NOAA and ICHEC models indicated a lower OKR yield decrease, whereas the CCCMA model projected the highest yield reduction for the 2050s and 2080s under the two RCPs. Therefore, a 30% (35 days) and reduced 10% (10 days) okra growing cycle length (OGCL) were predicted under RCP 8.5 by 2080s from the CCCMA model, while all the GCMs indicated no elongation period for OGCL by 2050s. In conclusion, the crops due to their mild drought tolerance could be considered for the potential for potential climate change adaptation crops.

Keywords Sweet potato, Okra, General circulation models, Representative concentration pathways, Climate change adaptation, Edo State

1. Introduction

The sweet potato (*Ipomoea batatas*) and Okra (*Abelmoschus esculentus L.*) are important tuber and vegetable crops. Several studies have shown that sweet potato is the fourth largest edible crop after rice, wheat, and maize globally with the global highest production of 94.9 million tons in China for the 2015 agricultural season [1,2]. However, okra is grown in the tropical and subtropical regions of the world across Africa to Asia, America, and Southern Europe [3]. Anonymous (2020) reported that India was the highest global okra production of 5.19 lac hectares. It is obvious that climate change (CC) has an effect on various economies such as energy consumption, tourism, forestry, and agriculture [4]. IPCC (2006) reported that the global air temperature is projected between 1.4 and 5.8oC higher by 2100 based on the regions and locations [6]. However, changes in climate may have significant effects on crop germination, growth, and yield since the crop phenology is temperaturedependent. High temperature could cause a reduction in the growth and formation of the storage root networking system by changes in the synthesis and activation of phytohormone [7] and alternation of physiological processes thus consequently leading to sweet potato yield reduction. Conversely, low and high temperatures could lead to early or late flowering, fruit filling, increase or decrease in crop growing length, and okra yield decrease.

Sweet potato and okra are widely cultivated in Nigeria. However, sweet potato has witnessed a drastic yield reduction from an average of 9 tons/ ha in the 1960s to 3 tons/ha in the 2020s, while an increase in production was only achieved through the increase in the planting area. Hence, the baseline okra production indicated a low yield reduction. Due to the fragility of the arable land in Nigeria, it is highly susceptible to abiotic, biotic, soil nutrient depletion, and global climate warming. This observation indicated that the decreases in crop yield could be majorly attributed to climate change due to an increase in global surface temperature and rainfall variability over Nigeria. The studies of [8,9] showed that northwest China experienced a significant climate in 1960 which caused worsened drought occurrence in most of the region. Having observed that CC effects vary from region to region, it is, therefore, significant to regionally evaluate climate change impacts on crop yield. Hence, the study of CC effects on okra and sweet potato yield at the country level is important to improve the crop yield per hectare and develop robust mitigation strategies for possible CC impacts on agriculture.

Edo State in South Southern Nigeria was chosen as the study area due to the significance of the selected crops (sweet potato and okra) to the current economic development and poverty reduction among the teeming population of the study region. In this study, the effects of CC on sweet potato and okra yield using a group of three (3) general circulation models (GCMs) under climate change scenarios: representative concentration pathways (RCP) 4.5 and RCP 8.5 for the future periods 2049-2069(the 2050s) and 2070-2100 (2080s) relative to 1977-2007. However, the study applies the statistical metrics of the multivariate regression model using projected climate (minimum temperature, maximum temperature, precipitation) and crop yield datasets to estimate projected CC on the future okra and sweet potato.

2. Materials and Methods

2.1 Study area

Edo State (Fig.1) is one of the States in Nigeria and is located at the South Southern part of the country. It is bounded in the south by delta state in the West by Ondo state in the North and North East by Kogi state and in the East by Anambra state. Edo State covers an area of 19,744km^2 and has a total population of 2,159,848 and population density of 109 (based on the 1991 census figure). The state has approximately between latitude 05^o 44'N and 07^o 34'N of the Equator and between latitude 06^o 04^o'E and 06^o 43^o'E. Edo State has annual mean rainfall of above 2,000mm, air temperature of 27^{o}c and relative humidity of above 80%. Fig.1 shows the map of Edo State indicating the study areas.

2.1 Datasets

2.1.1 Historical and projected climate datasets

A 31-year historical monthly climate data (maximum temperature, minimum temperature, and precipitation) from 1977-2007 was extracted from the CRU TS2.1 database through the Department of Agro-climatological, Ministry of Agriculture & Natural Resources, Edo-State, with a spatial resolution of 15 arc-minute. According to [10], it is essential not to depend on one GCM alone but several climate models when evaluating climate studies. Based on this, a group of three (3) GCMs selected from the 5th Coupled Model Intercomparison Project (CMIP5) was applied to project climate datasets for periods 2040-2069 and 2070-2100 under RCP 4.5 and RCP 8.5. Table 1 shows the description of selected general circulation models for the study.

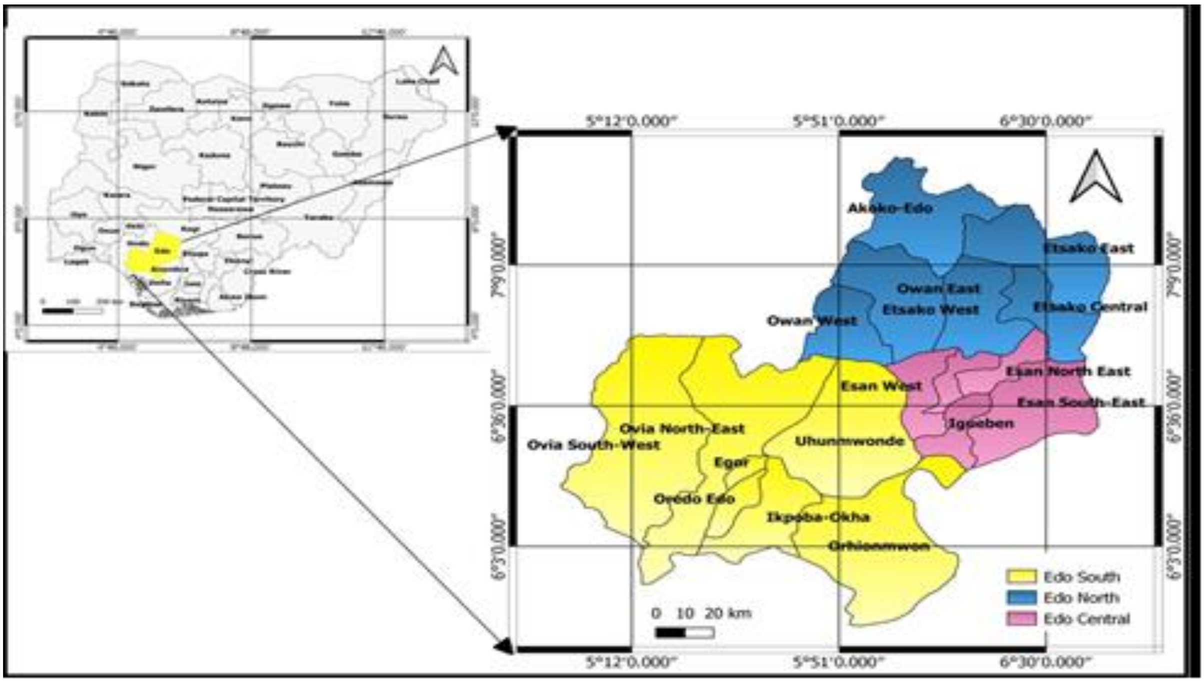

Figure 1: The map of Nigeria indicating the study area

Table 1: Properties of selected CMIP5 climate models used in this study

Model Name	Abbreviations	Spatial resolution
Canadian Centre for Climate Modeling & Analysis	CCCMA	48×96 cells, 3.750 ×3.750
Irish Centre for High End Computing	ICHEC	96×192 cells, 1.80 ×1.80
National Oceanic & Atmospheric Administration	NOAA	88×179 cells, 1.50 × 1.50

Source: [11]

2.2 Climate-Crop Yield

The baseline (1977-2007) crop yield datasets were obtained from the Ministry of Agriculture & Natural Resources, Edo State, Nigeria

2.2.1 Multivariate regression

The non-linear yield trend in okra and sweet potato was decoupled using the first difference method as explained in the study [12]. Multivariate regression was used to quantify the relationship between crop yield (Okra and Sweet potato) and climatic factors as follows:

$$Y_{baseline} = \emptyset + (\alpha * PPT) + (\beta * TMIN) + (\gamma * TMAX) \quad (1)$$

$$\partial Y_{okrCCCMA(2050S)} = \emptyset + (\alpha * \delta PPT_{CCCMA}) + (\beta * \delta TMIN_{CCCMA}) + (\gamma * \delta TMAX_{CCCMA}) \quad (2)$$

$$\partial Y_{okrCCCMA(2080S)} = \emptyset + (\alpha * \delta PPT_{CCCMA}) + (\beta * \delta TMIN_{CCCMA}) + (\gamma * \delta TMAX_{CCCMA}) \quad (3)$$

$$\partial Y_{spCCCMA(2050S)} = \emptyset + (\alpha * \delta PPT_{CCCMA}) + (\beta * \delta TMIN_{CCCMA}) + (\gamma * \delta TMAX_{CCCMA}) \quad (4)$$

$$\partial Y_{spCCCMA(2080S)} = \emptyset + (\alpha * \delta PPT_{CCCMA}) + (\beta * \delta TMIN_{CCCMA}) + (\gamma * \delta TMAX_{CCCMA}) \quad (5)$$

Where δY_{okr} and δY_{sp} are the observed changes in the okra and sweet potato yields due to projected temperature and precipitation, and φ is the predictive yield constant.

Equation (1) was used to establish the relationship between the baseline crop yield and climatic variables, while equations [2-3] were used to estimate the projected climate change on the okra yield for the 2050s and 2080s under the CCCMA model. However, equations [4-5] were applied to estimate the effects of changes in climatic variables on the sweet potato for the 2050s and 2080s.

3. Results and Discussion

3.1Changes in sweet potato and okra yield in Edo State

The sweet potato (sp) and okra (okr) yield trends from the period 1977 to 2007 showed a significant decrease for SP, while OKR increased during the baseline over the study area. SP decreased from 9.9 tons/ha in 1977 to 3.3 tons/ha in 2007 with an annual average decrease of 0.2 ton/ha at $P < 0.05$. However, okra yield increased an average of 0.03 ton/ha per year as shown in Figure 2. The finding shows similarity with the study of [13]. Conversely, an increase in sweet potato production during the baseline period was achieved by increasing the planting area from 367,000 ha in 1977 to 455,000 in 2007 [14].

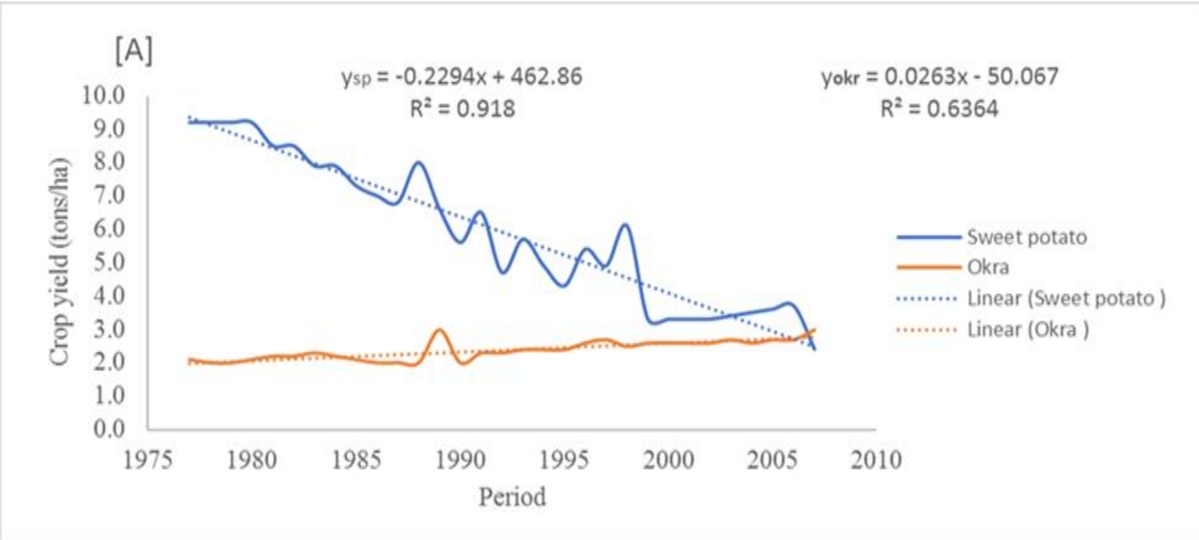

Figure 2a: Changes in crop yields from 1977-2007 in Edo State, Nigeria

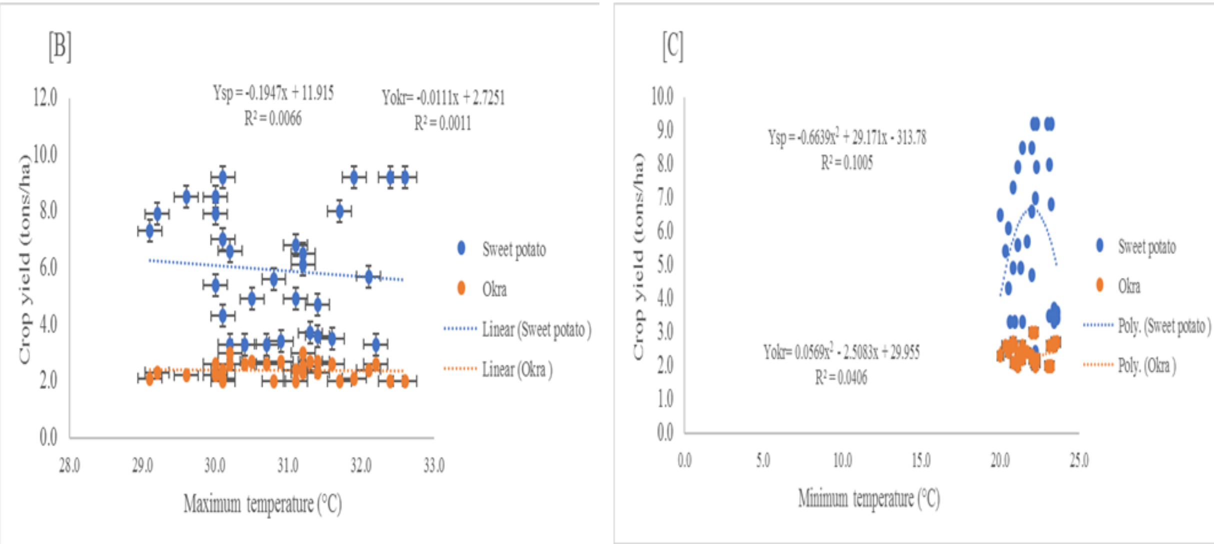

Figure 3a-b: Crop yield trend under baseline period temperature in Edo State, Nigeria

Hence, the effects of changes in climate on crop yields affected SP more than Okra despite that the tuber crop (SP) is resistant to moderate drought. SP grows very well under an ambient temperature between 21-26^oC and temperature above 29^oC affects the crop growth due to stomatal closure. However, the growing optimal surface temperature for OKR ranges from 24^oC to 27^oC; and crop water requirements (IWR) of about 570 mm throughout its growth cycle [12;14]. The study of [17] showed that optimum temperature ranges between 21 to 30 ^oC, with minimum and maximum temperatures of 18 ^oC and 35 ^oC. The result in Fig.2a-b shows the relationship between the crop yields (*SP and OKR*) and temperatures. The SP yield increased steadily from 7.8 tons/ha at the Tmax value of 28.6^oC to 29.3^oC and decreased gradually from 30.0^oC to 3.3 tons/ha at the maximum temperature value of 32.6^oC. Hence, okra yield increased from 2.4 tons/ha at a Tmax value of 29.2^oC to a maximum yield of 3.4 tons/ha at a Tmax value of 31.4^oC (Fig.2a). The result presented in Fig.2b shows that baseline minimum temperature is insignificant to the crop yield (SP and OKR). The observation showed that an increase in Tmax between 28-32^oC supported OKR yield, while maximum temperature between 28-30^oC was favourable to SP yield.

The results of the multiple regression model revealed that climate has a significant effect on okra and sweet potato yield over the study region. The finding showed that climate accounted for 71% and 66% yield variations for SP and OKR during the referenced period as shown in Table 2. The standardized negative coefficients for Tmax and Tmin suggested a decrease in SP yield with an increase in maximum and minimum temperatures, whereas an increase in Tmin could be beneficial to okra yield. Hence, the precipitation positive coefficient indicated that an increase in precipitation could be favourable to SP and OKR yields. The finding agrees with the studies of [15;16] which explained the relationship of climate variables and crop yield.

Table 2: Multivariate regression statistics for sweet potato and okra yield under baseline climate

Crops	Reg.Par	Reg. Const.	P_{rec}	T_{max}	T_{min}	R^2
Sweet potato	Reg.Const./Coeff	17.6	0.180	-0.842	-0.142	0.71
	P-value		0.232	0.341	0.360	
Okra	Reg.Const./Coeff	16.4	0.005	-0.316	0.070	0.66
	P-value		0.001	0.041	0.421	

Coeff. = Coefficient, P_{rec} = Precipitation, T_{max} = Maximum temperature, T_{min} = Minimum temperature, Reg. Const = Regression constant, Reg.Par = Regression parameters.

3.2: Crop Yield Responses to Climate Change

3.2.1 Sweet potato variations to changes in climate

The climate analyses results presented in Table 3-6 show the estimated climate change effects on *SP* and *OKR* for the 2050s and 2080s under RCP 4.5 and RCP 8.5 using three (3) sets of general circulation models (GCMs). The overview of the hindcast simulation indicated a slight increase in Tmax and Tmin from the chosen GCMs. CCCMA model projected an increase of Tmax with 1.3^oC; 2.3^oC and ICHEC predicted an increase of 1.0^oC and 1.6^oC for the 2050s and 2080s under RCP 4.5 relative to 1977-2007. However, mild increases were projected for the Tmin. High Tmax and Tmax were projected under RCP 8.5 more than RCP 4.5 with Tmax values of 0.7^oC; 1.1^oC for CCCMA and 1.1^oC; 1.4^oC for 2050s relative to referenced period. Hence, all the GCMs under the two RCPs showed a seasonal reduction in precipitation. These results have shown good agreement with the findings of several studies [21, 22].

Overall crop yield simulation results presented in Table 3 and 4 showed that the CCCMA model projected the highest reduction in sweet potato yield of 22.5% (1.26 tons/ha) and 27.7% (1.66 tons/ha) whereas yield reduction of 15.2% (0.85 ton/ha) and 18.6% (1.04 tons/ha) by NOAA was indicated for the 2049-2069 and 2070-2100 relative to 1977-2007 (Table 3 and Fig.3a-b). Hence, higher decreases in SP yields were noticed under climate change scenario-RCP 8.5 as presented in

Table 4 and Fig. 3c. Higher SP yield reduction of 8.0%; 9.2% and 3.6%; 3.9% were estimated from RCP 8.5 over RCP 4.5. The possible reason for this observation could be attributed to the higher temperature increases projected under RCP 8.5. The combined effects of temperature could lead to increase in evaporative demand and crop water requirements (CWR). Also, prolonged increases in ambient temperature cause acute water deficit, closure of plant stomatal, and reduction of sap flow. The combined processes lead to the shortening of sweet potato growing length and consequently yield.

Table 3: Projected changes in sweet potato under RCP 4.5 over Edo State

	SP yield reduction (%)		**SP yield reduction (Kg/ha)**	
Models	**2049-2069**	**2070-2100**	**2049-2069**	**2070-2100**
CCCMA	22.5	29.7	1260.0	1663.2
NOAA	15.2	18.6	851.2	1041.6
ICHEC	17.1	22.6	957.6	1265.6

Table 4: Projected changes in sweet potato under RCP 8.5 over Edo State

	SP yield reduction (%)		**SP yield reduction (Kg/ha)**	
Models	**2049-2069**	**2070-2100**	**2049-2069**	**2070-2100**
CCCMA	30.5	38.2	1708.0	2139.2
NOAA	22.6	27.8	1265.6	1556.8
ICHEC	20.7	26.7	1159.2	1495.2

Table 5: Projected changes in okra under RCP 4.5 over Edo State

	OKR yield reduction (%)		OKR yield reduction (Kg/ha)	
Models	2049-2069	2070-2100	2049-2069	20702100
CCCMA	18.4	22.5	441.6	540.0
NOAA	14.5	17.4	348.0	417.6
ICHEC	12.8	16.3	307.2	391.2

3.2.2 Predicted climate change on okra yield

The result in Tables 5 and 6 summarize the projected effects of CC on okra yield for the short and long term. The overall simulation indicated that projected climate has slight effects on OKR yield compared to sweet potato (Table 5, 6, and Fig. 3b). The CCCMA model predicted the highest okra yield reduction under the median and worst-case climate change scenarios RCP 4.5 and RCP 8.5 for the 2050s and 2080s, whereas the projections from the NOAA and ICHEC indicated lower OKR yield reductions. Also, the possible effects in temperature and reduced precipitation could lead to prolonging okra growing cycle length (OGCL) to 100 days (+30%) under RCP 4.5, while a decrease of 55 days for OGCL is predicted under RCP 8.5 by 2080s. Hence, the projected climate indicated no elongation period for the crop growing length by 2050 as predicted by all the ensemble GCMs. The finding showed that okra could be a better potential climate change mitigation crop than the sweet potato over the south southern, Edo State, Nigeria. The observation agrees with the studies [18;19;20].

Table 6: Projected changes in okra under RCP 8.5 over Edo State

	OKR yield reduction (%)		**OKR yield reduction (Kg/ha)**	
Models	**2049-2069**	**2070-2100**	**2049-2069**	**2070-2100**
CCCMA	24.6	30.5	590.4	732.0
NOAA	17.2	21.6	412.8	518.4
ICHEC	14.3	17.4	343.2	417.5

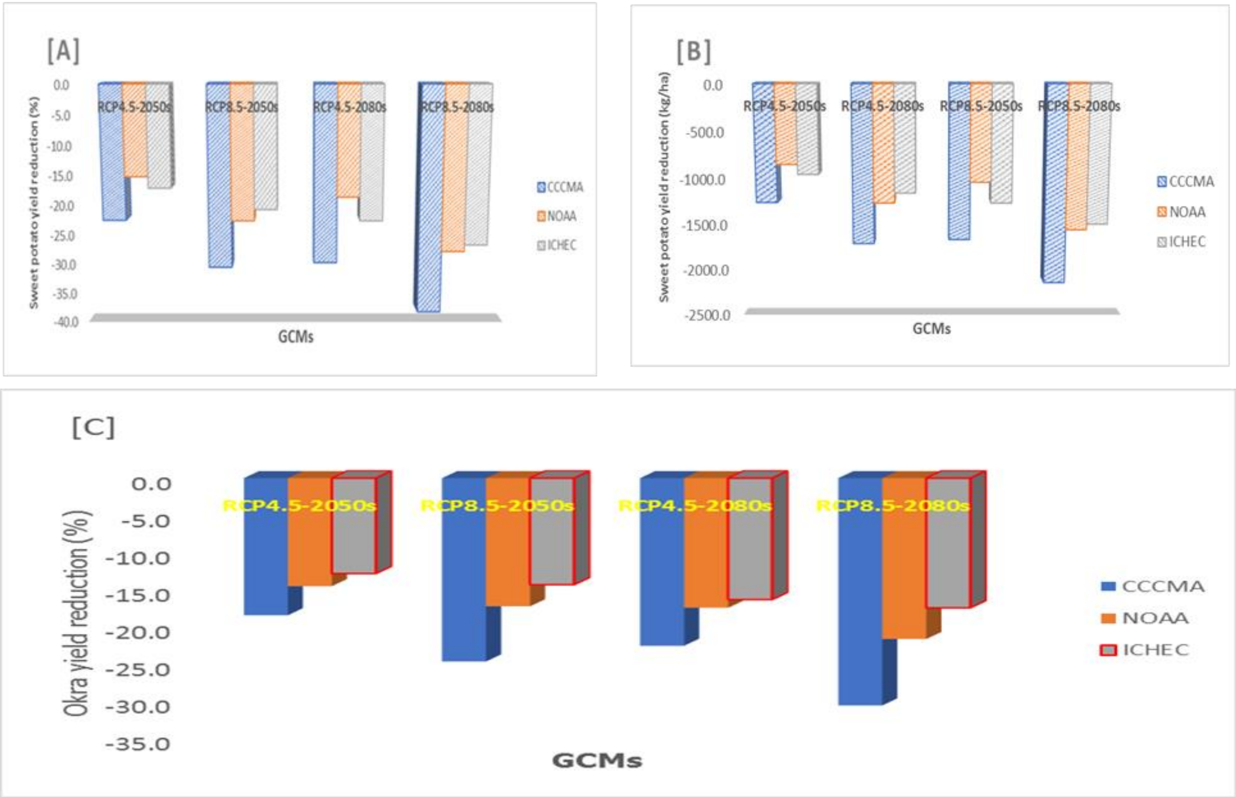

Figure 3: Changes in sweet potato yield under 3 GCMs in percent (a) and kg/ha (b), changes in okra yield reduction in percent (c) for 2050s and 2080s

4. Conclusion

Climate change study investigated the sweet potato and okra yield in response to projected climate in Edo State south southern Nigeria under median and worst-case emission scenarios (RCP 4.5 and RCP 8.5) using an ensemble of general circulation models for the short term (2049-2069) and at the end of 21st century (2070-2100). The outcome of the findings suggests that both crops will experience yield reductions during the 2050s and 2080s; yield decrease differs based on the selected GCMs. SP indicated higher yield decreases than OKR under the same conditions of hindcast climate analyses. Conversely, the crops could be considered as potential climate change mitigations crop due to their abilities to survive moderate drought occurrence and adaptability to various agro-ecological conditions. Since the projection of crop yield is dynamic and uncertain due to its dependence on possible damage of ozone and CO_2 fertilization, it is important to investigate the projected CC on the sweet potato growing length and OGCL to better under the yield behaviour.

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