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Research Article

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Assessment of Climate Change Effects on Cassava Water Requirements in Edo State, Nigeria

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Abstract The climate change (CC) study investigated the effects of projected climate on the crop water requirement (CWR) of cassava (Manihot esculenta Crantz) for 2030-2060 (the 2040s) and 2071-2100 (2080s) in comparison to the referenced period (1980-2010) using general circulation models (GCMs) under climate change scenario-representative concentration pathways (RCP 4.5). All the chosen GCMs indicated various degrees of temperature increases of 2.5°C-5.2°C by MPI, whereas MOHC and CCCMA predicted maximum temperature (Tmax) increase of 1.8°C-5.5°C and 1.1°C-2.2°C for 2040s and 2080s relative to baseline. Conversely, projected and historical climate datasets were run with CROPWAT 8.1 software to estimate reference evapotranspiration (ETo) and crop water requirement over the study region. Hence, MPI and MOHC models projected higher ETo values of 122.5 mm; 130.4 mm, and 119.6 mm; 128.5 mm in March for the 2040s and 2080s. However, the predicted increase in ETo could be attributed to the projected rise in temperature. Therefore, the simulation showed that increases in cassava CWR of 15.1%; 17.6% and 14.8%, and 18.1% were projected by CCCMA and MOHC models for 2030-2060 and 2071-2100 in response to baseline. Based on the projected increase in CWR from March to April, supplementary irrigation is needed to complement effective rainfall (Eff. Rain). Conversely, crop water requirement is likely to drop from April to May and increase from June to July, and finally decrease from August through September for the short (the 2040s) and long term (2080s) respectively. In conclusion, it is obvious that temperature increase significantly affects CWR and as such, it is important to adopt shift cultivation, sowing of drought-resistant cassava cultivar, water conservation, and holistic application of climate-smart agriculture (CSA).

Keywords Climate change, Crop water requirements, General circulation models, Manihot esculenta Crantz, CROPWAT Software

1. Introduction

Water is the most important natural resource for humans, plants, and animals which its shortage could cause negative reversible and irreversible effects. Hence, excessive precipitation on the other hand could be more catastrophic than agricultural and meteorological drought events due to reduced and high rainfall variability. Additionally, increases in temperature are the key driver for high evapotranspiration (ETo) and consequently lead to distortion in the hydrological cycle. [1] indicated that climate change (cc) is likely to have serious impacts on the hydrological cycle, water accessibility, and crop water requirements (CWRs). [2] revealed that climate warming has been attributed to the fluctuation of many components of the hydrological cycle such as changes in precipitation occurrence, distribution, intensity and increases in evaporative demand, and changes in surface runoff.

The climate condition of Edo State is tropical with the average precipitation of 1206.4 mm. The region has two climatic classifications as the rainy and dry seasons. The onset to cessation to rainfall occurs from May to October, while the dry period lasts from April to November with average maximum and air temperatures of 31.2^{o}C and 26.4^{o}C. Maize, cassava, groundnut, and rice are some of the important crops cultivated in the agro-ecological zones (AEZs) in Edo State, while cassava is the most cultivated crop with cultivated land increases of 36%, 40%, and 47% in 2010, 2015, 2018, and 2020 respectively. Agriculture in Edo State is predominantly rainfed and this makes it to be highly susceptible to changes in climate. Several studies have shown that CC is likely to further stress water availability, and agricultural production [3;1; 4]

An average cassava water requirement (CWRs) is about 400 mm to 600 mm and the temperature requirement is between 25-29^{o}C. At the initial-establishment stage (the first three months) the crop is highly sensitive to water deficit, while at the development and maturity cassava can withstand mild periods of drought [5]. Temperature an essential agrometeorological variable that determines crop phenological development. An increase in air temperature shortens crop growing length and consequently leads to low yield. [3] reported that a temperature increase of 1oC could change a crop's thermal limit and this is likely to decrease agricultural production between 5-25%. The finding of Mall et al. [6] indicated that global surface temperature (GST) is expected to increase by 1.4-3.0^{o}C from 1990 to 2100 for low greenhouse emission scenario, whereas for high emission scenario, the temperature is projected to increase from 2.5-5.8^{o}C. Conversely, projected temperature changes will affect crop sap flow, thermal limit, phenology, and crop yield. The effect of temperature increase is not limited to evapotranspiration, but also affects irrigation water requirement (IWRs) and crop water requirements (CWRs).

The climate study of [7] showed a rise in temperature leads to an increase in evapotranspiration. Hence, temperature increase, rise in reference evapotranspiration, wind speed, and sunshine hour in combination with crop coefficient (Kc) determines CWR. Several climate studies have shown that CC will negatively affect global future crop water requirements [7;8;3]. However, studies on CC effects on cassava water requirements over Edo State and Nigeria are generally limited, while many climate change studies on CWRs have been recorded on maize, groundnut, and rice over the study region.

The standard and well-accepted procedure for estimating CWR are through the application of CROPWAT software. The software uses robust meteorological variables (minimum and maximum temperature, sunshine hours, wind speed, relative humidity, precipitation) as inputs in combination with crop coefficient (Kc) to generate outputs such as reference evapotranspiration (ETo), CWR, solar radiation (Rs), IWRs, and actual crop evapotranspiration. CROPWAT software has globally been chosen over other process-based crop models due to its ability to simulate, estimate and predict CWR, IWR, ETo, and Rs under various climate change scenarios with reliable outputs.[3] revealed that the software performed very well in estimating CWR, irrigation planning, and scheduling from the past studies. Conversely, for effective water management and planning, it is essential to have good knowledge of CWR and changes in crop water requirements in response to CC. Therefore, in this study, baseline and projected cassava CWRs are computed using CROPWAT software version 8.1 for the short term (2040-2069) and long term (2070-2099) under three (3) general circulation models (GCMs) and two (2) representative concentration pathways (RCP 4.5 and RCP 8.5) in response to the baseline (1980-2010) over Edo State.

2. Materials and Methods

2.1 Study Area

The study covers Edo State located in the South-South region of Nigeria. The State lies at the latitude of 6.6342^{o}N and longitude of 5.930^{o}E at an elevation of 122 m above sea level and a total land square area of 17,802 km^{2}. The State has three distinct agro-ecological zones which comprise the rain forest and mangrove swamp in the South, a combination of little savannah and rainforest in the Central, and large Savannah and low rainforest in the North. Edo State shares boundaries with Kogi State to the north-east, Ondo State to the West, Delta State to the Southeast, and Anambra State to the east [9]. The State is a tropical climate with two distinct classifications as the rainy and wet seasons. The mean annual rainfall is about 1800 mm and the monthly air temperature of 27^{o}C. The annual relative humidity ranges between 80% and 85% from the northern to the southern part of the country. Fig. 1 shows the map of the study area.

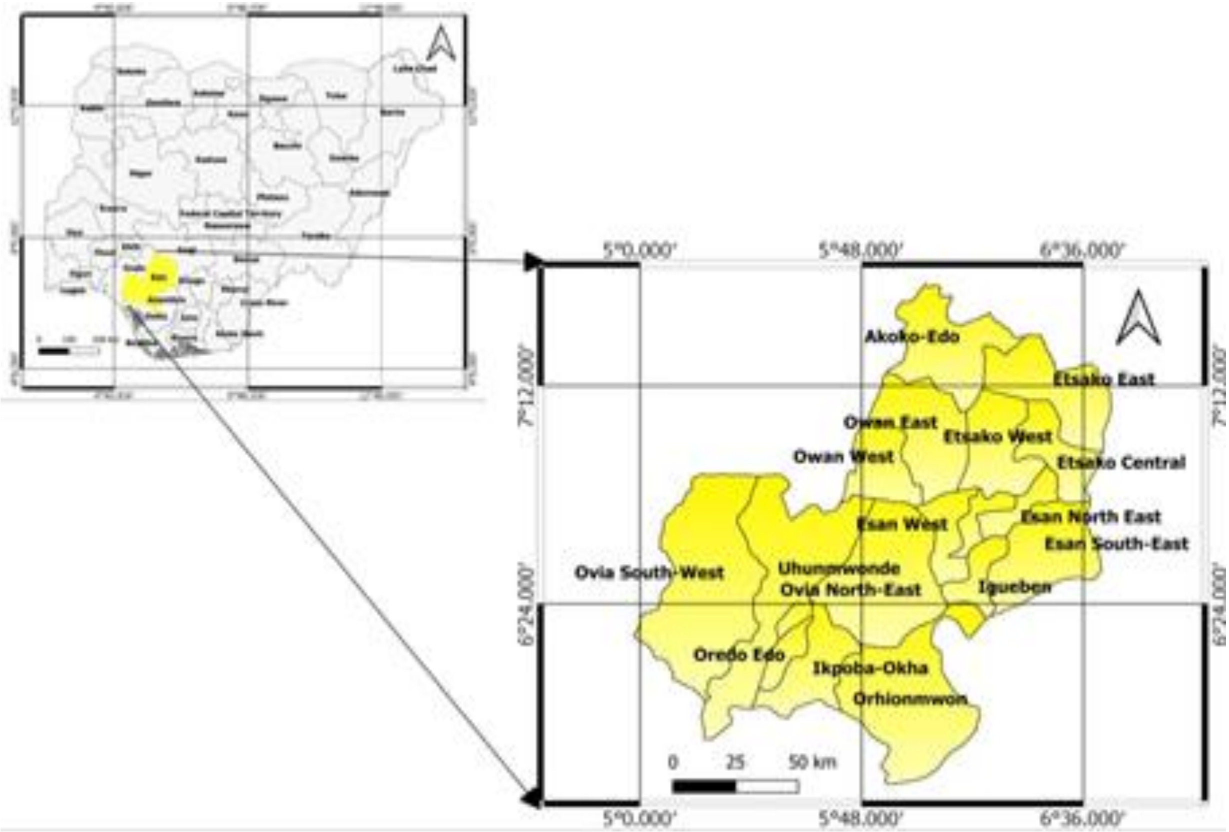

Figure 1: Location map of Edo State

2.2 GCMs Simulation Dataset

GCMs are typically run with various changes to forcing conditions, such as increased greenhouse gas concentrations in the atmosphere. According to [10], it is very important not to depend on one GCM alone, but several climate models predictions when developing assessment studies climate studies. Based on this, an ensemble of three (3) GCMs selected from the 5th Coupled Model Intercomparison Project (CMIP5) was used for this study. Statistical downscaling model (SDSM) which is a hybrid between a stochastic weather generator and a multilinear regression method, forcing synoptic-scale weather variables to local meteorological variables using statistical relationships [11] was used for the simulation. Historical monthly climate datasets for 1980-2010 were taken from the CRU TS2.1 database through the Department of Agro-climatological, Ministry of Agriculture & Natural Resources, Edo-State, Nigeria with a spatial resolution of 30 arc-minute. Future climate datasets (minimum temperature, maximum temperature, and precipitation) for the near (2030-2060) and long term (2071-2100) will be simulated from the six selected GCMs under the climate change scenario-Representative Concentrations Pathway (RCP 4.5). Table 1 shows the description of selected general circulation models, their spatial resolutions, and representative concentration pathways for the research study.

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
Max Planck Institute for Meteorology	MPI	96×192 cells, 1.90 ×1.90
Met Office Hadley Centre	MOHC	88×176 cells, 2.00 × 2.00

Adapted from [13]

2.3 CROPWAT Software

CROPWAT Irrigation model was used to compute the reference (ETo) and Cassava crop water requirement (CWR) under baseline (1980-2010) and future periods (2030-2060) and (2071-2100). The model, developed by FAO, is an irrigation management model to evaluate crop water requirements and irrigation needs [12]. The CROPWAT model was selected based on its ability to simulate the impact of various climate change scenarios on crop water requirement; and also, on the basis of previous successful studies and satisfactory performance in a number of worldwide locations under varying climate circumstances [14]. Table 2 shows the input and output parameters of the CROPWAT model.cassava–crop water requirements were predicted using CROPWAT software as shown in equation (1). The model also uses the in-built Pen-Monteith method to compute reference evapotranspiration (ET_o) (2):

$$CWR \quad = ET_o * Kc \qquad (1)$$

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \qquad (2)$$

CWR is crop water requirement in mm/day, Kc is crop coefficient and ET_o is reference evapotranspiration in mm/day. R_n is net radiation at the crop surface (MJ/m^2/day), G = soil heat flux density (MJ/m^2/day), T = mean daily air temperature at 2 m height (^{0}C), u_2 = wind speed at 2 m height (m/s); e_s= saturation vapor pressure (kPa/^{o}C); e_a = actual vapor pressure (kPa/^{o}C); e_s–e_a = saturation vapor pressure deficit (kpa); Δ = slope of vapor pressure curve (kPa/^{o}C) and γ = psychrometric constant (kPa/^{o}C).

3. Results and Discussion

3.1 Temperature Projection

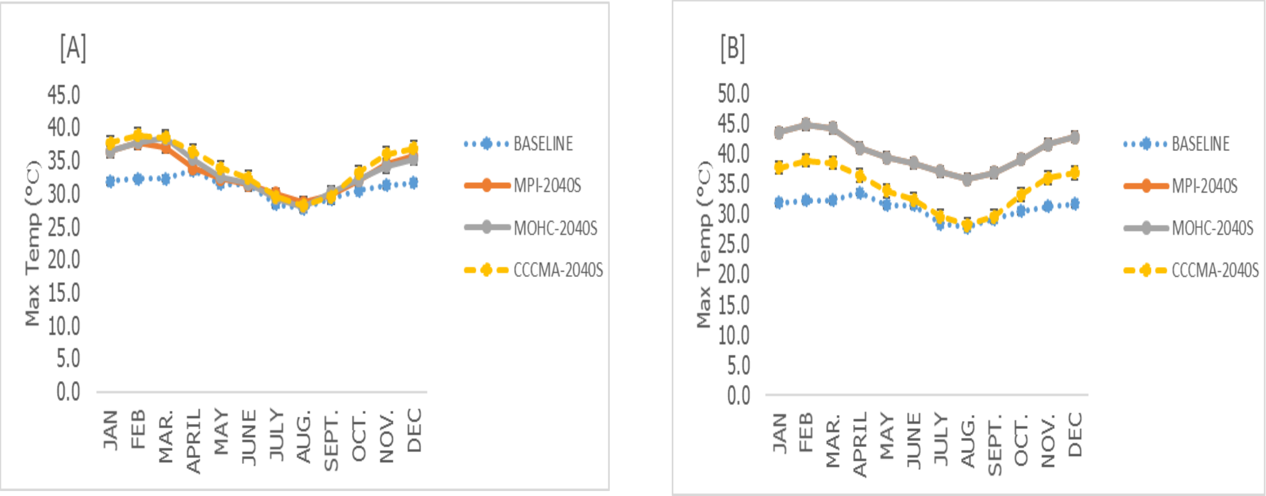

Figure 2: Temperature projection for 2030-2060 (a), and 2071-2100 (b)

The output of temperature projection showed increases in Tmax and Tmin for the 2040s and 2080s relative to the referenced period (1980-2100) by the selected GCMs over Edo State as shown in Fig 1a-b. However, the estimated annual Tmax was projected to increase by 2.5-5.2°C in MPI, 1.8-5.2°C (MOHC), and 1.1-2.2°C (CCCMA) for the 2040s and 2080s under the climate change scenario (RCP 4.5). The simulation runs indicated increases in annual changes for both minimum and maximum temperatures over the study region. The results of the projection showed very good agreement with the climate change studies in the literature [15;16;17]. Fig 2a-b shows the temperature projection for 2040s and 2080s respectively.

3.2 Reference Evapotranspiration

Historical and projected input variables (minimum and maximum temperature, wind speed, sunshine hour e.t.c) were run with CROPWAT software to compute reference evapotranspiration (ETo) and solar radiation (Rs) over the study region. Accurate estimation of ETo in combination with a crop factor (Kc) are essential input parameters to compute realistic crop water requirements (CWRs). Overall simulation indicated that October and March are the months with the lowest and highest estimated ETo by all selected GCMs (Fig. Ai and Aii).

Reference evapotranspiration increased from October through March, and the period represents the dry season. Again, it decreased from April to October which corresponds to the wet season. The finding is in agreement with the projections of reference evapotranspiration calculated using the Food and Agriculture Organization of the United Nations (FAO) 56 Penman-Monteith [18]. The observation shows that the regions are likely to experience a warmer climate with projected increases in temperature during the wet and dry periods as shown in (Fig. Ai and Aii). It is worthy of note that the predicted increase in temperature is responsible for the projected increase in reference evapotranspiration (ETo) since the temperature is the major driver of evapotranspiration. Fig 3 ai and aii shows the projected ETo from the selected GCMs

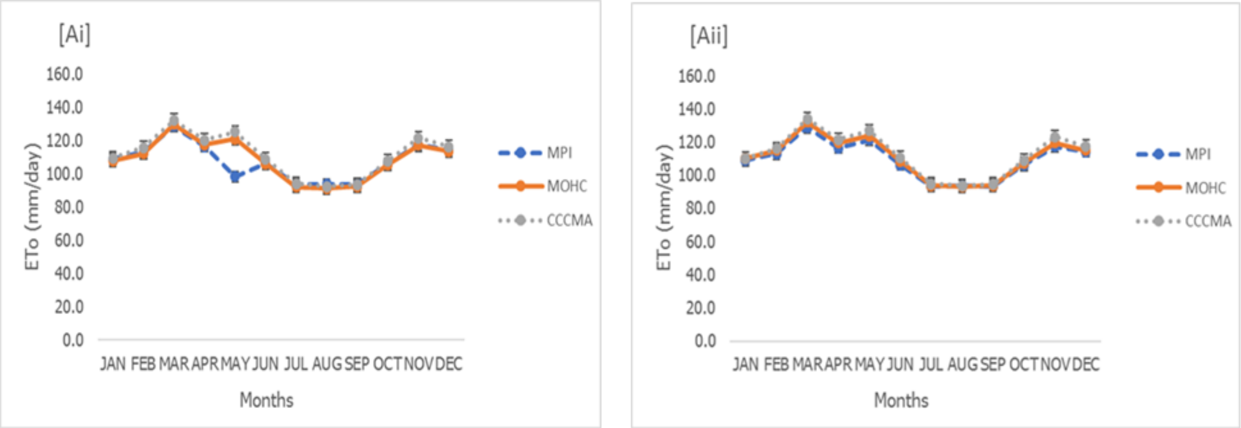

Figure 3: Reference evapotranspiration projections for 2030-2060 (ai), and 2071-2100 (aii)

3.3 Crop water requirements (CWR)

CROPWAT Software uses estimated reference evapotranspiration (ETo) computed using the in-built Pen-Monteith equation embedded in the software in combination with cassava crop coefficient at various stages (initial, development, and maturity) to compute baseline and future CWRs and irrigation water requirements (IWR) under various climate change scenarios. All the selected GCMs projected higher CWR by 2030-2060 than 2071-2100 in the month of March as shown in Table 2. Also, in April, MPI and MOHC predicted higher CWRs during the short term (the 2040s) than the long term (2080s), whereas the CCCMA model projected a higher CWR of 104.2 mm by 2080s than the estimated CWR value of 98.8 mm during the 2040s. Hence, CWR increased from March to July and reduced from August to September. The period of March to April is the initial stage, this is the period of crop germination and establishment and at this stage, the crop needs some moisture, and irrigation is required to supplement effective rainfall (EffRain). However, from May to July, the crop is at the developmental stages. During this stage, CWR is high, and as such irrigation is needed to supplement the gap between the CWR and EffRain. Conversely, from August to September, this period falls at maturity and harvesting stages where the effective rainfall is large enough to satisfy the CWR, and irrigation is not required.

Despite that cassava is a drought-resistant crop, the projected climate has a significant effect on cassava CWR, IWR, and yield. The changes in CWR were based on different GCMs simulations for a future period relative to the baseline as shown in Table 3. CCCMA and MOHC models estimated the highest CWRs in March with increases of 15.1 %; 17.6 % and 14.8%; 18.1% for the 2040s and 2080s in comparison to the baseline. respectively. However, there exists a reduction in a projected increase in changes in CWR from April to May and picked from June to July and finally dropped from August to September (Fig.4a-b). The observation can be attributed to projected temperature patterns. The overall result of the study indicates that the effects of CC will increase future cassava CWR and this will affect crop growth, development, and yield if supplementary water application is not carried out. However, irrigation schemes could be very difficult since CC will have serious impacts on river basins, surface, and groundwater which could further complicate the availability of irrigation water. Hence a shift in the growing period of cassava to April-May indicated a reduction in CWR by all the selected GCMs, which implies that there will be enough effective rainfall to meet up with CWR at the crop development stages. [3] revealed that a shift of growing period of wheat to November-October indicated an increase of CWR by 50 MCM/year, showing that shift cultivation is not advisable. Fig. 3a-b shows the predicted changes in CWR for short and long term.

Table 2: Baseline and projected cassava water requirements (mm) under RCP 4.5 in Edo State

	Baseline	**MPI**		**MOHC**		**CCCMA**	
Month	1980-2010	2030-2060	2071-2100	2030-2060	2071-2100	2030-2060	2071-2100
MAR	47.6	59.1	59.4	88.2	60.5	90.4	61.8
APR	88.7	99.8	95.0	99.5	96.7	98.8	104.2
MAY	143.6	149.6	151.1	147.3	150.9	154.7	155.4
JUN	140.8	151.1	151.6	147.4	151.4	155.5	155.6
JUL	133.1	150.1	151.2	147.6	148.8	150.7	151.4
AUG	124.1	142.9	139.6	127.0	137.0	137.5	138.3
SEP.	73.3	96.5	97.1	94.6	95.9	94.4	95.0

Table 3: Changes in cassava water requirements for periods under RCP 4.5

	MPI				**MOHC**				**CCCMA**			
	2040s		**2080s**		**2040s**		**2080s**		**2040s**		**2080s**	
Month	**Mm**	**%**	**mm**	**%**	**mm**	**%**	**mm**	**%**	**mm**	**%**	**Mm**	**%**
MAR	11.5	12.9	11.8	13.1	13.1	14.8	15.9	18.1	13.5	15.1	15.2	17.6
APR	11.1	12.5	6.3	7.1	10.8	12.2	8.0	9.1	10.1	11.3	15.0	17.4
MAY	6.0	4.2	7.5	5.2	3.7	2.6	7.3	5.1	11.1	7.7	11.8	8.2
JUN	10.3	7.5	10.8	7.6	6.6	4.7	10.6	7.5	14.7	10.4	14.8	10.5
JUL	17.0	12.7	18.1	13.5	14.5	10.9	15.7	11.7	17.6	13.2	18.3	13.7
AUG	18.8	10.1	15.5	12.4	10.7	4.3	12.9	6.2	13.4	10.8	14.2	11.4
SEP.	23.2	6.2	23.8	8.4	12.1	4.6	14.2	6.7	21.1	7.2	21.7	7.6

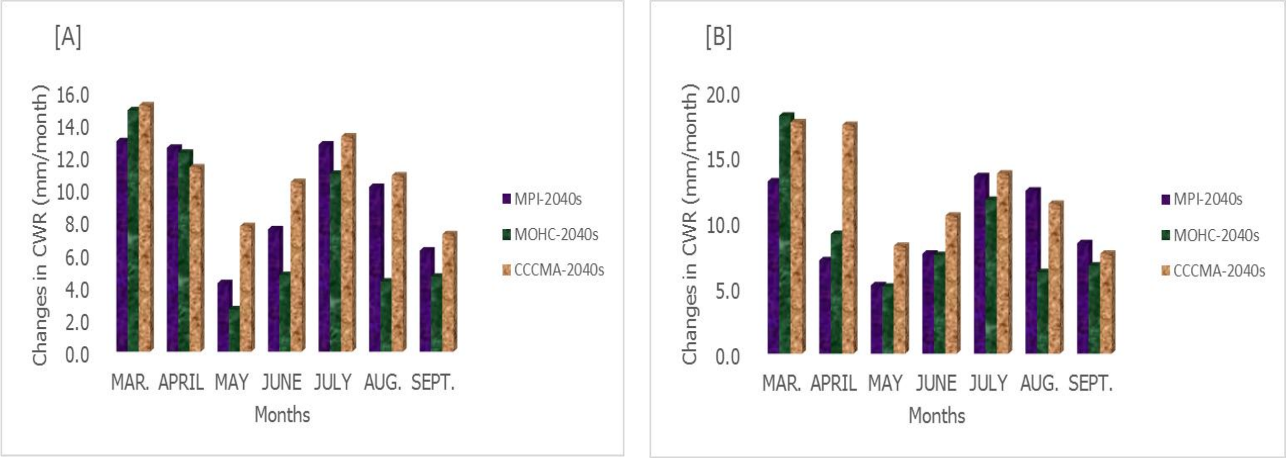

Figure 4: Changes in crop water requirements by 2030-2060 (a) and 2071-2100 (b)

4. Conclusion

The climate study investigated the climate change effects on Manihot esculenta Crantz water requirement over Edo State, Nigeria. The maximum temperature increased for the 2040s and 2080s relative to baseline. However, the temperature is a significant driver of reference evapotranspiration (ETo) and crop water requirements (CWRs). Hence, the output of the finding revealed that the percentage increase in CWR is at the highest during the germination and establishment (March and April) as projected by the selected GCMs for the 2040s, while in the 2080s, all the climate models followed the same pattern in March, and in April, MPI and MOHC models indicate decreases in CWR and CCCMA showed an increase in changes in CWR. However, the likely decrease in changes in CWR in May and June for the 2040s and 2080s corresponds to the early developmental stages and thus could be attributed to a possible increase in precipitation and effective rainfall. Hence, at the full development and early maturity stages, cassava leaves and canopy cover is large which consequently leads to high transpiration due to projected high-temperature rise. Based on the outcome of the study, it is obvious that CC has a significant effect on cassava water requirements. Therefore, it is important to adopt some mitigation strategies such as integrated water conservation and irrigation mechanism, planting of more effective drought-resistant cassava cultivar, shifting cultivation, and application of holistic climate-smart agriculture (CSA).

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