POTENTIAL IMPACT OF CLIMATE CHANGE ON CROP SUITABILITY IN NIGERIA

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Abstract
In Nigeria, where agriculture is a key source of income and uses rainfall as its primary water source for agricultural production, climate change has a severe negative influence on crop productivity. This study aims to establish the impact of changing climate on the suitability of cassava, rice and soybean production in Nigeria and detail these impacts. Ten Coupled Model Intercomparison Project 5 (CMIP5) Global Climate Models (GCMs), downscaled by the Coordinated Regional Climate Downscaling Experiment (CORDEX), were applied to carry out the crop suitability simulation using the suitability model, Ecocrop. The model shows that crop suitability is changing under projected future scenarios, and the changes in suitability are going to have major effects on cassava, rice and

Introduction

Agriculture is a major economic activity in West Africa. The agricultural sector employs almost 60% of the labour force and over 65% of all jobs depend on these industries (Serdeczny *et al*., 2017; Egbebiyi *et al*., 2019). Moreover, the agricultural sector in West Africa has contributed around 35% of the GDP over the past ten years, growing at an average rate of 5.9% and around 16.3% (or $6 billion) of the region's total exports of goods and services and 78% of its exports of food are related to agriculture (Blein*et al*., 2008). Also, through local production at country levels, agriculture alone meets around 80% of the region's food demands for the population (Egbebiyi *et al.,* 2019). For example, in Nigeria, over 70% of Nigerians work in agriculture, mostly at a subsistence level, and in recent years it accounts for 22.35 percent of the country's total GDP (World Bank, 2021). However, despite its economic contribution, Nigeria's agricultural sector faces numerous difficulties that have an impact on its productivity. These include climate change, poor land tenure systems, inadequate irrigation for farming, and land degradation. Other factors include inadequate financing, high post-harvest losses, low access to markets, low technology, high production costs, and poor input distribution (FAO website)

Climate change is putting the agricultural sector of tropical countries in jeopardy. This is due to shifts in weather patterns, which influence crop yields and production in these areas (Smith *et al*., 2014).The effect will be felt seriously in the tropics due to how climate change will alter weather patterns and water availability, with agriculture mainly rainfed in this region (Ilesanmi *et al*., 2012). In turn, crop yield and production cycles will be altered (Chemura *et al*., 2020). With lots of technological advancements in agricultural production, the effect of weather, especially temperature and rainfall plays a significant role in influencing crop production especially when most of this production is rainfed (Ochieng *et al*., 2016). Despite the potential role of multiple crops in the food basket, limited attention has been paid on assessing the impacts of climate change on multiple crops to provide farmers with options for diversification (Ray *et al.*, 2015).

Climate change is expected to have an impact on the stability of food production in many tropical countries by affecting crop potential. However, without quantitative assessments of where, by how much, and to what extent, none of this would be possible (Chemura *et al*., 2020),climate change is expected to have major negative impacts on the livelihoods and food security of such farmers. Governments and development professionals must confront the challenge of helping them to adapt (Shackleton *et al*., 2015). The predicted spatial and temporal shifts in temperature and precipitation are likely to result in diverse effects on crop productivity between different crops and regions. Increased temperatures are expected to increase crop water demand, which may lead to increased crop stress or reduced productivity (Zhao *et al*., 2017; Ilesanmi *et al*., 2023) with climate change expected to lead to reduced precipitation across all months of the growing season (Ugbah *et al*., 2020). In this study, we applied crop climatic suitability models to assess the impact of climate change agro-climatic suitability for cassava, rice and soybean in Nigeria. These crops make up the bulk of staple food available in Nigeria (Ene-Obong *et al*., 2013; Chiaka *et al*., 2022).

Materials and Methods

Study Area

This research was carried out across Nigeria. The region is found between 4°N and 14°N latitudes and 2°E and 15°E longitudes (Figure 1). It has an environment of tropical rainforest in the south and yearly precipitation of 1524 mm to 2032 mm. It also has the Savannah Zone, located north of Nigeria's tropical forest, representing the start of Northern Nigeria, with approximate annual precipitation ranging from 500mm to 1600mm with the Sahel savannah, found in the country's far north and has a desert environment with less than 500mm of annual precipitation (Ilesanmi *et al*., 2021).

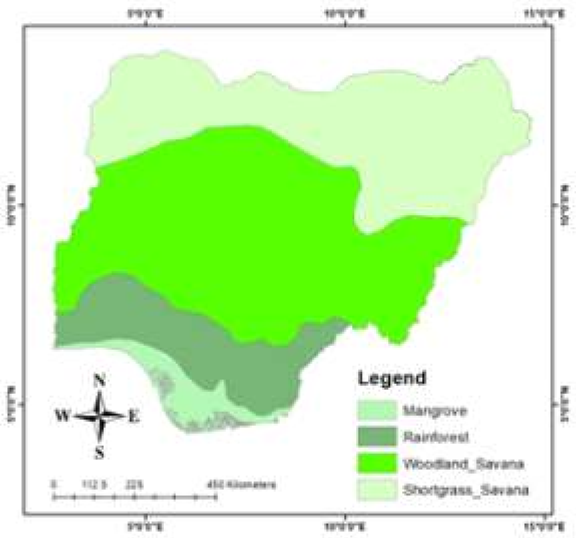

Figure 1: The Map of Nigeria

Data

The data applied for this research is in two sets, historical and future datasets. The historical data between 1981 and 2000 was obtained from the Climate Research Unit (CRU), University of East Anglia. The future dataset is the CORDEX model data which comprises of 10 selected GCMs that have been bias corrected. The data was downscaled at a resolution of 50km using the CMIP5 models. The models based on Representative Concentration Pathway 8.5 (RCP8.5) was used because it is the most realistic emission scenario mirroring what is obtained in Nigeria when compared to other scenarios in terms of greenhouse gas emission trajectories, and it also has the largest simulation ensemble members (Abiodun *et al*, 2019; Egbebiyi *et al.,* 2019b).

Model Description

The EcoCrop model is a tool designed by the FAO which incorporates fundamental mechanistic principles and industry-specific environmental range knowledge (Wichern *et al*., 2019).The Ecocrop model is a crop suitability model. It uses a crop growth suitability threshold dataset hosted by the FAO. This model was developed with basis on dataset obtained from the FAO (Egbebiyi *et al*., 2019). EcoCrop uses geospatial monthly precipitation and temperature data to assess suitability (FAO, 2016). For each crop, the model retrieves from the EcoCrop database the parameters that correspond to its acceptable temperature range, its acceptable range of total rainfall, and the length of the crop cycle. The calculation of the optimal, suboptimal, and non-optimal crop sustainability conditions based on the FAO datasets allows for the simulation of the suitability of crops in response to 12-month climate through the application of minimum temperature (t-min), Average Temperature (t-mean), and Annual Rainfall (precipitation) (Hijmans *et al*., 2001). The Ecocrop model evaluates the relative suitability of crops in response to a range of climates including rainfall, temperature, and the growing season for optimal crop growth. A suitability index is generated as follows: 0 < 0.25 (not suitable), 0.25 < 0.5 (marginally suitable), 0.5 < 0.75 (suitable), and 0.75 < (highly suitable) (Egbebiyi *et al.,* 2019). It should be noted that the months projected by the model simulations is the first of 3 months where the crops can be grown which in essence means if a the model projects a crop is grown in August, it can also be successfully cropped in the months of September and October)

Results and Discussion

Historical Crop Suitability and Planting Dates

The suitability and planting season of the three crops varies across Nigeria for the historical period. For example, the crop suitability map showed that the cultivation of soybean decrease as you move northward i.e. the highest and lowest suitability index are observed in the mangrove and rainforest towards the northern savannah zones of Nigeria respectively. Thus, it is highly suitable in the southern and up to the savannah short trees zone of Nigeria, marginally suitable in the northern part of the country while it's unsuitable in the extreme northern part of Nigeria. A similar spatial suitability pattern is also observed for soybean in the country. However, the opposite was observed for rice which is observed to be marginally suitable in the southern region but unsuitable in the Northern region of Nigeria .Climate is a major influence on the suitability and period of cultivation of crops. This is evident from our model validation analysis which shows there is a strong correlation between the observed data (CRU) suitability and CORDEX models simulated suitability as shown in Table 2. Also, results from the simulation of the historical crop growing season/planting period of cassava shows that the best time of planting is between the months of March – June; for rice is between the months of January – July while the period for soybean is between February – June.

Future Crop Suitability and Planting Dates

Studies have already shown that climate variables, especially rainfall and temperature are bound to change in the future, however there is still a lack of understanding on how this will affect crop suitability growth in Nigeria. This research examined how these changes will impact on crop suitability and growing season /planting dates of cassava, rice and soybean in Nigeria. Our result shows a projected decrease in the suitability of Cassava in the future over Nigeria. This implies cassava will become less suitable in the future compared to the historical period resulting in a shrink or reduction in the suitable areas in Nigeria. Cassava suitability showed a decreasing gradient from south to north as seen in. Historically, the Suitability Index Values (SIV) of cassava is between 1 – 0.2, and these SIV reduced between 0.2 to 0.35 in the mangrove, rainforest and woodland savannah region of the country except for the extreme northern region which is also described as the short grass savannah with no suitability. The future projections showed that for the regions where the crop is suitable, the SIV will reduce by an average of 0.35.This outcome is consistent with the findings of Jarvis *et al.* (2012) and Egbebiyi*et al.*(2019b), which found that although climate change may cause a drop in the compatibility and suitable cultivated areas for cassava, the crop will still be suitable across the region. In the southern region, the suitability has little or no change but as we travel further north towards the savannah zones, cassava suitability appears to reduce drastically. This might be associated with the projected drop in seasonal rainfall volume as latitudinal locations increases (IPCC, 2011; Olubanjo, 2019). The planting season for cassava is historically between April to June in southern Nigeria and May to October in northern Nigeria. The output of the simulation for future projection showed that the planting/cropping season may experience changes across the study area, especially in the northern region. The season in the mangrove and rainforest zones remains relatively unchanged while in the savannah zones, the season will experience a month delay in the middle belt of Nigeria while about two months of early planting is projected going further into northern Nigeria. This is in line with Manners *et al*., 2021 in their study carried over Central Africa that future climate will negatively impact the suitability of crops, especially for tuber crop except there are changes to their planting schedule.

Table 1: Projected Crop Suitability Over Nigeria for the Present and Future Periods

Model Name	Cassava Suitability		Rice Suitability		Soybean Suitability	
	Historical	**Future**	**Historical**	**Future**	**Historical**	**Future**
CRU	0.2 – 1	**N/A**	**0 – 0.8**	**N/A**	**0.0 – 0.7**	**N/A**
CanESM2	**0.2 – 1**	**-0.35**	**0 – 0.7**	**- 0.2S/ +0.2N**	**0.0 – 0.5**	**- 0.2**
CNRM-CM5	**0.2 – 1**	**-0.35**	**0 – 0.7**	**- 0.2S/ +0.2N**	**0.0 – 0.5**	**- 0.2**
CSIRO-Mk3.6.0	**0.2 – 1**	**-0.35**	**0 – 0.7**	**- 0.2S/ +0.2N**	**0.0 – 0.5**	**- 0.2**
GFDL_ESM2M	**0.2 – 1**	**-0.35**	**0 – 0.5**	**No change**	**0.0 – 0.5**	**- 0.2**
HadGEM2-ES	**0.2 – 1**	**-0.35**	**0 – 0.7**	**No change**	**0.0 – 0.5**	**- 0.2**
ICHEC	**0.2 – 1**	**-0.35**	**0 – 0.7**	**- 0.2S/ +0.2N**	**0.0 – 0.5**	**- 0.2**
IPSL-CM5A-MR	**0.2 – 1**	**-0.35**	**0 – 0.7**	**No change**	**0.0 – 0.5**	**- 0.2**
MIROC5	**0.2 – 1**	**-0.35**	**0 – 0.7**	**- 0.2S/ +0.2N**	**0.0 – 0.5**	**- 0.2**
MPI-ESM-LR	**0.2 – 1**	**-0.35**	**0 – 0.7**	**- 0.1**	**0.0 – 0.5**	**- 0.2**
NorESM1-R	**0.2 – 1**	**-0.35**	**0 – 0.6**	**- 0.2S/ +0.2N**	**0.0 – 0.5**	**- 0.2**
Ensmean	**0.2 – 1**	**No Change**	**0 – 0.5**	**No Change**	**0.0 – 0.5**	**No Change**

Ecocrop suitability Index: 0.0–0.25—Unsuitable/No suitability, 0.25–0.50—Marginally suitable, 0.50–0.75—Suitable, 0.75–1.00—Highly suitable

The study also showed that rice cultivation is very unsuitable in most parts of Nigeria. The ten (10) GCMs showed similar suitability and planting season patterns. Historically, rice is only suitable in the southern part of Nigeria (SIV ~ 0.3 to 0.5), especially in the riverine areas extending to the southern rain forest zone. This outcome is quite similar to reports from Bhutan which showed that rice suitability is mostly in the valley and flat areas of the country having a lower altitude which is also a typical topographical feature of southern Nigeria (Chhogyel*et al*., 2018). Future simulations showed that the suitability of rice production will remain unchanged and the regions which were previously not suitable will become further unsuitable as shown by the ensemble mean of the ten (10) GCMs. This is similar to the situation in many Eastern and South African nations, where the conditions in areas that were previously ideal for crop cultivation will become much less so, reducing the number of hectares that can be planted as well as the productivity of the remaining land. Agricultural practices are expected to be impacted by this in the future (IFAD, 2021).Also Abah and Petra (2016) carried out a study in central Nigeria which agrees that the suitability of rice in the region goes from being marginally suitable to being unsuitable. This unsuitability might invariably contribute to a decrease or loss in rice yield across Nigeria, a scenario that agrees with a study which showed that climate change will negatively impact the yield of rice in Bangladesh (Ara *et al*., 2016). The individual GCMs however produced a mixed suitability pattern where there is an improvement in suitability, mostly in the northern part of Nigeria and reduced suitability in the south. Despite this, rice will remain marginally suitable in the southern region of Nigeria (SIV ~ 0.5 down to 0.3) while it will still be unsuitable in the northern area of Nigeria (SIV ~ 0 up to 0.2). The planting/cropping season for Rice across Nigeria is also expected not to experience serious changes. The ensemble mean simulation showed that the cropping/planting season for rice, which historically is between the months of January through August (will experience no change except a bit of a delay in planting in the extreme southern part of Nigeria. In this region, the historical planting season begins in the month of Apr/May but future projection shows that the planting season can as well commence from the month of Mar/Apr.

Soybean is quite suitable across most past of Nigeria. Historical simulations for the crop shows that the despite being sustainable in Nigeria, the level of sustainability is mostly marginal. The crop performed best in the South-western region, extending eastwards as well as towards the fringe of the middle belt region of Nigeria, although, the suitability declines as we travel towards the extreme south, typified by mangrove forest and the extreme north which is the Sahel savannah. Future simulation for soybean suitability projects a decline. This mirrors the outcome of studies according to Caetano *et al*. (2018), Traoré *et al*. (2021) and Issifou *et al*. (2022) which reported that climate change will negatively impact the production of soybean in the republic of Benin in future by reducing its production areas. CORDEX models also projects the declination of soybean suitability across Nigeria to range between SIV ~ 0.1 – 0.3. By this, soybean will go from marginal suitability to very marginal suitability in the south while it will regress from very marginal suitability to being unsuitable in the north. In the rainforest and savannah regions where soybean is suitable in Nigeria, the historical planting/cropping season begins in the month of February in the south extending to the month of March in the north. Future projections shows that there will be very slight changes to the planting season with the cropping season delayed for about a month in the south while early planting by up to a month is also projected for the north. A study by Mall *et al*. (2003) in India and Bao *et al*. (2015) in the USA also showed that delaying the sowing dates would be advantageous to soybean production, according to the results of the mitigation option for lowering the detrimental effects of climate change on the crop. By implication, the season will begin in March for the southern region while February will be a suitable month to begin the cultivation of soybean in the northern region of Nigeria.

Adaptation strategies

Cassava, rice and soybean will be impacted by climate change based on the outcomes obtained from future simulations of these crops. The differences in their behaviour and response to rainfall and temperature in the future are evident when compared to historical climatic conditions across Nigeria. This research is also aimed at extracting/modelling adaptive measures to these projected changes in crops' response. Based on the outcomes from Ecocrop simulation, the ensemble mean showed that there will be little or no change in planting seasons for the 3 crops whereas individual GCMs presented diverse results. For changes in planting season of cassava, there will be a 2 months delay in the coastal region for cassava planting while there will be a delay of an average of 1 month for other regions similar to reports from Egbebiyi *et al*. (2019b) in which most crops examined across the West African region showed either no change in planting season or a month delay in planting season. In rice, there will be a relative no change in planting season and where there is the most change will be a 1 month delay in planting season. The scenario for cassava also repeated itself for soybean.

Options for adaptation beyond crop level were not investigated in this research, yet they have the potential to ameliorate deficiencies on crop production and yield that may be encountered due to climate change. However, other adaptation tactics, like embracing crop insurance, taking part in payment for work programs, or finding sources of off-farm income, can empower farmers to innovate while taking a greater risk, putting a new soil management practice into place (Eakin 2005; Beveridge *et al*., 2018). Proper dissemination of climate information to farmers in real time can also be adopted with adequate attention and support given to climate geo-engineering to help keep policy makers better informed about the pros and cons of climate change, particularly on how it impacts crop suitability in a bid to help improve food security in Sub Saharan Africa.

Conclusion

With the aim of deducing the effect of climate change on the suitability of producing cassava, rice and soybean in Nigeria, the crop suitability model used in this study has been able to simulate how the cultivated area and planting dates of these three crops will fare in the future. In general, the simulation results indicates that future climate conditions could pose a serious threat that may lead to a decrease in suitable area of these crops, with the suitability index values of these crops reducing by up to 0.35, 0.25 and 0.2 for cassava, rice and soybean respectively. This may probably cause a loss in yield if not adequately mitigated. These changes in suitability was also found to impact the planting pattern of these crops and our findings suggest that delaying the sowing dates of these crops in regions where necessary should be able to mitigate the detrimental effects of climate change in the future. However, change in management practices can also be adopted to ensure production losses are adequately mitigated. The present study has enhanced our understanding on crop suitability modelling over Nigeria and it affects three crops. The study will also help policy makers to informed decision in the choice of adaptation strategies that can help enhance the suitability of the crops and so as to meet the Sustainable Development Goals 1 (SDG 1) of zero hunger and food security in Nigeria and sub-Saharan Africa.

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