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Modeling Crop Production under Climate Change in Southeast Nigeria: Agroecology as a response

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Abstract

Nations of the world have seen unprecedented changes in climate variables in recent decades. But it is unclear to what extent climate change has impacted and will impact food systems in some developing regions, and how policymakers can frame an approach to encouraging adaptation and advancing climate-smart agriculture. Many studies attempting to link agroecology to climate change adaptation do so without understanding the potential of Agroecology not only to mitigate climate change – which is the weak response – but to reverse its impact and 'climate proof' our food systems. By modeling the near and far future impacts of climate change on crop production, we showed how climate will impact crop production under two crop production systems (agroecology and non-agroecology production systems). The overarching aim is to derive sustainable development strategies and lessons for policymakers and climate researchers - essential components of environment and Agricultural development. Using case studies from Nigeria, we observed that transitioning to agroecology, even at the farm level also transforms farm designs, thereby affecting their overall food and nutrition status. The result showed that the use of agroecology management practices not only reduces the impact of climate change in the near future but will also lead to increased crop yield in the future. The finding suggests that to feed the over 400 million projected population of Nigeria by 2050, the use of agroecological practices will be a better alternative to the conventional farming methods. To advance the use of agroecological farming methods, governments at every level in Nigeria need to mainstream organic agriculture in national government policies. This is important as it will not only address climate change impacts but also hunger and poverty.

Keywords: Agroecology, Bio-economic farm models, Crop Syst, Aqua Crop, Organic farming**,** sustainable development

1. Introduction

The impact of climate change undermines efforts in achieving the Sustainable Development Goals. According to the Intergovernmental Panel on Climate Change, climate change is the alteration in global climatic patterns, which can be observed by the changes in weather properties over a period of time (IPCC, 2007a). The impact of climate change has become evident, not only in the threats it poses to the environment, but also in the fight toward poverty eradication, disease control, and zero hunger. These effects are traceable to their direct and indirect impact on the agricultural sector, especially in crop production (Ume, 2018). Although substantial efforts have been directed toward climate change mitigation (i.e. addressing the causes of climate change), there is also a critical need to build resilience capacities within the agricultural sector and national food systems. As stated in IPCC (2007) such climate resilience framework and adaptive capacities will help grapple with current and future impacts of climate change. According to the IPCC (2007, p.3), climate change adaptation is the “adjustment in natural or human systems to a new or changing environment". This means that efforts in climate change adaptation among farmers will create a system capable of cushioning present and future impacts from Climate Change thereby enabling farmers to cope with future climate change outcomes.

Furthermore, the climate change and food security report of the Food and Agricultural Organization (FAO) indicated that changes in climate properties will aggravate the challenges confronting food crop systems (Food and Agriculture Organization, 2018). According to the report, climate change will have a direct and indirect impact on crop growth, market flows, and livelihood assets of the rural populace. In recent decades, progress in climate research has improved the understanding of how climate change influences agricultural productivity, triggers biodiversity losses, and undermines sustainable development efforts (Kessete, Moges, and Steenhuis, 2019; Mamoon and Rahman, 2019; Mengistu *et al.*, 2019). As recent changes in climate properties have been more rapid compared to any other time in human history, literature has called

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for innovative research direction that critically projects climate impacts to establish targeted and more coordinated adaptation decisions (Mengistu et al., 2019). Key to the ability of farmers to make an informed decision and adapt to climate change and variability will be access to relevant information and knowledge (Challinor *et al.*, 2005).

In Nigeria, due to high poverty levels, population expansion, and heavy dependence on rain-fed agriculture, climate change impact on the national economy of most nations in the region is expected to be exacerbated as agriculture plays a dominant role in supporting economic growth and rural livelihoods (Boko, 2007). According to Challinor et. al. (2005) crop farmers in Africa are vulnerable to climate change impacts due to three critical reasons: 1) vulnerability of crops to variability in climate properties, 2) low adaptive capacity of farmers, and 3) institutional failure in facilitating climate change adaptation. The foregoing suggests that in Africa, there exists the triple burden of high poverty levels, population expansion, and the growing demand to safeguard the environment (Ume, 2017). These challenges place the demand on farmers at all levels to increase productivity in other to meet the food security needs of the population. The need for achieving food and nutritional security and at the same time some level of environmental stewardship among farmers in Africa have called for a rapid shift from conventional agricultural practices to a more sustainable production method. This call transcends a shift in farming practices that employs external inputs, which has adverse effects on the soil and people's health, to a sustainable organic farming system that simultaneously supports environmental sustainability and food productivity, while promoting rural livelihoods. Agroecology and organic agriculture have been advanced as a sustainable farming practice that can improve the above challenges, as it has been proven to be efficient, productive, and resilient (Altieri and Toledo, 2011; Altieri, Funes-Monzote and Petersen, 2012; Wezel *et al.*, 2014).

According to FAO (2008), climate change impact first affects food systems and livelihood groups with a higher level of vulnerability. Ume, Opata, and Onyekuru (2021) noted that among farmers in Nigeria, the female smallholder farmers are expected to be of low adaptive capacity and high exposure and sensitivity to climate impacts due to socioeconomic and institutional factors that undermine their adaptation efforts. There is, therefore, a growing focus on the need for "transformational adaptation" (Eakin and Wehbe, 2009), that is the re-evaluation of institutional and socioeconomic factors or relations, established over time, which determine limits the adaptive capacity of smallholder farmers. Institutional transformation is therefore imperative if meaningful adaptation effort is to be achieved in overcoming the impact of climate change as smallholder farmers contribute over 70% of food and labor in Nigeria. Most of the governments in the continent still assume that maximizing food production will automatically lead to a reduction in food insecurity and malnutrition. It is also widely assumed that commercialization in agriculture and large-scale agribusiness lead to better food systems, with better-nourished food system members. Research has shown that around 80% of the Africa's poor derive their livelihoods from production-based entitlement and not market based entitlements (Thompson, 2015). Given this fact, food system initiatives built narrowly on strengthening green revolution strategies may ignore the bulk

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of the continent's poorest individuals. We need to create a food system in which smallholder farmers can become empowered actors.

This research intends to provide context-specific evidence on the need for agroecology and sustainable agriculture in counteracting the impact of climate change in the agricultural sector in Nigeria. The overarching aim is to study the climate change implications and sustainability of organic farming compared to conventional farming, thereby deriving evidence and lessons for policymakers, and eliciting informed actions and procedures on how to fashion agroecological strategies. This will help fast-track the development of Agroecosystem practices in the food systems of Africa. To achieve, this research will seek to provide answers to the following questions:

i) What is the impact of climate change on crop productivity in Nigeria?
ii) What are the different agroecology measures employed by smallholder farmers in adapting to the impact of climate change on crop productivity?
iii) How effective are the adaptation measures adopted by farmers in different agroecological regions?

2. Agroecology and farming systems in Nigeria

By definition, a farm that is not more than 5 hectares is categorized as a small scale (CGIAR, 2013). Based on this classification, over 80% of farmers in Nigeria are smallholder farmers (Mgbenka and Mbah, 2016), as over 80% of farmers in Nigeria farm below 5 hectares. This set of farmers produces over 98% of the food consumed in Nigeria apart from wheat and about 99% of total crop output (Mgbenka and Mbah, 2016), suggesting that they play the dominant role in the agricultural sector of the economy. This also points to the fact that a typical characteristic of the production system in the country is that a disproportionately greater portion of the farming output rests in the hands of smallholder farmers. Therefore, one can reasonably submit that a typical farming community in Nigeria comprise of smallholder farmers, producing food (crop and animal), not just for family consumption but for commercial purposes as well. According to Adewumi & Omoresho (2002), it is the progress of these farming communities that will, to a great extent, determine the progress of the agricultural sector.

Nigeria is a federation comprising 36 states with six geopolitical zones and seven vegetation types: Mangrove Swamp and Coastal Vegetation, Lowland Rain Forest, Freshwater Swamp Forest, Derived Savanna, Sudan Savanna, Guinea Savanna, and Sahel Savanna. In all these zones, farming is predominantly small-scale. Despite the small-scale nature of farming in the country, Nigeria is the highest producer of maize and cassava globally followed by Brazil (Opata *et al.*, 2021), and the highest producer of rice in Africa (Akpoti *et al.*, 2021). The southeast region of Nigeria has seen unprecedented changes in climate variables for more than two decades (Chukwuemeka, Alaezi, and Ume, 2018). But it is unclear to what extent climate change has impacted and will impact major food crops in southeast Nigeria, and how policymakers can frame an approach to

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encouraging adaptation and advancing climate-smart agriculture. This study seeks to examine these concerns and understand how and to what extent changes in climatic conditions will affect crop farmers' productivity in the short and long run. The overarching aim is to derive evidence and lessons for policymakers and climate researchers - essential components of climate change and international development.

Small-scale farmers produce a greater percentage of these three crops. According to the Animal Science Association of Nigeria, large-scale farmers are mostly concentrated within the animal sub-sector (Finelib, 2019). Although the impact of climate change on food and nutritional security and environmental sustainability is continuously gaining attention across Nigeria, the Southeast region is however complicated as it is also burdened with environmental issues such as soil erosion (Okorafor, Akinbile, and Adeyemo, 2017). However, because the technology employed in the agricultural revolution for climate change adaptation in required capital, only a large few farmers could maximize production under climate change.

In some other parts of Africa such as Kenya and Tanzania, we have seen how effective Agroecology and indigenous knowledge can be in fostering sustainable agriculture among smallholder farmers through soil fertility improvement (Simon, Montero, and Bermudez, 2020), drought control (Botelho, Cardoso and Otsuki, 2016) and platform for social interactions among farmer (Silici, 2014). The emphasis should now shift from the big-scale transformation approach to the small-scale improvement strategy approach, which is attuned to Nigerian age-long farm practice. Innovative approaches to increase productivity enhance the resilience of agricultural systems, and give back control of the food system to the smallholders are therefore needed. No published research covering the knowledge and practice of agroecology by farmers in southeast Nigeria based on detailed and consistent field data is available. Rural empowerment and inadequate research in the area of indigenous knowledge use is listed as a constraint in the newly adopted Nigeria's Agriculture Transformation Agenda (Federal Ministry of Agriculture and Rural Development, 2017).

According to Wezel, Bellon, & Doré (2009) the word 'agroecology' was first mentioned in Bensin (1928). Since then, the term has increasingly attracted the interest of policymakers, advocacy groups, and researchers from different disciplines. Alexander and Jauneau (2011) attribute this rise in popularity to the need for agriculture to respond to the many sustainability challenges including food security, biodiversity conservation, and rural development. Over the years, due to the multidisciplinary/cross-disciplinary nature of the term "agroecology", diverse definitions and conceptualizations have emerged. Table 1 presents the different definitions and conceptualizations starting from Bensin (1928) when the world was first used.

The definitions presented show that the concept of agroecology has been an evolving concept both in research and in practice. Between 1928 and 2000, agroecology was conceptualized as a method of applying principles of ecology in climate and land management to increase farm production with reduced immediate ecological consequences production (Bensin, 1928; Azzi, 1956;

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Gliessman, 1998). From the year 2000, the 'food system component was added to the definition. Here, agroecology as a concept is discussed beyond farm-level analysis and immediate biophysical impacts at the farm and field to include how all the elements of a food production-distribution-consumption system come together and interact with one another (Dalgaard et al., 2003; Francis et al., 2003; Clements & Shrestha, 2004; United States Department of Agriculture (USDA), 2007). Subsequently, the emphasis shifted to food sovereignty and the right to food, without losing the sustainable production and food system components (De Schutter, 2011; FAO, 2014; Edwards, 2017).

Ever since the concept of agroecology has continuously evolved and re-formed. In fact, because of the diversity of ways the term agroecology is understood and approached, the Food and Agricultural Organization (FAO) has maintained a database of definitions of agroecology from published documents, authored by researchers, academia, civil society, legal documents, governments and policies(FAO, 2019c). In fact, the FAO (2019) database currently has 401 definitions, in English, French, and Spanish which shows the variety of ways in which agroecology is approached or conceptualized. However, in general, the underlining characteristic of agroecology as a practice is the need to minimize the use of external chemicals in crop or animal production, in that regard, for this study, the categorization of farmers into agroecology and non-agroecology is based on the use and non-use of chemical in crop production.

3. Materials and methods

3.1 Model choice

There are three kinds of quantitative methods of climate impact investigation; these are the agronomic models, the Ricardian models, and the agroecological zoning studies (Kessete, Moges, and Steenhuis, 2019). Whereas the Ricardian models depend on long-term time-series data, it flaws in terms of forecasting agricultural productivity under changing climates (Reinsborough, 2003). To capture the effect of climate change on crop productivity, agronomic models such as CropSyst and DSSAT are usually employed to capture the complexity involved in crop yield modeling (Challinor *et al.*, 2005). In this regard, such models could uncover the sensitivity of the impact of climate change on crop yields, management practices, and the biophysical environment. Several studies have employed this model to predict yields as well as to conduct climate change impact assessments at the farm level impact of climate change (Stöckle, Donatelli and Nelson, 2003; Stöckle *et al.*, 2014; Abi Saab, Todorovic, and Albrizio, 2015). Hence, their usefulness in simulation has been proven largely and well employed in climate change impact modeling. The disadvantage of this technique, however, is that they ignore an important aspect of crop production which is the decision makers' adaptation behavior (Schönhart, Schmid, and Schneider, 2011). However, it is generally acknowledged that the decision makers' adaptation behavior is endogenous in understanding the impact of climate change on crop production, especially in the prioritization of adaptation options.

The above flaws necessitated the need to adopt the well-known integrated models known as the bio-economic farm models (BEFM) in this study (Linderhof, Janssen, and Achterbosch, 2019; Pahmeyer, Kuhn, and Britz, 2021). In this study, we simultaneously accounted for biophysical changes as well as agroecology management decisions for different farming systems. This means that the BEFM allows for accessing the different levels of agroecology practices that a farmer decides to adopt on the farm. Because data for the analysis was based on the same agro-ecological zone with similar soil type and fertility, it becomes easy to isolate the impact of farmers' decision or choice of use of agroecology practices. This makes the bio-economic farm models appropriate for ex-ante assessment of different climate, policy, and technological scenarios even with limited availability of data (Linderhof, Janssen, and Achterbosch, 2019).

3.2. Farm survey and modeling approach

We identified 19 agricultural zones based agroecological diversity of the zones (Morgan, 2019). We calibrated the BEFM for the agricultural zones in Southeast Nigeria (Aba, Umuahia, Bende, Okigwe, Orlu, Owerri, Enugu, Agbani, Udi, Awgu, Nsukka, Enugu Ezike, Ebonyi North, Ebonyi South, Ebonyi Central, Aguata, Anambra, Awka and Onitsha). We differentiated these zones based on similarities in soil characteristics. We surveyed 1221 farm households from the different agricultural zones during the years 2020–2021. We used the sampling procedure of IMEA (2010) in the selection of farm households. We used the BEFM taking into account the risk component. The aim is to consider the impact of climate change on the three main crops cultivated in the region (maize, rice, and cassava). As a first step in the modeling process, we spatially downscaled the climate change scenarios to the local level. Downscaling is a process of deriving regional or local climate information from a general circulation model. The downscaled scenarios are applied to the crop model. With the combination, we can estimate the impact of climate change on the productivity of the crops under consideration. Figure 1 shows a schematic representation of the process. To calibrate the simulation of the crop model, we used the actual farm management practices as well as crop experiment data collected from farm surveys. The outcome of the simulation model (in this case, the crop yield) is used in the farm-level stochastic optimization model to show the impact of climate change (yield performance).

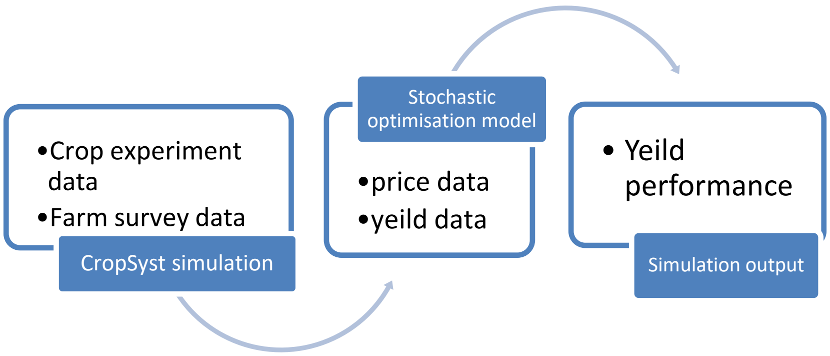

Fig. 1. Flow chart of our modeling system.

3.3 Climate change scenarios

We employed the A2 greenhouse gas emission scenarios of the Intergovernmental Panel on Climate Change (IPCC) in this analysis (IPCC, 2007b). The A2 scenario was preferred as it is the higher end of the Special Report on Emissions Scenarios (SRES) emissions. From an adaptation and impact point of view, a farm system that adapts to a larger climate change scenario can as well adapt to a smaller climate change scenario. The scenario assumes that there will be an increase in growth, the population will peak by the mid-century, and there will be an increase in new technologies. From the 23 General Circulation Models (GCM), we downscaled the temperature and precipitation for future periods. This gave rise to a monthly temperature deviation (ΔT) and monthly precipitation deviation (ΔP) from the historic data supplied. The result is presented in Table 1. The figures as presented in Table 1 show that in all the agricultural zones precipitation and temperature increased but the variation differs among the agricultural zones.

Table 1. Model scenarios indicate the mean annual precipitation and temperature changes with respect to the baseline scenario.

	A2 (2010–2039)		A2 (2070–2100)	
	Temperature (°C)	**Precipitation (mm)**	**Temperature (°C)**	**Precipitation (mm)**
Aba	27.9	60.86	30.1	102.3
Umuahia	28.9	99.73	32.0	112.5
Bende	28.9*	66.23	31.1	96.2
Okigwe	28.2	70.86	30.4	152.8
Orlu	28.1	114.08	29.2	124.2
Owerri	28.2	75.01	32.1	98.2

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Enugu	28.2	72.0	30.5	63.2
Agbani	29.9	67.2	33.2	61.5
Udi	28.1	77.0	30.5	61.0
Awgu	28.9	85.7	32.1	98.1
Nsukka	30	114.5	33.5	122.2
Enugu	28.9*	87.2	32.6	74.8
Ezike	28.8	103.5	31.1	115.0
Ebonyi North	30.1	121.1	33.9	121.8
Ebonyi South	29.1	148.5	32.1	135.8
Ebonyi Central	30.1	121.1	32.1	115.0
Aguata	28.9*	144.0	31.5	122.0
Anambra	28.9*	150.0	31.6	135.2
Awka	28.9*	132.0	31.5	111.9
Onitsha	28.9*	122.0	31.5	129.0

* Signifies extreme variations

To determine the variations in yield amount under different climate change scenarios, we apply the obtained climate change scenarios to the crop simulation models. We employed the stochastic weather generators (WGs) to estimate the daily data since the crop model will require daily time step data.

3.4 Crop model

We analyzed the crop yields under the near-future scenario (2011–2040) and far future scenario (2071–2100) with the help of Cropping Systems Simulation (Crop Syst) and AquaCrop models. Calibration of the Crop Syst and Aqua Crop model was carried out based on conservative parameters stipulated in (Hs*iao et al*, 2009). The models were validated using data collected in the 2020 and 2021 cropping seasons. The production of cassava was simulated by Crop Syst while the production of maize and rice was simulated by Aqua Crop. The models were calibrated with experimental data based on input using Agroecology management (use of organic fertilizer, push and pull technology, and zero tillage) and Non-agroecology management (inorganic fertilizers, pesticide use, and soil tilling practices). These were carried out for three years of weather and growth records. The input use of agroecology and non-agroecology farm management patterns were used to indicate the two-management option of interest in the study. The models were then utilized for the above-mentioned sceneries and periods.

3.5. Estimation of value-variance

Our interest is not only to investigate the yield variance as a result of climate change but to also understand the covariance between them. This is important in order not to produce a wrong estimation of impact. For example, in the case of a mixed or multiple cropping situation, without the use of a stochastic modeling framework, we might end up over or underestimating impacts. We used the expected value-variance framework strategy to capture the effect of risk associated with crop allocation and input use levels as a result of agricultural decisions employed (Hardaker

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and Lien, 2010). In the expected value-variance framework strategy, we determine the choice of activities or crop combination, which will provide the farmer with the highest utility by taking into consideration the utility variability and its corresponding covariance for the different crop combination choices. The approach is utilized to assess what the impact of climate change will be as a result of a farmer's responses in terms of resource use and crop combinations. Using the BEFM model, we can determine what the optimal cropping allocation and crop combination will be for different climate sceneries. The optimization was based on certainty equivalent (CE) which is the expected income and variance of income of the different combinations (Riddel, 2012). The expected certainty equivalent is given by

$$maxEU = E(Y) - \frac{\lambda}{2} V(Y)$$

$$Subject\ to\ Bj \geq \sum_{i=1}^{n} aijHi$$

Where *E(Y)* = total expected income

V(Y) = Income variance

λ = Absolute risk aversion

Bj = availability of *j*th resource

aji = input use coefficient for crop *i*,

Hi is the area under each crop

The expected certainty equivalent can be used to estimate the risk-free income such that options with higher expected certainty equivalent are preferred over the option with lower expected certainty equivalent. We used the survey data to measure the availabilities and constraints employed in the equation. We used the long-term prices as compiled in FAOSTAT and the farm level price, variable and fixed costs, depreciation and tax were from our survey data.

4.0 Results

4.1. How will climate change impact the yield of major crops in Nigeria?

The result as presented in Table 2 show that in the near future, climate change will lead to an increase in maize production by 0.5 tons per hectare for non-agroecology management methods, corresponding to a 29.4% increase in yield. For the agroecology management methods, the increase in yield was found to be about 0.4 tons per hectare corresponding to a 33% increase in yield. In terms of cassava production, for Non-agroecology management practices, cassava yield will increase by 0.4 tons per hectare corresponding to a 3.6% increase in yield. For the agroecology management practices, we observed a decrease in yield in the near future. The decrease was found to be about 0.1 tons per hectare, corresponding to a 0.9% decrease in yield. This finding corresponds to the reports of Adhikari, Nejadhashemi, and Woznicki,(2015) and Calleja-Cabrera *et al.*, (2020) who indicated that climate change will lead to a decrease in yield in root crop production but contradict the finding made by Chukwuma, Stephanie, and Nuppenau (2020) that in the near future agroecological methods will boost yield. Finally, in terms of rice production we found that in the near future, climate change would lead to an increase in yield both for the agroecological and non-agroecological management farming systems. For the non-agroecology farming system, we observed an increase of about 1 ton per hectare and for the agroecology farming system; we observed a similar amount of increase (0.9 ton per hectares).

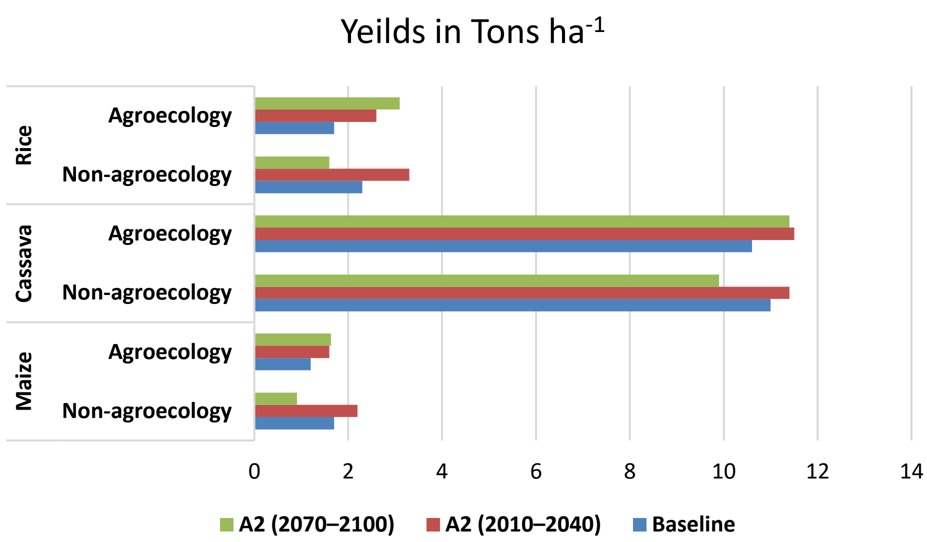

Fig. 2. Crop yield volatilities under different climate change scenarios and management options

In the long run, we observed more variation between the two farming systems. For the non-agroecology farming system, we observed a decrease in yield across the three crops under consideration. Starting with the maize crop, we found that in the long run there would be a substantial decrease in the yield of maize for the non-agroecology farming systems. While climate change will lead to 0.8 tons per hectare decrease in yield under the non-agroecology farming system, we observed that climate change would not have any significant impact on maize production using agroecological practices. The result in Table 2 shows that in the long run under climate change there will be an increase in production by 0.43 tons per hectare. For the cassava crop, we observed that under climate change, there would be a reduction in yield of about 1.1 tons per hectare in the long run under the non-agroecology farming system. Conversely, in the long run

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under climate change, there will be an increase in cassava production by 0.8 tons per hectare. Similarly, for rice production, a similar trend was observed. While climate change will lead to a decrease in rice yields by 0.7 tons per hectare in the far future, we observed that in the far future under climate change, rice yield would increase by 1.4 tons per hectare under the agroecology cropping system.

4.2 How will climate change impact farmers' income?

The expected gross margins under different climate change scenarios and management options in the agricultural zones of southeast Nigeria are presented in Table 2. Even though there was an increase in rice yield under the non-agroecological system, we observed a negative gross margin. This could be explained by the emphasis on rice production in the area (UNEP, 2015) as introduced in the model, which might lead to a glut. The returns from rice production might become very low and even negative in the far future. In addition, in the far future climate scenario, agroecological system appears to be more suitable for small-scale farmers than the conventional farming system. Apart from cassava where we observed a 1.8 USD reduction per hectare, there is a consistent increase in gross margin for all the three crops under consideration. In the near future, we observe an increase in welfare for small-scale farmers producing maize and cassava but a reduction in gross margin for farmers producing rice. This is the case for both the agroecology and non-agroecology farmers.

Table 2. Projected gross margins under (USD ha$-^{1}$).

Crop	Management option	Baseline	A2 (2010–2040)	A2 (2070–2100)
Maize	Non-agroecology	102.3	122.8	117.2
	Agroecology	72.0	102.6	153.2
Cassava	Non-agroecology	116.2	146.5	111.3
	Agroecology	105.3	122.2	120.4
Rice	Non-agroecology	338.5	129.2	-94.8
	Agroecology	313.1	243	270.1

5.0 Discussion

To provide meaningful insight into the result, we discuss the findings following the research questions stipulated earlier.

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5.1 What is the impact of climate change at the farm level in Nigeria

Climate change will have a positive impact on the production of basic crops in Nigeria in the short run. However, in the long run, there will be a negative impact depending on the management practices employed. It is interesting to point out that in the near future we did not observe any significant reduction in yield for the three crops under consideration. This is in line with report by Haider (2019) that climate change impact will be much observable in the far future.

To explain the impact of climate change at the farm level, we discuss the dynamic soil factors vulnerable to climate impact. The soil quality can depend on a number of factors. Quality soil has the robust ability to support crop needs. The implication is that adaptation options that are targeted for the far future will be necessary for others to ensure sustainable development and food security. It is expected that the population of Nigeria will spike to about 400 million people by 2050 (World population review, 2019). This shows that the farming system required to feed this population has to ensure continuous yield in the long run. The soil air and water temperature affect crop maturity. This change is induced by the change in atmospheric temperature and precipitation. An increase in temperature due to climate change might lead to the heating up of the soil water, leading to evaporation of water from the soil. Although this impact can be reduced through irrigation, in places where water is scarce, irrigation might not be possible. Over a long period, the impact of climate change might lead to drought, salination, and desertification. This will lead to the loss of peat soils (Boko, 2007), which further impact the ability of soil crop needs.

To further understand the impact of climate change on the soil, we need to understand the dynamic properties of soil that are non-static. These dynamic properties include the organic matter content of the soil and alteration of the soil pH levels.

The soil organic matter the soil determines several soil functions such as the soil nutrient-supplying power, water holding capacity of the soil, the soil structure, and the food for the huge numbers of organisms that live in the soil. According to Palm, Gachengo, Delve, Cadisch & Giller (2001), it is the soil organic matter that has the highest potential to be impacted by climate change. With increase in the temperature across the agricultural zones, there will be a net release of soil organic matter due to increased decomposition and mineralization of the organic matter content in the soil. With this release over time, the soil organic matter content will be substantially reduced (Palm et al., 2001). Indirectly, with the rapid decrease in the soil organic matter, major soil properties such as the water holding capacity, aggregate formation, and stability, cation exchange capacity, and the general soil nutrient content.

Apart from the soil organic matter, the soil acidity, or pH, are highly sensitive to climate change impact. At the farm level, the impact of climate change can be observed in the effect it has on the soils and the alteration of the functions that soil performs for crop production. The important factors that determine the soil pH are the rate of weathering of parent material and vegetation types (Baveye *et al.*, 2020). This means that one of the direct effects of climate change will be the change

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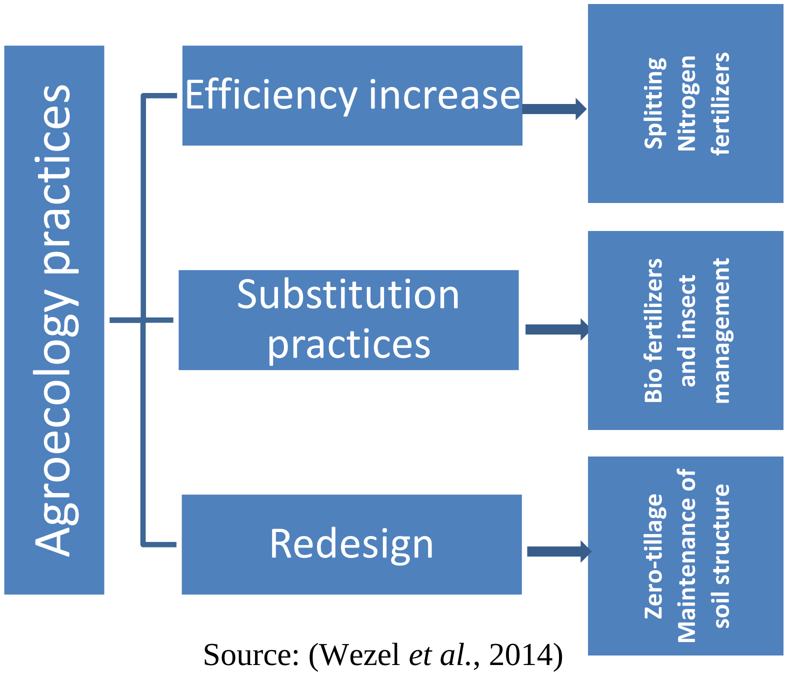
in pH levels. An increase in precipitation will lead to an increase in leaching, which will lead to the increase in the level of soil acidity. Our result showed that in all the agricultural zones that the precipitation will increase over the near and far future. This increase in precipitation will create more humid environments which are known to decrease soil pH over time due to soil acidification as a result of leaching occasioned by the high amounts of rainfall. In the agricultural zones such as the Okigwe zone and Ebonyi north agricultural zones where precipitation increase was observed to be up to 20%, it suggests the possibility of increased pH levels in these areas.

Another impact of climate change on the soil pH level is the increased CO2 concentration in soil water. The dissolving of CO2 in water has been found to reduce soil pH levels (Zhang *et al.*, 2021). With the dissolution of carbon dioxide in water, there will higher release of hydrogen ions, which leads to a decrease in pH level. Indirectly, the organic matter decomposition and decay occur as a result of increased temperature. The soil organic matters contain the element carbon (C) (Zhang *et al.*, 2021), as they decompose, the carbon is released into the water. Because the carbon is unstable, they easily react with oxygen to form CO2.

In terms of greenhouse gas emissions Baveye *et al.*, (2020) showed that nitrous oxides are one of the major agricultural emissions from farming. According to Menšík, Hlisnikovský, and Kunzová (2019) the nitrous oxides gas possesses over 300 times the potential to cause global warming than carbon dioxide. Since nitrogen forms the primary nutrient in fertilizers, when farmers introduce it into the soil, the unused nitrogen is released into the atmosphere as nitrous oxide. The use of synthetic nitrogen fertilizers by conventional farmers has been known to release unused nitrous oxides, while natural nitrogen from nitrogen-fixing crops like legumes, compost, and manure does not release nitrous oxide (Menšík, Hlisnikovský, and Kunzová, 2019).

5.2 What are the different agroecology measures employed by smallholder farmers in adapting to the impact of climate change

Climate change will have a positive impact on the production of basic crops in Nigeria in the short run. However, in the long run, there will be a negative impact depending on the management practices employed. Using information from the farm household survey, we identified three agroecological practices employed by smallholder farmers in coping with climate change impact. The agroecological practice includes the use of organic fertilization, the use of biological insect control measures, and the adoption of reduced or zero tillage. We present the agroecological practices according to the analytical framework in Wezel *et al.*, (2014) corresponding to three categories: increase efficiency in the use of inputs, the direct substitution of inputs, and total redesign (Figure 3). By increase in efficiency, we refer to agroecological practices adopted by farmers to decrease the consumption of inputs e.g. Splitting Nitrogen fertilizer application. At the same time, not compromise crop productivity. Substitution practices refer to the direct replacement of external chemical inputs such as pesticides and fertilizers by adopting the use of organic fertilizers, and push-and-pull technology. Lastly, redesign refers to changes in the farming system such as moving from tillage to agroforestry (Wezel *et al.*, 2014).



Source: (Wezel *et al.*, 2014)

Splitting nitrogen fertilizer application

According to the farmers surveyed who employ the splitting nitrogen fertilizer application technique, the approach helps them to supply optimum nitrogen requirements for the crops without incurring waste. The idea is that nitrogen is supplied to the crop only when it is needed. By matching the supply with the demand, excess nitrogen is left in the soil, thereby reducing the evaporation of nitrous gases. In this way, the agroecological practices not only improve adaptation by ensuring that plants receive adequate nutrient, but also aids in the mitigation of climate change. To understand the uptake and allocation dynamics, farmers base the idea on the inverse relationship between crop nitrogen requirement and plant growth. This phenomenon applies to all crops (Lemaire, Jeuffroy, and Gastal, 2008). According to the farmers, the nitrogen requirement for crops decreases monotonically with crop growth. This is based on the fact that the ontogenetic or visible morphological characteristics of crops, especially in leaf area per unit of plant mass declines with growth. In addition, the remobilization of Nitrogen from shaded leaves up to top leaves also declines with nitrogen deficiency. This is also evident in yellowish leaves at the top relative to lower leaves. With these indicators, farmers can determine when nitrogen supply will be needed (Lemaire, Jeuffroy, and Gastal, 2008).

Organic and bio-fertilizers

Utilisation of bio-fertilizers is another way to improve nutrient availability without the use of chemical fertilizers. Bio-fertilizers are microorganisms that have the ability to colonize rhizosphere that has the ability to supply primary nutrients to the soil, thereby promoting the growth of the host plant (Gautam *et al.*, 2021). The arbuscular mycorrhizal fungi (AMF), Plant

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growth-promoting rhizobacteria (PGPR), and, and nitrogen-fixing rhizobia are the three major groups of microorganisms that are considered biofertilizers (Wezel *et al.*, 2014): the most common bio-fertilizer is the nitrogen-fixing rhizobia which have been in existence for centuries. Recently, there have been efforts in the commercialization of PGPR and AMF inoculants, especially in Europe and America (Gautam *et al.*, 2021). The bio-fertilizers have been reported to be very effective in uptake of N, growth promotion, and maintaining crop yield in the face of climate change (Wezel *et al.*, 2014; Dasgupta *et al.*, 2021; Maan and Garcha, 2021).

Organic fertilization entails substituting the use of inorganic fertilizers. It also entails fertilization efficiency as it helps in the improvement of general soil fertility. In terms of redesign, the use of organic fertilization can be a critical factor. This is because, to ensure that there is sufficient inorganic manure for the soil, there will be a need for integration of crop and animal farming system, hence a redesign of the farm. Soil biological activities and mineralization increased with the application of organic fertilizers. Although it involved higher labor and energy demand, organic fertilization can lead to sufficient utilization of soil Nitrogen (Maan and Garcha, 2021).

Natural insect control

Biological and botanical insect control is an agroecological practice that aims to replace the use of synthetic pesticides. Botanical insect control is natural pesticides, botanical pesticides, or simply botanicals. These natural pesticides are used to counteract the associated negative effects of synthetic pesticides while efficiently serving the purpose of pesticides. Although they have not been effectively used on large scale, farmers who employ the use of these natural pesticides in Nigeria on the small scale observe positive effects. Our interview with the farmers showed that the use of these botanicals is of immense benefit to the farmers, especially when they cannot afford the cost of chemical pesticides. Studies have shown that climate change can lead to increase pest infestation (Grünig *et al.*, 2020; Skendžić *et al.*, 2021). This is due to increased temperature and humidity (Skendžić *et al.*, 2021). With the use of natural insect control, farmers can address the challenge of pest infestation naturally without attracting additional costs. This might explains the increase in the gross margin under climate change for the agroecological farming system. Natural pesticides are derived from several sources. These include those derived from the seeds of the trees, pyrethrum extracted from flowers, crude aqueous extracts of plants, and those that are based on plant essential oils (Nemet, 2009; Wezel *et al.*, 2014; Kassie *et al.*, 2020). For traditional agriculture among small-scale farmers, and for organized organic farming where synthetic pesticides are not allowed, the use of botanicals has been very effective (Picco *et al.*, 2016).

Biological pest control as an agroecological practice replaces synthetic pesticides. The bio-organisms release natural enemies into the agroecosystems which have been proven effective in pest control (Fenibo, Ijoma, and Matambo, 2021). The so-called biopesticides involve the use of

AMF inoculants, bacteria, or other fungi to control organisms that harm crops (Fenibo, Ijoma, and Matambo, 2021). According to Fenibo, Ijoma, and Matambo (2021), biopesticides eliminates pest in three ways (i) through a process known as antibiosis (antagonistic association between two organisms), (ii) through competition, and (iii) through the inactivation of pathogen germination (Using pheromones to disturb sexual reproduction of targeted insect pests is another biological control option). Another importance of natural pesticides and biological pest control is that it reduces the risk risks to human health as water pollution is avoided.

Redesign

Practices that are considered redesign practices are those practices that affect the large part or even the whole of the cropping system (Wezel *et al.*, 2014). This means that the farmers adopting these practices engage in a holistic shift and rethinking of their cropping system in response to climate change. Most of the efficiency and substitution practices can also be classified as redesigns (e.g. organic farming). Another important redesign is the adoption of zero-tillage agroforestry practice. While zero-tillage entails that the farm does disturbance the soil in terms of tilling before planting seeds, agroforestry means an intentional integration of shrubs and trees into the farming systems that will generate environmental benefits for the farmer (Brown *et al.*, 2018). The trees and shrubs are grown among or around the crops. Most times, agroforestry practices are natural in that farmers intentionally plant in forest areas. Other times, the farmers develop an artificial forest planting trees and shrubs among the crops.

The agroforestry redesign bridges the gap by integrating agriculture and forestry into an integrated system that is capable of addressing the environmental problem of climate change. It improves resilience in the cropping systems and even lessens the impacts of climate change. Small-scale farm household surveyed is of the opinion that adopting the agroforestry redesign has helped them in improving crop yield as it increases the soil fertility and reduces heat from the sun while providing other benefits to human welfare.

5.1 How effective are the agroecology practices in counteracting climate change impacts

Recent studies suggest that is likely impossible to meet the Paris Agreement's goal of reducing the impact of climate change without major reductions in emissions from food and agriculture (Farrelly, 2016; FAO, 2019a; Poppe, Vrolijk and van Dijk, 2021). The premise was supported by the World Resources Institute study, which reported among several industries that emissions from the agricultural sector need to be reduced by 39 percent by the year 2050. Critics have argued that moving to organic farming will lead to a reduction in yields (Elizabeth Amechi and Caleb, 2015). They argue that the use of organic farming will mean greater land use. For instance, a study by Xu *et al.*, (2018) suggested that 100 percent adoption of organic farming will increase the lands needed to produce the same amount of food production. The study also argued that a conventional production system would yield the same food under climate changes and soil degradation.

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However, just as elicited in this study, the findings only hold for the near future. However. In addition, controlled trials at the Rodale Institute have shown it is possible to get the same yields in some organic systems over the long term, and more research may help more farmers achieve those yields in the fields of the future. “Conventional yields are high because there have been decades of research and billions of dollars invested,” said Jessica Shade, the director of science programs at the Organic Center. “Organic is a pretty nascent field, and it gets a pretty limited amount of funds. Even with that small amount of funding, we’ve seen dramatic increases in yield.”

Studies have shown global evidence of soil mismanagement either through obvious mismanagement or ignorance. the conventional farming system, although it produces increased crop yields in the near future, only succeeds in putting increased pressure on the soil (FAO, 2019a) leading to soil degradation. Our finding suggests that for the three crops assessed in this study, the adoption of agroecology practice will provide a better adaptation option to coping with the impact of climate change in the far future. These findings can be explained as follows.

Firstly, at the farm level, farmers’ decisions in terms of the production systems and soil management practices employed play a significant role in determining yield under climate change. Although the use of inorganic fertilizer and other green revolution strategies might lead to improved food production in the near future, over a long period of turn, the yield will gradually reduce below what it would be if sustainable production patterns were followed. This is in line with the law of diminishing returns (Shephard, 1974; Shi *et al.*, 2020)which suggests that there will be a decrease in marginal yield which a consistent use of external inputs, assuming all other factors remain constant. Our findings suggest that agroecology provides an alternative cropping system that might be effective in grappling with diminishing returns.

Secondly, it has also been suggested by Elizabeth Amechi and Caleb (2015) that organic farming increases water infiltration capacity at the same time reduces surface runoff. This has the effect of preventing flooding of agricultural fields and reducing soil erosion. These two advantages make it possible for the agroecological farmlands to robustly adapt to climate change impacts, thereby increasing yields.

Thirdly, the practice of organic agriculture and zero tillage can also help combat the impact of climate change by improving the amount of carbon in the soil (Baveye *et al.*, 2020). Improvement of carbon storage in the soil over a long time has the potential of raising productivity under climate change scenarios. By implication, the use of these agroecological practices by storing more carbon in the soil there will be lower carbon emissions to the atmosphere, thereby not only an adaptation strategy but also a mitigation response. Many similarly, the use of push and pull technology practices have shown to be critical in returning crop nitrogen and residues to the soil which has been found to enhance productivity and favors carbon storage (Baveye *et al.*, 2020).

Fourthly, organic farming and zero tillage have been found to increase the water-holding capacity of the soil. With the increased temperature in the near and far future, soils rich in organic matter content will be better in their water holding capacity properties compared to conventional soils. additionally, with an increase in precipitation, erosion and flooding are highly controlled in organic soils compared to conventional soils (FAO, 2019b).

Finally, the push and pull technology has been shown to be instrumental in increasing the conservation of soil moisture in farms where the technology is utilized. The desmodium plants serve as cover crops that help to reduce the intensity of the sun's heat on the soil, thereby preventing excessive evaporation from the soil. In this way, soil water content loss is minimized. Furthermore, the nitrogen fixation property of the desmodium plants helps to fix nitrogen in the soil, thereby eliminating the need for artificial nitrogen application which has been found to deplete soil fertility in the far future (Nemet, 2009).

6.0 Limitation of the study

The study assumes that all the farm households surveyed are commercial farms, hence did not take into account the associated household consumption demands. This means that commercial and subsistence farm households were not differentiated. Secondly, the changes in yield as determined do not take into account the possibility of diseases and pest incidences. This is also the case for the crop type, as the study did not take into account the possibility of improved varieties and technological changes.

7.0 Conclusion

This study investigated the role of agroecology in counteracting the negative impact of climate change on crop production in Nigeria. By modeling the near and far future impacts of climate change on crop production, we showed how climate will impact crop production under two crop production systems (agroecology and non-agroecology production systems). Our climate and crop models show the climate change impact on cassava, maize, and rice production in Nigeria. These three crops were selected as they are the three most common staple crops produced in Nigeria. The result showed that the use of agroecology management practices not only reduces the impact of climate change in the near future but will also lead to increased crop yield in the future. The finding suggests that to feed the over 400 million projected population of Nigeria by 2050, the use of agroecological practices will be a better alternative to the conventional farming methods. To advance the use of agroecological farming methods, governments at every level in Nigeria need to mainstream organic agriculture in national government policies. This is important as it will not only address climate change impacts but also hunger and poverty.

Beyond adaptation, governmental agricultural policies in the country should also acknowledge organic farming as a potent strategy for mitigation and reducing greenhouse gas emissions due to the potential of organic farming in sequestering carbon from the atmosphere. The government at all levels should begin to help farmers adapt to climate change by promoting agroecological practices. This can be done by investing in climate research and extension service delivery. Green evolution strategies in developing nations such as Nigeria should incorporate initiatives that are based on the principles of agroecology (Emeana *et al.*, 2019) into the Nationally Intended Mitigation Contribution (NIMC).

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