The Economic Impact of Climate Change on Plantation Agriculture in Nigeria: Implication for Enhanced Productivity

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Abbreviations and acronyms

AEM	Agro-economic Model
AEZM	Agro-ecological Zone Model
AfDB	African Development Bank
ARAP	Accelerated Rainf-ed Arable Programme
AUC	Commission of the African Union
CBN	Central Bank of Nigeria
CC	Climate Change
CCCMA	Canadian Centre for Climate Modelling and Analysis
CCLM	Climate Limited-area Modelling Community
CEEPA	Centre for Environmental Economics and Policy in Africa
CLM-C	Climate Limited-area Modelling Community
CORDEX	Coordinated Regional Climate Downscaling Experiment
CRIN	Cocoa Research Institute of Nigeria
CSA	Climate Smart Agriculture
DMI	Danish Meteorological Institute
EA	Enumeration Area
ECOWAS	Economic Community of West African States
FAO	Food and Agricultural Organization
FGN	Federal Government of Nigeria
GCMs	Global Climate Models
GEF	Global Environmental Fund
ICTP	International Centre for Theoretical Physics
IPCC	Intergovernmental Panel on Climate Change
KNMI	Royal Netherlands Meteorological Institute
NBS	Nigeria National Bureau of Statistics
NIMET	Nigeria Meteorological Agency
PFM	Production Function Model
RCMs	Regional Climate Models
SMHI	Swedish Meteorological and Hydrological Institute
UNECA	United Nations Economic Commission for Africa

Abstract

This study used the Ricardian analytical framework to examine the relative importance of climate normals (average long-term temperature and precipitation) in explaining net revenue per hectare (NRh) for cocoa farms in Nigeria under supplementary irrigated and rainfed conditions. A farm-household survey involving 280 cocoa farmers across seven cocoa-producing states in Nigeria was carried out. Net revenue per cocoa hectare was regressed on climate, household socioeconomic characteristics and other control variables. The results indicate high sensitivity of NRh to climate normals in Nigeria, depending on whether cocoa farms are supplementary irrigated or not. On the average, annual increases in temperature and decreasing precipitations are associated with NRh losses for rainfed farms, whereas it increases for irrigated cocoa farms. Projections of future climate change impacts using different climate scenarios (i.e., 6 CORDEX Regional Climate Models [RCMs] Ensemble between 2036-2065 and 2071-2100, and a 2.5^{0}C increase in temperature only, a 5% decrease in rainfall only, and a uniform 2.5^{0}C increase in temperature and a 5% reduction in precipitation from 2050-2100), suggest a wide range of outcomes on NRh for both rainfed and supplementary irrigated cocoa farms. Specifically, the various climate scenarios predict a fall in NRh for rainfed farms, compared to net gains for irrigated cocoa farms. This clearly shows irrigation as an important adaptation strategy by farmers in Nigeria to reduce the harmful effects of climate change.

Keywords: Climate change, cocoa agriculture, Ricardian valuation, climate change projections, Nigeria.

JEL Classification: O13, O21, Q54

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1. Introduction and background

Agriculture is a very climate-sensitive sector. According to the *Fifth Assessment Report* of the Intergovernmental Panel on Climate Change (IPCC), climate change will amplify existing stress on agricultural systems, particularly those in arid and semi-arid environments in Africa (IPCC, 2014). There are several reasons for this. Firstly, as pointed out by the World Bank (2008) and Hassan (2010), about 80% of agriculture in Africa is still mainly rainfed and, therefore, highly vulnerable to changes in climatic conditions such as droughts, higher temperatures and reduced precipitation levels. Secondly, agriculture in Africa is extensively practised on relatively fragile soils, in a mostly extensive manner, with little use of inputs (Mendelsohn and Dinar, 1999; Mano and Nhemachena, 2006). Thirdly, as discussed in IPCC (2007), Odingo (2008) and Hassan (2010), the presence of multiple stresses like endemic poverty, poor governance and weak institutions, inadequate health services, limited access to capital and markets, poor infrastructure and technology including natural resource conflicts, reduce the adaptive capacity of farm households in Africa to cope with the numerous vagaries of climate change. Finally, most African governments devote very meagre financial resources to the agricultural sector, which reduces investment levels in scientific research and action programmes needed to better understand and respond to climate change (Hassan, 2010).

In West Africa, the vulnerability of the Nigerian agricultural sector to climate change is of particular interest to policy makers because agriculture is considered a major growth driver in the country and for the West African sub-region. The sector employs close to 50%-60% of the total workforce in the country, and accounts for over 30%-40% of the country's GDP (World Bank, 2014). Close to 75% of agricultural production in Nigeria is contributed by the tree crops sub-sector (i.e., cocoa, rubber, coffee and palm produce). For example, between 2006 and 2012, a total of about 1.2 million tons of output from tree crops were exported from Nigeria. This accounted for over 40% of the total export value derived from agricultural exports (Central Bank of Nigeria [CBN], 2014). The contribution of cocoa among these tree crops to the nation's economic development is not in doubt. In terms of foreign exchange earnings, no single agricultural export commodity has earned more than cocoa. With respect to employment, the cocoa sub-sector offers quite a sizeable number of people with employment, both directly and indirectly. Additionally, it is an important source of raw materials, as well as a source of revenue to the governments of cocoa-producing states in Nigeria. Due to its importance, the recent Federal Government of Nigeria (FGN) concern of diversifying the export base of the nation has placed cocoa in the centre-stage as the most important export tree crop.

However, there are growing concerns that climate change may be impacting negatively on cocoa production in Nigeria. The first real evidence of climate change impacts on cocoa production was during the 1972/73 drought event, when production declined from about 216,000 metric tons to less than 150,000 metric tons. Thereafter, the production trend has consistently declined despite the agricultural conditionality of the structural adjustment programme (SAP), which was introduced immediately after the major drought occurrence. Some of the key questions that still remain unanswered and of great concern to policy makers are: what proportion of change in cocoa production is due to the impacts of climate change? What are the economic implications of climate change on cocoa production in Nigeria? How do cocoa farmers in Nigeria adapt to changing climatic conditions? As climate variables worsen, what is the likely future for this important plantation tree crop in the country?

This paper will attempt to provide answers to some of the key questions using a climate-land value analytical framework (i.e., Ricardian model) pioneered by Mendelsohn, Nordhaus and Shaw (1994) to predict the potential economic damage to US agriculture from CC. The analytical framework is applied to Nigeria in seven different cocoa-producing states in order to assess: (i) the potential economic impacts of climate change on cocoa productivity in Nigeria; and, (ii) to evaluate the importance of irrigation (supplementary) as an alternative pathway to mitigate the likely impact of climate change on cocoa farming in Nigeria. The central goal of the study is to contribute to the sparse existing literature in Africa, and in developing countries in general. Additionally, we wish to determine what policy response options can be derived from the study to help mitigate the effects of climate change on plantation agriculture in Nigeria.

The rest of the paper is structured as follows: section two reviews existing literature on climate change and agriculture from a global perspective, narrowing down to Nigeria. Section three gives an overview of climate change and cocoa productivity in Nigeria, including the study objectives. In section four, the data as well as the empirical Ricardian model developed for the analysis are presented. Section five reports the empirical findings and discussion, while the conclusion and potential policy implications are presented in section six.

2. Climate change and agriculture: Global evidence

Climate change and agriculture is now the subject of global concern. The *Fifth Assessment Report* of the Intergovernmental Panel on Climate Change (IPCC) affirms, beyond reasonable doubt, that climate change will amplify existing stress on agricultural systems, particularly those in arid and semi-arid environments. The same report states, with high confidence, that the impacts on resources or commodities in one place will have far-reaching effects on prices, supply chains, trade, investment and political relations elsewhere. Thus, climate change will progressively threaten economic growth and human security throughout Africa and beyond, unless a development pathway resilient against climate change is adopted in the nearest future (IPCC, 2014).

The African Union declared 2014 as the "*Year of Agriculture and Food Security in Africa*" and launched, concurrently, its strategies for an imperative transformation to Climate Smart Agriculture (CSA) to reach food security and ease poverty throughout the continent. The Economic Community of West African States (ECOWAS) has also underlined the importance of climate change impacts, adaptation and mitigation measures in its strategic plan for 2010-2019. Guided by their "Climate for Development in Africa Programme" (ClimDev-Africa), the African Development Bank (AfDB), in collaboration with the Commission of the African Union (AUC) and the United Nations Economic Commission for Africa (UNECA), has coined "Greening Africa" as their key challenge, particularly for the years ahead.

Nonetheless, our knowledge and awareness of climate change impacts on African agriculture is still very limited. This mainly stems from the fact that most empirical studies, to date, are based on industrial economies where climate change impacts are less damaging due to better adaptation techniques and technology. Notwithstanding, these studies laid the foundation for the increasing number of developing countries' applications. Lessons learnt from these earliest applications can be found in the works of Jin et al (1994), Escano and Buendia (1994), Amien et al (1996), Kapetanaki and Rosengweig (1997), Mathews et al (1997), Kumar and Parikh (1998), Sanghi (1998), Sanghi et el. (1999), Luo and Lin (1999), Kumar and Parikh, (2001), Chang (2002), Kurukulasuriya and Ajwad (2003), Seo et al (2005), etc.

Although the African literature on climate change impacts on agriculture appears scanty, the subject matter is gradually attracting much attention (Molua, 2002; Molua and Lambi 2007; Hassan, 2008). However, it may appear that Downing (1992), Onyeji and Fischer (1994), El-Shaer et al (1997), Hulme et al (2001), Seleka (1999), Molua (2002), Gbetibouo and Hassan (2005), Deressa et al (2005), Dinar et al (2008), Hassan and Nhemachena (2008a, 2008b), Kurukulasuriya and Mendelsohn (2008), were among the first African researchers to measure the economic impact of climate change on African agriculture. This was followed by a series of multi-country analyses carried out in 11 African countries and led and coordinated by the Centre of Environmental Economics and Policy in Africa, University of Pretoria, and the World Bank, in close collaboration with many agencies in the involved countries.

In this series, Mano and Nhemachena (2006) find that when farm revenue in Zimbabwe is regressed against various climates, soil, hydrological and socioeconomic variables in a Ricardian framework, the net effect of climate change on agriculture in Zimbabwe is quite significant. Sensitivity analysis of alternative climatic scenarios, that is, 2.5^{0}C and 5^{0}C increases in temperature resulted in a decrease in net farm revenues of approximately US\$0.3 and US\$0.3 billion, respectively. In Kenya, the results were not much different. Mariara and Karanja (2006) find that climate change also affects agricultural productivity using a seasonal Ricardian analysis. The results showed that increased winter temperatures are associated with higher crop revenue, but increased summer temperatures have a negative impact. Increased precipitation is positively correlated with net crop yield. The result further suggests that there is a non-linear relationship between temperature and revenue, on the one hand, and between precipitation and revenue on the other.

For Cameroon, Molua and Lambi (2006) find that a 3.5% increase in temperature associated with a 4.5% increase in precipitation in the absence of irrigation facilities would be detrimental to Cameroon's agriculture, leading to a loss of almost 46.7% in output value. This would negatively affect the economy as a whole, since close to 30% of Cameroon's national GDP comes from agriculture. In Egypt, empirical results from four variants of the standard Ricardian model showed that a rise in temperature would have negative effects on farm net revenue (Model 1). In the second, third and fourth models, adding the linear term of hydrology, the linear and quadratic terms of hydrology, and the hydrology term and heavy machinery to the analysis improved the adaptability of farm net revenue to high temperature. Marginal analysis indicated that the harmful effect of temperature was reduced by adding the hydrology term and heavy machinery to the analysis. Also, estimates from two climate change scenarios showed that high temperatures will constrain agricultural production in Egypt (Eid et al, 2006).

Other studies in this series include Sene et al (2006), who assessed the impacts of climate change on the revenues and adaptation of farmers in Senegal and finds that farmers have several ways of adapting to climatic constraints in Senegal. These include diversifying crops, choosing crops with a short growing cycle, and weeding early in the north and late in the south. For Seo and Mendelsohn (2006), using two variants of the standard Ricardian model results suggest that the livestock net revenues of large farms in Africa fall as temperatures rise, but that small farms are not temperature sensitive (Model 1). In the second model, the authors find that higher temperatures reduce both the size of the stock and the net revenue per value of stock for large farms. In Kurukulasuriya and Mendelsohn (2006), assessing the impact of climate change on African cropland from 11 countries involving over 9000 farmers, the authors find that net farm revenue falls are associated with decreasing precipitation and increasing temperatures for all the surveyed farms.

In Burkina Faso, Ouedraogo et al (2006) find that, if temperature increases by 1°C, farm revenue will fall by US\$19.9/ha, while if precipitation increases by 1mm/month, net revenue increases by US$2.7/h using a standard Ricardian model. The elasticity shows that agriculture is very sensitive to precipitation in Burkina Faso. In Ethiopia, the results were not much different; Deressa (2006) also finds that net farm revenue would fall in summer and winter if temperature increases, whereas an increase in precipitation during spring will increase net farm revenue. Simulation of uniform scenarios, that is increasing temperature by 2.5^{0}C and 5^{0}C, and decreasing precipitation by 7% and 14%, suggest that increasing temperature and decreasing precipitation are both damaging to Ethiopian agriculture. However, the author concludes that decreasing precipitation appeared to be more damaging than increasing temperature. Also in Zambia, Jain (2006), finds that an increase in the November-December mean temperature and a decrease in the January-February mean rainfall have negative impacts on net farm revenue in Zambia, whereas an increase in the January-February mean temperature and mean annual runoff has a positive impact.

In the context of Nigeria, the academic literature is still very scanty. Very few studies have quantitatively examined the economic impacts of climate change on Nigerian agriculture. In fact, a review of the peer-reviewed literature suggests that there are less than five or so peer-reviewed documented studies for Nigeria. These are the works of Lawal and Emaku (2007), Omolaja et al (2009), Ajewole and Iyanda (2010), Ajayi et al (2010), and Ajetomobi et al (2011). In Lawal and Emaku (2007), the authors find that while temperature is positively correlated with cocoa yield, rainfall and relative humidity are negatively correlated with cocoa yield. In Omolaja et al (2009), the main finding arrived at is that increasing precipitation and favourable temperature promote the flowering intensity of cocoa in Nigeria. For Ajewole and Iyanda (2010), the main findings are that cocoa yield is less sensitive to decreasing rainfall (0.0073) but more sensitive to increasing temperatures. In line with these findings, Ajayi et al (2010) find cocoa yield also less sensitive to annual rainfall levels, compared with temperature increases. For Ajetomobi et al (2011), increasing temperature is associated with revenue decline for dry land rice farms in Nigeria, compared with net farm revenue rises for irrigated rice farms, and also that increasing precipitation reduces farm revenue for dry land rice farms, whereas it increases revenue for irrigated farms.

Given the huge gap in the literature on the impacts of climate change on Nigerian agriculture, this study seeks to make a modest contribution to the academic literature on the economic impacts of climate change on Nigerian cocoa agriculture. It intends to do so using a Ricardian analytical framework to assess the relative importance of climate normals (average long-term temperature and precipitation) in explaining net farm revenue per cocoa hectare in Nigeria under irrigated (supplementary) and rainfed conditions. This is particularly important as it teases out the importance of irrigation as a local adaptation technique to climate change by farmers.

3. Climate and cocoa productivity in Nigeria

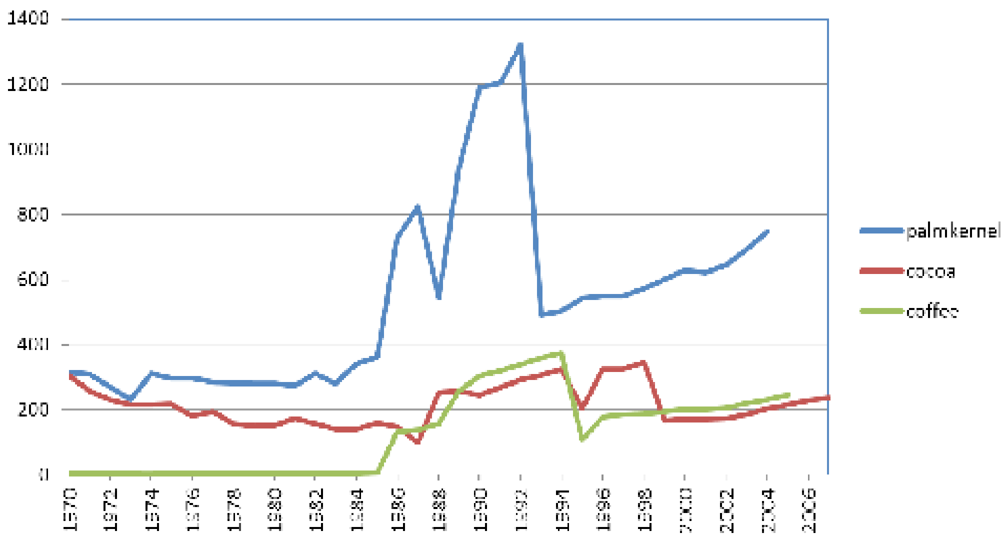
Cocoa, scientifically known as *Theobroma cacao*, is a tropical tree crop with heights ranging between 5-10 metres. It does best in the forest lowlands of the humid tropics, specifically between latitudes 20^0 North and South of the Equator. This region is warm and humid, implying an area with relatively high temperatures and heavy rainfall. Put differently, cocoa requires relatively high temperature of 15^0C to 30^0C, and annual rainfall between the ranges of 1200-2000mm for optimum growth and development. Areas with a higher rainfall of more than 2000mm are still favourable to cocoa growth and development. About 10 hours of sunshine, as found in the warm, humid tropics, are necessary for the flowering of cocoa and the ripening of the fruits. Anything far less or more will result in poor yields. High relative humidity ranging between 50% and 70% is equally required for the optimum growth and development of cocoa. In terms of soil, cocoa requires deep and well-drained soil with a relatively large amount of clay. The clay helps to conserve water during the dry season. Also, the litter on the top soil must be rich in organic matter. When the fruit is ripe, it is used as industrial raw material for producing cake, chocolate, beverages, wine, drugs, body lotion and cattle husks. Also, the unprocessed baked cocoa seed is a major export commodity to developed nations.

Cocoa was introduced in Nigeria in 1874 from Fernando Po, now Equatorial Guinea. It is grown mainly in seven states in the south-south region of Nigeria namely; Cross River, Abia, Edo, Ondo, Ekiti, Oyo and Ogun states. Productivity within these regions varies; however, Cross River, Ondo and Ekiti states rank highest in terms of productivity. The contribution of cocoa to the nation's economic development is not in doubt. In terms of foreign exchange earnings, no single agricultural export commodity has earned more than cocoa. With respect to employment, the cocoa sub-sector still offers quite a sizeable number of people with employment, both directly and indirectly. In addition, it is an important source of raw materials, as well as source of revenue to governments of cocoa-producing states. Because of its importance, the recent Federal Government's concern of diversifying the export base of the nation has placed cocoa in the centre-stage as the most important export tree crop.

However, water availability, rising temperatures and extreme weather conditions are threatening production and livelihoods in the major cocoa-producing regions of Nigeria. This is hitting poor smallholder growers the most, as they lack the resources necessary to adapt and tackle climate change-related challenges. The first real evidence of climate change impacts on cocoa production was experienced during the 1972/73 drought event, when production fell from about 216,000 metric tons in 1976, and 150,000 metric tons in 1986, therefore reducing the country's market share to about 6% and to fifth-largest producer to date (Figure 1). The key questions that remained unanswered and of great concern to policy makers in Nigeria are:

- What proportion of change in cocoa production is due to the impacts of climate change?
- What are the economic implications of climate change on cocoa production in Nigeria?
- How do cocoa farmers in Nigeria adapt to changing climatic conditions?
- As climate variables worsen, what is the likely future for this important plantation tree crop in Nigeria?

Figure 1: Output trends in major agricultural commodities in Nigeria (1970 – 2007)



Source: Authors' compilation based on CBN Statistical Bulletin (2007).

The aim of this study is to provide answers to some of the key questions using a climate-land value analytical framework (i.e., Ricardian model) pioneered by Mendelsohn, Nordhaus and Shaw (1994) to predict the potential economic damage to US agriculture from climate change.

More specifically, the study intends to evaluate:

1. The potential economic impacts of climate change on Nigerian cocoa agriculture under irrigated and rainfed farming;
2. The importance of irrigation as an alternative pathway to climate change mitigation in Nigeria; and,
3. To examine the likely future impacts of climate change on cocoa farming in Nigeria.

4. Data description and econometric procedures

Data

Temperature and precipitation data are key to climate-land value analysis. Because climate change involves longer-term trends than short-term variations, the use of monthly climate normals are usually preferable (Reinsborough, 2003). On the basis of this, monthly climate normals (i.e., January to December monthly means for precipitation and average temperature) from 1981 to 2010 were used. These data were obtained from Nigeria's Meteorological Agency (NIMET), Lagos. There are 32 stations in the country (Table 1). Given significant variation in temperatures across geographic locations (driven primarily by elevation as shown in Table 1), we accounted for seasonal temperatures and precipitations. Data on soil types for the seven cocoa-producing states in Nigeria were obtained from the Food and Agricultural Organization (FAO). The FAO soil statistics include information about the major and minor soils in each location, as well as the slope and texture. In all, there exist four types of soil in the states, and all of them were used in the analysis (Table 2).

Table 1: Weather stations in Nigeria

Station	Elevation	Latitude (DD)	Longitude (DD)
Abuja	3440	9250	7000
Bauchi	6090	10283	9817
Benin City(civ/mil)	790	6317	5600
Bida	1430	9100	6017
Calabar	630	4967	8350
Enugu	1400	6467	7550
Gusau	4690	12167	6700
Ibadan	2340	7433	3900
Ibi	1110	8183	9750
Ikom	930	5967	8717
Ilorin	3050	8483	4583
Jos	12850	9867	8900
Kaduna (civ/mil)	6420	10600	7450

Station	Elevation	Latitude (DD)	Longitude (DD)
Kano/Mallam aminu	4810	12050	8533
Katsina	4270	13017	7617
Lagos/Ikeja	380	6583	3333
Lagos/Oshodi	190	6550	3350
Lokoja	440	7800	6733
Maiduguri	3540	11850	13083
Makurdi (mil)	970	7683	8617
Minna	2600	9617	6533
Nguru	3440	12883	10467
Ondo	2870	7100	4833
Onitsha	860	6150	6783
Oshogbo	3040	7783	4483
Port Harcourt	180	4850	7017
Potiskum	4880	11700	11033
Sokoto	3020	13017	5250
Warri	60	5517	5733
Yelwa	2430	10883	4750
Yola	1740	9233	12467
Zaria	6640	11133	7683

Source: Nigeria's Meteorological Agency (NIMET), Oshodi, Lagos, Nigeria.

Table 2: State soil variables

State	Soil type
Abia	(La)-Ferralitic Soils of the Coastal Plain Sand and Escarpment
Cross River	(La)-Ferralitic Soils, Dominant Colour Yellowish Brown (not differentiated)
Edo	(La)-Ferralitic Soils, Dominant Colour Yellowish Brown (not differentiated)
Ekiti	(Jc)-Ferruginous Tropical Soils on Crystalline Acid Rocks
Ogun	(Li)-Ferrallite Soils, Dominant Colour Red on Loose Sandy Sediments
Ondo	(Jc)-Ferruginous Tropical Soils on Crystalline Acid Rocks
Oyo	(LVf)-Ferric Luvisol Soils, Reddish Sandy Clay Loam

Source: Adopted from Ajetomobi 2011.

Farm-level data on net revenue per cocoa farm hectare and its determinants were collected from a random sample of 280 cocoa farmers spread all over the agro-ecological zones. The survey covered seven states in the country, which were selected to represent the major cocoa-producing regions in the country. These include, Cross River, Abia, Edo, Ondo, Ekiti, Oyo and Ogun states of Nigeria. There were significant variations in temperatures and precipitations of the states. The differences were driven mainly by elevations. In each state, four enumeration areas (EAs) were used, making a total of 28 EAs. From each EA, 10 farmers were purposely selected based on a cocoa production record of more than 20 years (i.e., long enough to have experienced the effects of climate change on farmlands). The enumerators were all drawn from the Nigeria National Bureau of Statistics (NBS) with extensive fieldwork experiences.

The questionnaire used was adopted and modified from the Global Environmental Fund (GEF) Regional Climate, Water and Agriculture Project that was led and coordinated by the Centre for Environmental Economics and Policy in Africa (CEEPA) of the University of Pretoria and the World Bank. The questionnaire had seven sections. Sections one and two focused on household characteristics and the employment status of the head of the household. Section three dealt mostly on land tenure issues and household labour composition for farming activities, including their costs. In section four, more in-depth questions were asked concerning farming activities such as: primary crops grown, harvested and sold on farmlands in the past 12 months; the average yields obtained in a normal year; source of water used for farming, including the specific irrigational system employed for farming; various costs associated with seeds, fertilizer and pesticides purchased, as well as those related to the use of farm machinery (light, heavy and animal power), including the cost of buildings used in supporting agricultural farm work. Section four equally probed animal ownership in terms of the total number of livestock, poultry or other farm animals kept, sold, lost and consumed during the last growing season. In section five, farmers were specifically asked about access to information on farming activities, source of information, as well as the cost involved in getting such information; while section six requested for information on estimates of farm household's total income (for both farming and non-farming activities), taxes paid and subsidies received. Finally, section seven asked about farmers' perception of short- and long-term climate change effects and their adaptation strategies in response to these changes.

Based on this, it was therefore possible to calculate net farm revenue per cocoa hectare (NRh) for all the 280 sampled farm households. This was defined as gross revenue less per hectare cost of the following input variables: seeds, fertilizer, pesticide, insecticide, herbicide, farm labour, depreciation on machineries, including other farming costs. The survey equally collected information on household socioeconomic and demographic characteristics as shown in Table 3.

Econometric procedure

In order to assess the economic impacts of climate change on cocoa farmlands in Nigeria, a Ricardian cross-sectional model is used. It is named after David Ricardo following his pioneering work on the theory of "economic rents" in 1817. Ricardo observed that land values would reflect land productivity at a site under perfect competition (Ricardo, 1817). This implies that any factor that influences the productivity of land will be reflected in land value or net farm revenue. The value of land or net farm revenue contains information about the value of climate as one attribute of land productivity. Much of the pioneering work on climate-land value analysis in Africa draws extensively from the work of Mendelsohn et al (1994). Mendelsohn et al (1994) showed that, by regressing farmland value or net farm revenue on climate, household and other control variables, it is possible to measure the marginal contribution of each variable to farm income as capitalized in land value or net farm revenue. This principle is usually captured through a net farm revenue equation of the form (Mendelsohn et al, 2009):

$$NRh = \sum P_i Q_i (X, C, S, Z) - \sum P_x, X. \quad [1]$$

where, NRh represents net revenue per farm hectare ; P_i is the market price for crop i ; Q_i is the output of crop i ; X is a vector of purchased inputs other than land; C is a vector of climatic variables such as temperature and precipitation; S is a vector of control variables such as soil types, population density, farmland altitude and irrigation; Z is a set of economic variables and P_x is a vector of input prices. Under this framework, a farmer is assumed to maximize NRh by choosing input (X) subject to C, S and Z. Thus, the Ricardian model is a reduced form model that examines how exogenous variables such as C, S and Z affect farmland values or net farm revenues (Mendelsohn et al, 2009).

However, because most agricultural crops grow and develop under optimum temperature and precipitation levels, values far above or below the preferred climatic conditions would obviously reduce crop productivity. This, therefore, suggests that the relationship between net farm revenue (NRh) and the climatic variables (*C*) should be hill-shaped as extensively discussed in the Ricardian literature (see, e.g., Reinsborough, 2003; Seo et al, 2005; Kurukulasuriya and Mendelsohn, 2008; Deressa and Hassan, 2005; Mendelsohn et al, 2009).

To, therefore, capture this hill-shaped relationship in our empirical specification of the net farm revenue function, we assume a quadratic functional form as follows:

$$LnNRh_i = \alpha_0 + \alpha_1 C + \alpha_2 C^2 + \alpha_3 S + \alpha_4 Z + \varepsilon \quad [2]$$

where, ε represents the error term and α_i represents regression coefficients. The marginal impact of a single climate variable (c_i) on the net revenue evaluated at the mean of that variable is given as,

$$E\left[\frac{dNRh}{d_{\ i}}\right] = \alpha_{1,i} + 2 * \alpha_{2,i} * E[c_i] \quad [3]$$

One major advantage of the net farm revenue specification is that it accounts for the direct impacts of climate on yields of different crops, as well as the indirect substitution of different inputs, introduction of different activities, and other potential adaptations by farmers to different climates (Mendelsohn and Dinar, 1999). However, the method has been extensively criticized on several grounds that: (i) crops evaluated under the RM are not subject to controlled experiments across farms as is the case with the production function model (PFM), the agro-economic model (AEM) or the agro-ecological zone model (AEZM) (Hassan, 2010); (ii) it fails to account for future changes in technology, policies and institutions (Mendelsohn, 2009); (iii) it assumes that the prices of inputs and outputs remain constant, which introduces a bias in the analysis (Mendelsohn, 2009); (iv) it equally fails to account for the effect of factors that do not vary across space, such as carbon-dioxide concentrations that can be beneficial to crops (Seo et al, 2005; Mendelsohn et al, 2009, Hassan, 2010); and, (v) it could sometimes overestimate the potential damage to farmland values caused by climate change when the role of irrigation is not factored in (Reinsborough, 2003). However, Seo et al (2005) argue that these problems are significant but not too fatal. For example, global prices are not expected to change drastically as a result of CC. Equally, carbon-dioxide can be included exogenously, as can new technology in the analysis. In addition, most studies now include irrigation as an important control variable in several empirical estimations of the Ricardian model.

In the empirical estimation procedure, net farm revenue was regressed on climate, household socioeconomic characteristics, and other control variables. Following Reinsborough (2003) and Seo et al (2005), three seasons were used to define our climate variables that correspond to the three predominant seasons experienced in Nigeria. That is, the dry season (average precipitation and temperature data for the months of October to March), the heavy rainy season (average precipitation and temperature data for the months of April to September), and the harsh Harmattan period (average precipitation and temperature data for the months of December to January). As indicated earlier, both linear and squared terms of the temperature and precipitation variables were included in the empirical specification of Equation 2 to capture the optimum temperature and precipitation levels of cocoa. When the coefficient of the quadratic term is positive, the climate response function is U-shaped and when negative, the function is hill-shaped (Reinsborough, 2003). However, note that because seasonal climate variables are often used, the process is somehow complex and likely to result in a mixture of positive and negative quadratic coefficients across seasons (Mendelsohn et al, 2009).

In addition, the climate variables were specified in their interactive forms to check for climate interaction effects on net farm revenue per hectare. These include interacting dry season temperature with precipitation, rainy season precipitation with temperature, and Harmattan temperature with precipitation. For the control variables, urban/rural characteristics, farmland altitude and irrigation, among others, have been shown to significantly affect land value or net farm revenue other than climate change alone (Reinsborough, 2003; Seo et al, 2005; Ouedraogo et al, 2006; Kurukulasuriya and Mendelsohn, 2006; Mendelsohn et al, 2009). To control for this in the empirical specification of our climate response function (Equation 2), population density was included to capture urban/rural characteristics, main source of water (irrigation or not), and farm altitude were used as three important control variables.

5. Empirical results

Sample statistics

Table 3 presents the summary statistics of the key variables used in the analysis. On average, the net farm revenue per hectare was NGN42,558.9 (US$283.7) for all farms, NGN45,339.12 (US$302.3) for supplementary irrigated cocoa farms, and NGN 31,386.7 or about US$209.2 for rainfed cocoa farms. The mean monthly temperatures corresponding to these seasons used in the analysis were 32.4^{o}C for the dry season, 25.7^{o}C for the heavy rainy season, and 19.6^{o}C for the Harmattan season. Similarly, the mean monthly precipitations corresponding to the dry season was 47.7mm, 169mm for the heavy rainy season, and 12.7mm for the Harmattan season.

The soil type on which the farmers operated is a function of geographical location. These soil types are: (La)-Ferralitic Soils of the Coastal Plain Sand and Escarpment; (La)-Ferralitic Soils, Dominant Colour Yellowish Brown (not differentiated); (Jc)-Ferruginous Tropical Soils on Crystalline Acid Rocks; (Li)-Ferrallite Soils, Dominant Colour Red on Loose Sandy Sediments; (Jc)-Ferruginous Tropical Soils on Crystalline Acid Rocks; and, (LVf)-Ferruginous Tropical Soils, Washed with Iron Segregation, Reddish Sandy Clay Loam (Ferric Luvisol). More than 42.9% of the sampled farmers cultivated on La soil type, while about 28.7% farmed on the Jc soil type. On the other hand, about 28.4% of the farmers were split equally in terms of cocoa cultivation between the Li and LVf soil types.

The average farm size devoted to cocoa cultivation was about 2.4 hectares from a total household farm size of 6.5 hectares. On average, close to three household members were engaged in cocoa farming as their primary occupation from a total household size of about seven members. Male-headed households dominated the sample (95%) while the average year of schooling was about nine years (i.e., junior secondary school). The average age for the sample was about 55 years, with an average of 22 years of farming experience. Furthermore, more than 80% of the sampled farmers relied on rain for agriculture, while only about 20% reported making use of irrigated farming (i.e., supplementary irrigation). In terms of credit accessibility, less than 33% of the farmers acknowledged having access to any form of credit facilities, while about 14% reported receiving farm subsidies. In terms of fertilizer usage, the yearly average of the sample was about 776kg, with more than 93% reporting using pesticides. Equally, the average farm visit time from an agricultural extension worker was estimated to be less than two hours. However, more than 66% of the sampled farmers reported having received advice from an agricultural extension worker in the past 12 months preceding the survey. Further still, more than 72% of the sampled farmers reported using multiple farmlands for cocoa farming, while about 74% reported practicing mixed farming. Finally, in terms of market accessibility, more than 52% acknowledged using urban areas for the sale of cocoa produce with a mean market distance of about 90km.

Table 3: Summary statistics of the sampled cocoa farms

	All Farms		Rainfed		Irrigated	
Variable Def. and Measurement	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Socio-economic variables						
NRh (in Naira)	42,558.9	46,774.8	31,386.7	17387.2	45,339.1	51,202.7
	($283.7)	($311.8)	($209.2)	($115.9)	($302.3)	($341.4)
Age of household head (Years)	55.3	12.72	56.7	13.3	52.4	11.7
Education (Years)	9.1	4.1	6.5	5.01	12.5	10.6
Farming_expirience (Cocoa)	22.8	10.8	23	3.95	21.9	5.0
Household_size (No. of persons)	7.5	3.8	5.3	2.19	6.2	2.7
Agricultural variables						
Total farm area (Hectares)	6.5	4.8	5.3	2.2	7.9	5.3
Visit from extension worker (No.)	2.5	2.6	2.6	2.9	2.2	2.4
Farm_labour (Cocoa farming)	2.9	2.1	3.6	2.8	2.3	2.2
Crop_area (Cocoa hectares)	2.4	1.0	1.4	1.4	1.6	1.0
Distance to urban market (km)	90.5	142.7	86.4	78.5	82.9	62.6
Aggregate measures (proportions)						
% of farms headed by male	95.0%		90.0%		97.0%	
% of farmers with access to credit	33.6%		39.0%		37.0%	
% of farms that received subsidy	14.0%		5.5%		45.5%	
% of farms using suppl. irrigation	19.9%		0%		100%	
% of farmers keeping livestock	46.7%		40.0%		37.0%	
% of farms using pesticides	93.0%		95.0%		97.0%	
% of farms over 5 hectares	11.5%		7.4%		22.6%	
% of farms with extension contacts	66.0%		56.9%		55.6%	
% of farms on La soils	42.9%		52.2%		19.5%	
% of farms on Jc soils	28.7%		21.3%		46.2%	
% of farms on Li soils	14.2%		14.2%		25.6%	
% of farms on LVf soils	14.2%		12.3%		8.8%	
Climate variables						
Monthly dry season temp. (oC)	32.4	4.82	28.6	1.12	28.9	1.05
Monthly rainy season temp. (oC)	25.7	1.13	25.1	0.91	24.5	0.82
Monthly Harmattan temp. (oC)	19.6	6.5	25.0	3.0	25.9	3.41
Monthly dry season precip. (mm)	46.7	33.9	37.3	23.8	33.7	21.15
Monthly rainy season precip. (mm)	169.0	15.9	139.2	28.4	150.7	22.9
Monthly Harmattan precip. (mm)	12.7	21.4	21.2	13.1	18	14.5
Control Variables						
Population density	251.9	19.93	251.7	19.9	252.3	20.4
Irrigation	19.9	0.40				
Altitude (m)	1238.8	139.3	1217.3	146.3	1332.8	110.2
Obs.	280			224		56

Ricardian model estimates

Table 4 presents three Loglinear regressions on net farm revenue per hectare for Nigerian cocoa farms. In the first regression (i.e., column one), net farm revenue is regressed on climate variables alone. Though this model fits well as many of the climatic variables, including their squared terms, are statistically significant, it fails to take into account the effects of household socioeconomic characteristics on net farm revenue. As reported in Reinsborough (2003), this category of independent variables are important because they reflect the potential of the farmlands for alternative uses. That notwithstanding, the model highlights the direction and magnitude of climate impacts on net farm revenue. The implications of the findings are taken up later.

Table 4: Loglinear specification of Ricardian model for all farms

	Climate only		Climate with CC Inter.[a]		Full Model Without Inter[b]	
	(2)		(3)		(4)	
	Coef.	*t-Stat.*	*Coef.*	*t-Stat.*	*Coef.*	*t-Stat.*
Dry season temp.	-0.917	-0.27			-1.193	**-2.78**
Dry season temp.2	-0.023	**-9.10**	-0.021	**-8.27**	-0.058	**-5.64**
Rainy season temp.	-6.568	**-3.52**			-0.079	**-0.71**
Rainy season temp.2	-0.0045	**-1.27**	-0.0045	**-1.27**	-0.0032	**-0.96**
Harmattan temp.	-8.805	**-7.72**	-8.805	**-7.72**	0.534	**1.68**
Harmattan temp.2	1.877	**7.79**	1.877	**7.79**	0.075	**10.47**
Dry season precip.	-0.086	**-3.25**			-0.113	**-3.46**
Dry season precip.2	0.00075	**2.41**	-0.00023	**-5.76**	-0.0010	**-4.49**
Rainy season precip.	-0.0123	**-0.40**			0.088	**0.22**
Rainy season precip.2	-0.00023	**-5.40**	-0.00005	**-0.58**	-0.0009	**-4.80**
Harmattan precip.	-0.0035	**-0.12**			-0.210	**-0.56**
Harmattan precip.2	0.00019	**5.65**	0.0017	**6.32**	0.0061	**4.82**
Dry season temp.*precip.						
Rainy season precip.*temp.			-0.0027	**-3.19**		
Harmattan temp.*precip.			0.0015	**2.23**		
La_soil_type					-3.005	**-7.35**
Jc_soil_type					-2.432	**-6.93**
Li_soil_type					-2.576	**-7.10**
LVf					-2.416	**-6.74**
Farm Altitude					0.014	**1.82**
Irrigation					0.191	**3.24**
Population_density					-0.030	**-3.24**
Access_credit					0.199	**4.05**
Education_head					-0.034	**-1.64**
Farm_experience					-0.0037	**-0.60**
Crop_area					0.0045	**0.43**
Household_ size					-0.018	**-1.02**
Market_distance (km)					-0.446	**-2.85**
No of visit by ext. worker					0.335	**1.24**
Total farm area (hectare)					-0.067	**-1.53**
Constant	12.9	7.64	13.1	**7.72**	26.4	**10.4**
F-Statistics	12.1		12.1		13.6	
Adj. R-Squared	0.29		0.27		0.46	
Observations	280		280		280	

[a] Showing estimated results for model with only climatic variables used as the independent variables.

[b] Results for climate response function specified in Equation 2.

In the second regression (i.e., column 2, Table 4), net farm revenue is regressed on climate and climate interaction effect variables. The fit is, however, the worst as many of the significant climatic variables in the first model are dropped due to collinearity problems. That notwithstanding, many of the squared terms for temperature and precipitation remained significant as in the first model and unchanged in sign and similar magnitude; however, the squared term of rainy season precipitation is no longer significant though negative as in model 1. This implies that there is an optimal level of precipitation during the rainy season that, above and beyond, net farm revenue per hectare decreases. Of the temperature-precipitation interaction effect variables, rainy season temperature-precipitation interaction has a very large significant negative effect on net farm revenue, whereas Harmattan temperature-precipitation interaction has a significant positive effect on net farm revenue. For the former, it signifies that during the rainy season, net farm revenue decreases for hotter and wetter cocoa farms; while during Harmattan, net farm revenue increases for hotter and wetter cocoa farms.

In the third regression (i.e., column 3, Table 4) that corresponds to our climate response function (Equation 2), net farm revenue is regressed on climate variables (C), their squared terms (C^2), soil types and three important control variables (S), including household socioeconomic characteristics (Z). This model seems to provide the best fit and the results one would most likely expect and therefore, used for all subsequent climate calculations. The adjusted R-squared for the model is much better with a higher goodness of fit value of 0.46. The effects of some of the significant variables from the "climate only" model in Table 4 are unchanged in sign and quite similar in magnitude. Dry season temperature and precipitations are significant and with large negative effects on net farm revenue as in model 1. Their squared terms remained significant and unchanged in sign as in model 1, indicating that there are optimal levels of temperature precipitation during the dry season that, above and beyond, net farm revenue per hectare decreases. The squared term for rainy season precipitation is equally significant and negatively correlated with net farm revenue. The four soil types all have a large significant negative effect on net revenue per cocoa farm hectare.

Furthermore, of the control variables, irrigation is significant and positive as expected, so also is population density. Of the socioeconomic variables included in the analysis, with the exception of access to credit and distance to urban markets, the rest are all insignificant. This is to say that farmers who have greater accessibility to credit facilities have higher net farm revenue than those without. Of course, one would expect such an empirical finding, as cocoa farming is very capital intensive. Similarly, farmers who are closest to urban markets have higher net farm revenue per cocoa hectare than those with less accessibility to urban markets. This may be linked to higher cost associated with longer market distance.

Column 2, Table 5, reports the marginal impacts of climate on net revenue per farm hectare of the full model (i.e., model 3) reported in Table 4 (i.e., column 4). The marginal analysis simply shows the infinitesimal change in temperature and precipitation on cocoa farming in Nigeria. As observed (i.e., row 6, column 2 in Table 5), the annual temperature impact is close to -5,698.4 Nigerian Naira or about US$38.0 per degree Celsius evaluated at the mean of the sample. However, the most harmful temperature effects are associated with the dry and rainy season. Conversely, for the precipitation impacts, the marginal calculations also revealed that annual precipitation impact is 40 Naira or about US$0.30 increase in net revenue per mm/month, and the most harmful precipitation effect due largely to dry season precipitation. The marginal impact analysis equally reveals that, while temperature increase is strictly detrimental to cocoa farming in Nigeria, infinitesimal precipitation increase is strictly beneficial to cocoa farms in general. This may be linked to the use of supplementary irrigation by cocoa farmers. The implication of this is taken up in the subsequent paragraphs.

Table 5: Marginal impacts of climate on cocoa NRh (Naira)

Variables (1)	Full Model Marginal (2)	Irrigated Marginal (3)	Rainfed Marginal (4)
Temperature			
Dry Season	-9,302.7	-349.9	-13,528.7
Rainy Season	-7,165.2	12,403.8	-16,118.7
Harmattan Season	-627.2	5,187.2	-1,547.6
Annual	**-5,698.4**	**5,747.0**	**-10,398.3**
Precipitation			
Dry Season	-218.8	192.96	-368.92
Rainy Season	88.8	-742.51	-11.16
Harmattan Season	250.1	1,124.34	766.94
Annual	**40.0**	**191.60**	**128.95**

Marginals of each climate variable calculated at the mean of the sample.

Table 6 presents a comparison of supplementary irrigated farms versus rainfed cocoa farms. In the supplementary irrigated farm model, the inclusion of the quadratic terms complicated the estimation as many climatic variables are dropped due to collinearity. Similarly, the inclusion of the temperature-precipitation interaction effect, as well as the control variables, seems to make the situation more problematic as very large and unrealistic confidence intervals are produced for the estimates. By simplifying the model without the C^2 and S variables included, more precise estimates are obtained. The results are presented in column 2, Table 6, while those of the rainfed model are presented in column 3. There are many significant differences between the estimates of the two models. In the irrigated model, for example, it thus appears that warm rainy seasons and dry Harmattan seasons are best for net farm revenues, whereas wet dry seasons are best for net revenues of rainfed farms. Also, irrigated farm net revenues are significantly affected by Jc and Li soil types, whereas net revenues of rainfed farms are affected by La and Jc soil types. Of the socioeconomic variables, number of years of farming cocoa is more influential for irrigated farm revenues than rainfed farms. Similarly, while distance to urban markets is highly influential in explaining net rainfed farm revenues, it is less influential for net irrigated farm revenues. The same could be said concerning farm altitude. It significantly affects rainfed farms more than irrigated farms.

Table 6: Loglinear specification of rainfed and irrigated farm samples

Variable (1)	Irrigated Model (2)		Rainfed Model (3)	
	Coef.	*t-Stat.*	*Coef.*	*t-Stat.*
Dry season temp.	-0.0035	-0.18	-0.902	-0.62
Dry season temp.^{2}			-0.135	**-3.06**
Rainy season temp.	0.124	**3.53**	-0.601	-1.40
Rainy season temp.^{2}			-0.012	**-3.67**
Harmattan temp.	0.519	**2.30**	-0.315	-0.50
Harmattan temp.^{2}			0.034	**8.51**
Dry season precip.	0.0019	0.32	0.104	**3.23**
Dry season precip.^{2}			-0.00005	-1.17
Rainy season precip.	-0.0074	-1.75	0.191	0.02
Rainy season precip.^{2}			-0.00003	**-2.06**
Harmattan precip.	0.0112	1.82	-0.808	-0.65
Harmattan precip.^{2}			0.0290	0.02
Rainy season precip.*temp.				
Harmattan temp.*precip.			0.00060	**2.00**
La			2.927	**9.62**
Jc	-0.106	**-2.47**	-0.239	**-5.75**
Li	2.927	**9.62**		
LVf				
Farm Altitude			-0.025	**-9.23**
Access_credit	0.083	**3.82**	0.180	**3.10**
Farm_experience	-0.011	**-2.63**	-0.032	-1.91
Cropland	-0.0020	-0.69	-0.213	**-3.12**
Household_size	0.0036	0.75	-0.0150	-1.08
Market_distance (Km)	-0.051	-1.89	-0.045	**-2.85**
Constant	16.4	**2.20**	21.4	**8.56**
F-Statistics	37.2		17.1	
Adj. R-Squared	0.87		0.56	
Observations	56		224	

Columns 3 and 4 of Table 5 show the marginal impacts of climate in the irrigated and rainfed regression models of Table 6. The annual temperature marginals for rainfed farms are much larger than those of irrigated farms. The impact is 5,747 Nigerian Naira or about US$38.3 per degree Celsius for supplementary irrigated farms compared to -10,393.3 Nigerian Naira or about US$69.3 per degree Celsius for rainfed farms. The harmful temperature effect in the irrigated farm model is due largely to dry season temperature, whereas the beneficiary effects are due mainly to rainy season and

Harmattan temperature effects. For rainfed farms, harmful temperature effects are associated with all the three seasons. Similarly, the annual changes associated with decrease increasing impacts are net gains of 191.6 Nigerian Naira (US$1.3) per mm/month for irrigated farms and 128.9 Naira (US$0.86) per mm/month for rainfed farms. In general, irrigated cocoa farms are more sensitive to increase precipitation during the rainy season, while rainfed farms are most vulnerable to decrease precipitation during the dry and rainy seasons.

Projections with climate scenarios

As discussed in Reinsborough (2003), there are many contentious issues involved in trying to use the estimated Ricardian results to predict how temperature and precipitation will affect future net farmland revenues. Firstly, estimating beyond the range of observed data may be problematic, especially when the estimated relationships are not exactly as expected. For example, it is expected that the square terms of the climatic variables should all be negative, assuming cocoa has optimum temperature and precipitation levels. However, while the squared terms of dry season temperature and precipitation, as well as rainy season temperature and precipitation variables exhibit a hill-shaped relationship, Harmattan temperature and precipitation squared exhibit a U-shape. This could be quite problematic in accurately forecasting the effects of future climate change on net revenue per hectare for Nigerian cocoa farms. Secondly, other variables such as soil types and farmers' socioeconomic characteristics that are assumed unchanged with temperature and precipitation changes will certainly be affected in reality. For example, increased rainfall and sunshine certainly affects the moisture content of the soil and hence, plant growth and productivity. However, as the changes to be estimated are quite moderate, using the results of the full model (i.e., column 3, Table 4) and those of Table 6 to predict the future impacts of climate on net revenue per hectare for all farms, irrigated and rainfed, should not be too problematic. As emphasized by Mendelsohn et al (2006), the aim of the projection is not to examine how net farm revenue actually changes, but simply to isolate the effect of climate change alone on farm revenue, assuming all other conditions are held constant. These may include price changes, investment, population and the use of technology, etc.

In order to carry out the projections, two climatic scenarios are used. In the first scenario, projected temperature and precipitation are generated based on a multimodel ensemble of regional climate models (RCMs) participating in the Coordinated Regional Climate Downscaling Experiment (CORDEX; Giorgi et al, 2009). The CORDEX RCMs downscale a number of Coupled Model Intercomparison Project, Phase 5 (CMIP5; Taylor et al, 2012) Global Climate Models (GCMs) for two Representative Concentration Pathways (RCP4.5 and RCP8.5). The RCMs are integrated over the whole African domain with a grid interval of 50km. For more detailed information on the CORDEX experiments, see Jones et al (2011), and for a list of GCM-RCM combination so far available over West Africa, see Sylla et al (2015). To date, the CORDEX data constitutes the most comprehensive RCMs projections available for the African domain.

Figures 2 and 3 show absolute precipitation and temperature changes (Future minus Historical; in mm d-1 and Kelvin, respectively) for each of the CORDEX RCMs averaged over the whole of Nigeria, and for both RCP4.5 and RCP8.5 during the two future time slices (2036-2065 and 2071-2100). In general, an increase in precipitation is projected in all cases, except for the Climate Limited-area Modelling Community (CCLM) that produces a substantial decrease for the RCP8.5 during 2071-2100. The highest precipitation increase of more than 1mm d-1 is simulated by RegCM4 of the International Centre for Theoretical Physics (ICTP), Italy. Although the multimodel ensemble projects more rainfall, it is clear that the various CORDEX RCMs produce different magnitude and sign of the precipitation changes over Nigeria. However, the temperature change (i.e. Figure 2) shows a consistent warming across all RCMs, with the highest change (more than 4 °C) projected during 2071-2100 for the RCP8.5.

Figure 2: Absolute precipitation change (in mm d-1) for both the climate scenarios RCP4.5 and RCP8.5 and for two future time windows 2036-2065 and 2071-2100

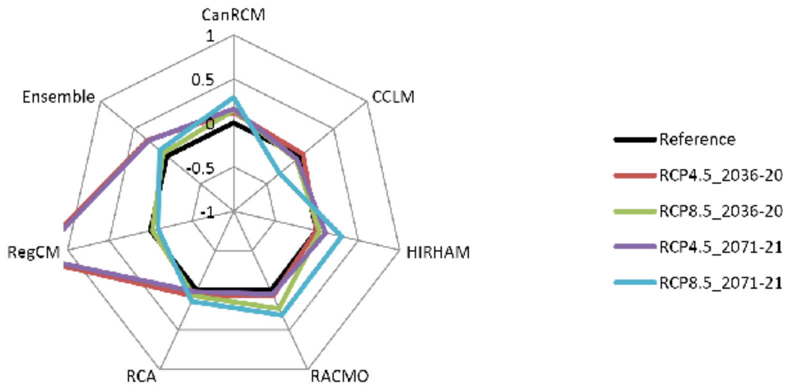
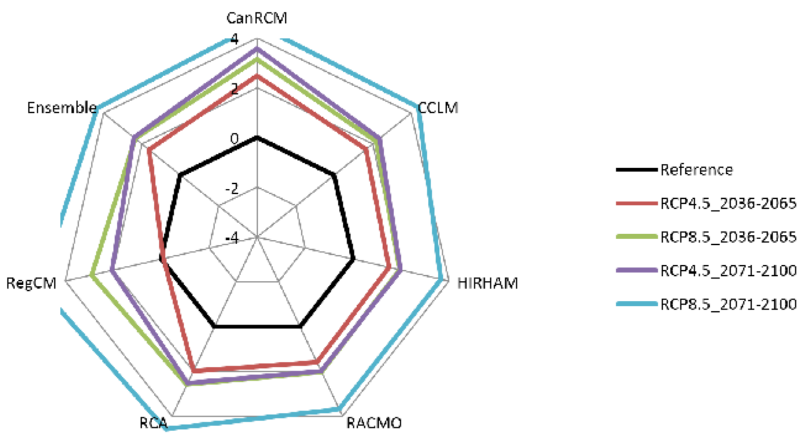


Figure 3: Absolute temperature change (in Kelvin or °C) for both the climate scenarios RCP4.5 and RCP8.5 and for two future time windows 2036-2065 and 2071-2100



With regard to these results, we also generate temperature and precipitation changes by applying hypotheses of 2.5°C increase in temperature and 5% decrease in precipitation from observations (1981-2010) used as baseline scenarios (i.e., second scenario). These similar hypotheses (+2.5°C to 5°C, and 7% to 14% decrease in precipitation) were already tested for Africa croplands by Kurukulasuriya and Mendelsohn (2006) and Mano and Nhemachena (2006). The project changes from the different climate scenarios generated are summarized in Table 7.

Table 7: (a): Monthly seasonal temperature (in °C) as generated from CORDEX and hypotheses of +2.5 °C from observations (baseline period 1981 – 2010); (b): Monthly seasonal precipitation (in mm/month) as generated from CORDEX and hypotheses of -5% precipitation decrease from observations (baseline period 1981-2010)

CORDEX (Temperature Projections)						***2.5 °C Temp. Increase from Observations (see Table 3)***		
(a)	Historical	RCP4.5	RCP4.5	RCP8.5	RCP8.5	**Tb+2.5°C (All Farms)**	**Tb+2.5°C (Rainfed Farms)**	**Tb+2.5°C (Irrigated Farms)**
Period	(1976-2005)	(2036-2065)	(2071-2100)	(2036-2065)	(2071-2100)	(2050 - 2100)	(2050 - 2100)	(2050 - 2100)
Dec-Jan	22.58	24.19	24.98	24.93	26.88	22.1	27.5	28.4
Apr-Sep	25.2	26.8	27.59	27.53	29.45	28.2	27.6	27
Oct-Mar	24.46	26.12	26.89	26.84	28.85	34.9	31.1	30.5
CORDEX (Precipitation Projections)						***5% Precip. Decrease from Observations (see Table 3)***		
(b)		RCP4.5	RCP4.5	RCP8.5	RCP8.5	**Pb - 5% (All Farms)**	**Pb - 5% (Rainfed Farms)**	**Pb - 5% (Irrigated Farms)**
Period	(1976-2005)	(2036-2065)	(2071-2100)	(2036-2065)	(2071-2100)	(2050 - 2100)	(2050 - 2100)	(2050 - 2100)
Dec-Jan	2.79	10.5	10.53	3.24	3.42	12.065	20.14	17.1
Apr-Sep	174.12	183.78	183.09	177.66	178.92	160.55	132.24	143.165
Oct-Mar	30.51	38.19	38.22	30.78	32.19	44.365	35.435	32.015

Where, Tb=baseline temperature, Pb=baseline precipitation.

These range of climate change scenarios (i.e., first and second) were fitted into the results of the full model (in Table 4) and those of Table 6 to examine how future changes in climate would affect net revenue per hectare for cocoa farms in Nigeria under all farms, irrigated and rainfed conditions. The simulated results are reported in Tables 8 and 9. The effects vary a great deal across cocoa farms in terms of annual and seasonal impacts. In the first scenario, based on the 6 CORDEX RCMs Ensemble (Table 8), the calculations reveal marked variations in net farm revenues per hectare across the different cocoa farms in Nigeria. As shown, both the RCP4.5 and RCP8.5 scenarios predict drastic declines in net farm revenues per hectare between 2036-2065 and 2071-2100. This would occur mostly in the dry seasons for all farms, as well as for rainfed farms. The seasonal losses range from NGN -58.0 ($0.39) to NGN -83 ($0.55) for all farms, and from NGN -110.9 ($0.74) to NGN -148.8 ($0.99) for rainfed farms. A striking prediction from the 6 CORDEX RCMs Ensemble suggests that irrigated farm revenues will increase across all the seasons, with the most beneficial effects expected during the Harmattan season. However, in terms of annual revenue losses, only rainfed farms are expected to record net revenue declines in the future. These losses are expected to range from NGN -25.2 ($0.17) to NGN -29.1 ($0.19) between the periods of 2036-2065 and 2071-2100.

Table 8: Impacts of CORDEX Ensemble (6 RCMs) scenarios on cocoa NRh

		CORDEX Scenarios				
		Historical	RCP4.5	RCP4.5	RCP8.5	RCP8.5
		(1976-2005)	(2036-2065)	(2071-2100)	(2036-2065)	(2071-2100)
All Farms	Dec-Jan (Harmattan)	76.16	81.67	85.00	85.71	94.30
	Apr-Sep (Rainy season)	10.41	7.76	7.73	9.03	8.23
	Oct-Mar (Dry season)	-58.01	-68.53	-72.92	-71.28	-83.44
	Annual	***9.52***	***6.97***	***6.60***	***7.82***	***6.36***
Rainfed Farms	Dec-Jan (Harmattan)	29.59	28.39	29.45	32.36	35.07
	Apr-Sep (Rainy season)	30.98	30.76	29.65	28.75	26.51
	Oct-Mar (Dry season)	-110.94	-134.72	-140.97	-129.93	-148.77
	Annual	***-16.79***	***-25.19***	***-27.29***	***-22.94***	***-29.06***
Irrigated Farms	Dec-Jan (Harmattan)	28.15	29.07	29.48	29.37	30.39
	Apr-Sep (Rainy season)	18.24	18.36	18.47	18.50	18.73
	Oct-Mar (Dry season)	16.37	16.38	16.38	16.36	16.36
	Annual	***20.92***	***21.27***	***21.44***	***21.41***	***21.83***

In the second scenario (Table 9), firstly a 2.5^{0}C increase in temperature only is associated with seasonal net farm revenues per hectare loss of NGN -126.2 ($-0.84) for all farms and NGN -153.9 ($-1.03) for rainfed farms during the period (2050-2100). These losses are expected also during the dry season as initially predicted by the 6 CORDEX RCMs Ensemble. Secondly, reducing rainfall by 5% is equally associated with net farm revenue losses of NGN -108.5 ($0.72) for all farms and NGN -151.2 ($1.0) for rainfed farms during the dry season. Similar seasonal losses are associated when a simultaneous 2.5^{0}C increase in temperature and a 5% reduction in rainfall are considered. The combined effect is a reduction in net farm revenue per hectare of about NGN -125.8 ($0.84) for all farms, and NGN -173.9 ($1.2) for rainfed farms during this same period. Irrigated farms are, in general, less sensitive to any of these changes, as was predicted by the 6 CORDEX RCMs Ensemble. However, note that while the 6 CORDEX RCMs Ensemble predicts future net revenues decline only for rainfed farms, the second case climate scenarios considered in the paper predict annual net revenue declines for all farms and rainfed farms. The most harmful effects being associated with temperature rise rather than rainfall decline.

Table 9: Impacts of +2.5^{0}C and -5% changes in temperature and precipitation on cocoa NRh

		IPCC Scenarios based			
		Baseline Tb & Pb	Tb+2.5°C & Pb	Tb & Pb-5% Pb	Tb+2.5°C & Pb-5%Pb
		(1981 - 2010)	(2050 - 2100)	(2050 - 2100)	(2050 - 2100)
All Farms	Dec-Jan (Harmattan)	64.00	73.15	64.03	73.19
	Apr-Sep (Rainy season)	11.42	10.79	13.19	12.56
	Oct-Mar (Dry season)	-108.94	-126.22	-108.46	-125.75
	Annual	***-11.17***	***-14.09***	***-10.42***	***-13.33***
Rainfed Farms	Dec-Jan (Harmattan)	30.68	34.35	30.26	33.94
	Apr-Sep (Rainy season)	24.76	21.68	23.49	20.40
	Oct-Mar (Dry season)	-153.93	-176.34	-151.19	-173.59
	Annual	***-32.83***	***-40.10***	***-32.48***	***-39.75***
Irrigated Farms	Dec-Jan (Harmattan)	30.04	31.34	30.03	31.33
	Apr-Sep (Rainy season)	18.32	18.63	18.38	18.69
	Oct-Mar (Dry season)	16.37	16.36	16.36	16.35
	Annual	***21.58***	***22.11***	***21.59***	***22.12***

Where, Tb=baseline temperature, Pb=baseline precipitation.

6. Conclusion and policy implication

This paper assesses the economic implications of climate change (i.e., average long-term temperature and precipitation) on net farm revenues per cocoa hectare in Nigeria under rainfed and irrigated (supplementary) conditions. The results indicate high sensitivity of net revenues to climate normals in Nigeria. The degree of sensitivity to climate normals, however, depends on whether cocoa farms are irrigated or not. In general, both temperature and precipitation were more sensitive to marginal changes in rainfed farms' revenue than those of irrigated farm revenues. For example, the annual temperature marginals for supplementary irrigated cocoa farms is about NGN 5,747 (US$38.3) per degree Celsius compared with NGN -10,393.3 ($69.3) per degree Celsius for rainfed farms. Similarly, the annual changes associated with decrease precipitation impacts are net gains of NGN 191.6 (US$1.3) per mm/month for irrigated farms, compared with NGN 128.9 (US$0.86) per mm/month for rainfed farms. Furthermore, the marginal analysis shows that while irrigated cocoa farms are more sensitive to decrease precipitation, especially during the rainy season, rainfed farms are most vulnerable to decrease precipitation both in the dry and rainy seasons.

Projections of future climate impacts based on 6 CORDEX RCMs Ensemble and a 2.5°C increase in temperature and 5% decrease in precipitation coupled with a simultaneous 2.5^{0}C increase in temperature and a 5% reduction in rainfall, suggest a wide range of outcomes on net farm revenues for all cocoa farms in Nigeria. In the first scenario (i.e., CORDEX experiments), both the RCP4.5 and RCP8.5 scenarios predict drastic declines in net farm revenues per hectare for all farms and rainfed farms between 2036-2065 and 2071-2100. The seasonal losses range from NGN -58.0 ($0.39) to NGN -83 ($0.55) for all farms, and from NGN -110.9 ($0.74) to NGN -148.8 ($0.99) for rainfed farms. Irrigated farms are, in general, less sensitive to the different CORDEX scenarios. All the scenarios predict net farm revenue increases during these periods.

In the second scenario, the empirical analysis also predicts drastic declines in net farm revenues per hectare for all farms and rainfed farms between 2050-2100. The combined effect of a simultaneous 2.5^{0}C increase in temperature and a 5% reduction in rainfall are associated with a reduction in net farm revenues per hectare of about NGN -125.8 ($0.84) for all farms and NGN -173.9 ($1.2) for rainfed farms. Again, irrigated farms are, in general, less sensitive to any of the changes used in the climate predictions.

The results clearly demonstrate the importance of supplementary irrigation as an adaptation strategy by cocoa farmers to reduce the harmful effects of climate change on cocoa agriculture in Nigeria. However, serious neglect by the national and sub-national governments of Nigeria to invest in irrigational farming systems may be partly responsible for the declining cocoa productivity trend experienced in the country. This certainly demands more investment in irrigation to support local farmers to cope with climate change uncertainty. Additionally, providing farmers with secure property rights to their land and water may help create incentives for local cocoa farmers to invest more heavily in irrigated farming. Furthermore, government support for local agricultural research institutions to help produce more tolerant, and climate-resistant high breed seed varieties that are suited to warmer climate conditions is likely to boost farm productivity. Finally, creating awareness and encouraging farmers to participate in index-based crop insurance programmes is most likely to support farmers in mitigating adverse and heterogeneous effects of climate change and natural catastrophes encountered during farming activities (Barnett, 2014; Barnett and Mahul, 2007; Kunreuther, 1996; FAO, 2011; IFAD 2011. In Latin America, for example, 18 of the 25 countries have already introduced agricultural insurance programmes (World Bank, 2010).

References

Adams, R.M., D. Glyer and B.A. McCarl. 1989. "The economic effects of climate change in U.S. agriculture: A preliminary assessment". In D. Tirpak and J. Smith, eds., *The Potential Effects of Global Climate Change on the United States: Report to Congress.* EPA-230-05-89-050, Washington, D.C.

Adams, R.M. et al. 1990. "Global climate change and US agriculture". *Nature,* 345: 219-24.

Adams, R.M., R.A. Fleming, C. Chang, B.A. McCarl and C. Rosenzweig. 1993. *A Reassessment of the Economic Effects of Global Climate in US Agriculture*. Washington, D.C.: U.S Environmental Protection Agency.

Adams, R.M. et al 1999. "The economic effects of climate change on US agriculture". In R. Mendelsohn and J. Neumann, eds., *The Economic Impact of Climate on the Economy of the United States*. Cambridge, UK: Cambridge University Press.

Ajayi, I.R. et al. 2010. "Modelling rainfall as a constraining factor for cocoa yield in Ondo State". *American Journal of Scientific and Industrial Research*, ISSN: 2153-649X doi:10.5251/ajsir.2010.1.2.127.134.

Ajetomobi, J., A. Abiodun and R. Hassan, 2011. "Impacts of climate change on rice agriculture in Nigeria". *Tropical and Subtropical Agroecosystems*, 14(2011): 613 -22.

Ajewole, D.O. and S. Iyanda. 2010. "Effect of climate change on cocoa yield: A case of Cocoa Research Institute (CRIN) farm, Oluyole Local Government Ibadan Oyo State". *Journal of Sustainable Development in Africa*, 12(1): 350-358.

Amien, I. et al 1996. "Effects of interannual climate variability and climate change on rice yields in Java, Indonesia". *Water, Air, and Soil Pollution,* 92:29-39.

Barnett, B. and O. Mahul. 2007. "Weather index insurance for agriculture and rural areas in lower income countries". *American Journal of Agricultural Economics,* 89: 1241-47.

Barnett, B. 2014. "Multi-peril crop insurance: Successes and challenges". *Agricultural Finance Review,* 74(2): 200-16.

Bruce, J., H. Lee and E. Hates, eds. 1996. *Climate Change 1995: Economic and Social Dimensions*. Cambridge, U.K.: Cambridge University Press for IPCC.

Central Bank of Nigeria (CBN). 2014. *Annual Statistical Report*. Central Bank of Nigeria, Abuja, Nigeria.

CEEPA. 2006. Special series on climate change and agriculture in Africa. Centre for Environmental Economics and policy in Africa (CEEPA) Discussion Paper Series, University of Pretoria, South Africa.

Chang, C.C. 2002. "The potential impact of climate change on Taiwan's agriculture". *Agricultural Economics*, 227: 51-64.

Cline, W.R. 1996. "The impact of global warming on agriculture: Comment". *American Economic Review,* 86: 1309-12.

Darwin, R.F., M. Tsigas, J. Lewandrowski and A. Raneses. 1995. "World agriculture and climate change: Economic adaptations". Agricultural Economic Report No. 703. United States Department of Agriculture, Economic Research Service, Washington, D.C.

Darwin, R. 1999. "A farmer's view of the Ricardian approach to measuring agricultural effects of climate change". *Climate Change*, 41: 371-411.

Deressa, T.T. 2006. *Measuring the Economic Impact of Climate Change on Ethiopian Agriculture: Ricardian Approach*. CEEPA Discussion Paper No. 25. Centre for Environmental Economics and Policy in Africa -CEEPA, University of Pretoria, South Africa

Deressa, T. and R. Hassan. 2005. "Economic impact of climate change on crop production in Ethiopia: Evidence from cross-section". *Journal of African Economies*, 18(4): 529-54.

Deressa, T., R. Hassan and D. Poonyth. 2005. "Measuring the economic impact of climate change on South Africa's sugarcane growing regions". *Agrekon*, 44(4): 524-42.

Dinar, A., R. Hassan, R. Mendelsohn and J. Benhin. 2008. "Climate change and African agriculture: Impact assessment and adaptation strategies". Earthscan, London.

Downing, T.E. 1992. *Climate Change and Vulnerable Places: Global Food Security and Country Studies in Zimbabwe, Kenya, Senegal and Chile*. Research Paper No. 1. Environmental Change Unit, University of Oxford, U.K.

Eid, M.H., S.M. El-Marsafawy and S.A. Ouda. 2006. *Assessing the Economic Impacts of Climate Change on Agriculture in Egypt: A Ricardian Approach*. CEEPA Discussion Paper No. 16. Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, South Africa.

El-Shaer, H.M. et al. 1997. "Impact of climate change on possible solution for Egyptian agriculture in the future". *Migration Adaptation Strategy for Global Change,* 24: 233-50.

Escano and Buendia. 1994. "Climate impact assessment for agriculture in Philippines: Simulation of rice yield under climate change scenario". In C. Rosenzweig and A. Iglesias, eds., *Implications of Climate Change for International Agriculture: Crop Modelling Study*. Washington, D.C.: U.S.E.P.A., Philippines Chapter.

Easterling, W.E. et al. 1993. "Agricultural impacts and responses to climate change in the Missouri–Iowa–Nebraska–Kansas MINK region". *Climatic Change,* 24: 23-61.

FAO. 1996. "Agro-ecological zoning: Guidelines". *FAO Soils Bulletin*, 73. Rome, Italy.

FAO. 2011. "Agricultural insurance in Asia and the Pacific Region". RAP Publication, 2011/12.

Gbetibouo, G. and R. Hassan. 2005. "Measuring the economic impact of climate change on major South African field crops: A Ricardian approach". *Global and Planetary Change,* 47(2-4): 143-52.

Giorgi, F., C. Jones, and G. Asrar. 2009. "Addressing climate information needs at the regional level". The CORDEX framework. *WMO Bulletin*, July 2009.

Hassan, R., 2010. "Implications of climate change for agricultural sector performance in Africa: Policy challenges and research agenda". Journal of African Economies, AERC Supplement 19(2). ii77-ii105.

Hassan R. 2008. "Implications of climate change for agricultural sector performance in Africa: Policy challenges and research agenda". Paper presented at the African Economic Research Consortium (AERC) Biannual Research Workshop. Entebbe, Uganda, May 31 – June 6.

Hassan, R. and C. Nhemachena. 2008a. "Determinants of climate adaptation strategies of African farmers: Multinomial choice analysis". *African Journal of Agricultural and Resource Economics,* 2(1): 83-104.

Hassan, R. and C. Nhemachena. 2008b. "Measuring the economic impact of African agriculture". Draft Report, CEEPA, University of Pretoria, South Africa.

Hulme, M., R.M. Doherty, T. Ngara, M.G. New and D. Lister. 2001. "African climate change: 1900-2100". *Climate Research,* 17: 145-68.

IFAD. 2011. *Weather Index-Based Insurance in Agricultural Development: A Technical Guide*. IFAD-WFP Weather Risk Management Facility (WRMF), International Fund for Agricultural Development.

Iglesias, A. and M.I. Minguez. 1997. "Modelling crop-climate interactions in Spain: Vulnerability and adaptation of different agricultural systems to climate change". *Migration and Adaptation Strategy for Global Change*, 1:273-88.

Iglesias, A., C. Rosenzweig and D. Pereira. 1999. "Agricultural impacts of climate change in Spain: Developing tools for a spatial analysis". *Global Environmental Change,* 10: 69-80.

Intergovernmental Panel on Climate Change (IPCC). 2014. Climate Change 2014: Synthesis Report and Summary for Policymakers. IPCC.

Jain, S. 2006. "An Empirical Economic Assessment of Impacts of Climate Change on Agriculture in Zambia." CEEPA Discussion Paper No. 27. Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, South Africa.

Jin, Z., D. Ge, H. Chen and J. Fang. 1994. "Effects of climate change on rice production and strategies for adaptation in Southern China". In C. Rosenzweig and A. Iglesias, eds., *Implications of Climate Change for International Agriculture: Crop Modelling Study*. Washington, D.C.: U.S.E.P.A., Philippines Chapter

Jones, C., F. Giorgi and G. Asrar. 2011. "The coordinated regional downscaling experiment: CORDEX An international downscaling link to CMIP5". *CLIVAR Exchanges*, 56(16): 34-40.

Kaiser, H.M. et al 1993. “Adaptation to global climate change at the farm level”. In H. Kaiser and T. Drennen, eds., *Agricultural Dimensions of Global Climate Change*. Delray Beach, Fla.: St. Lucie Press.

Kapetanaki, G. and C. Rosengweig. 1997. “Impact of climate change on maize in central and Northern Greece: A simulation study with ceres-maize”. *Migration Adaptation Strategy for Global Change,* 1:251-71.

Kumar, K. and J. Parikh. 1998. “Climate change impacts on Indian agriculture: The Ricardian approach”. In A. Dinar et al, eds., *Measuring the Impact of Climate Change on Indian Agriculture.* World Bank Technical Paper No. 402, Washington, D.C.

Kumar, K. and J. Parikh. 2001. “Indian agriculture and climate sensitivity”. *Global Environmental Change*, 11(2): 147-154.

Kunreuther, H. 1996. “Mitigating disaster losses through Insurance”. *Journal of Risk and Uncertainty*, 12: 171-87.

Kurukulasuriya, P. and I. Ajwad. 2003. “Estimating the impact of climate change on small holders: A case study on the agriculture sector in Sri Lanka”. School of Environment and Forestry Study, Yale University, New Haven, USA.

Kurukulasuriya, P. and R. Mendelsohn. 2006. *A Ricardian Analysis of the Impact of Climate Change on African Cropland*. CEEPA Discussion Paper No. 8. Centre for Environmental Economics and Policy in Africa, University of Pretoria, South Africa.

Kurukulasuriya, P. et al 2006. *“*‘Will African agriculture survive climate change?” *World Bank Economic Review*, 20(3): 367-88.

Kurukulasuriya, P. and R. Mendelsohn. 2008a. “A Ricardian analysis of the impact of climate change on African cropland”. *African Journal of Agricultural and Resource Economics,* 2(1): 1-23.

Kurukulasuriya, P. and R. Mendelsohn. 2008b. “Modelling endogenous irrigation: The impact of climate change on farmers in Africa”. World Bank Policy Research Working Paper No. 4278. The World Bank, Washington, D.C.

Lawal, J. O. and L.A. Emaku. 2007. "Evaluation of the effect of climatic changes on cocoa production in Nigeria: Cocoa Research Institute of Nigeria (CRIN) as a Case Study." *African Crop Science Conference Proceedings,* 8: 423-426.

Luo, Q. and E. Lin. 1999. “Agricultural vulnerability and adaptability in developing countries: The Asian-Pacific region”. *Climate Change*, 43: 729-43.

Mano, R. and C. Nhemachena. 2006. *Assessment of the Economic Impacts of Climate Change on Agriculture in Zimbabwe: A Ricardian Approach*. CEEPA Discussion Paper No. 11. Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, South Africa.

Mathews, R.N. et al. 1997. “Simulating the impact of climate change on rice production in Asia and evaluating options for adaptation”. *Agricultural Systems*, 54: 399-425.

Mariara, K.J. and F.K. Karanja. 2006. *The Economic Impact of Climate Change on Kenyan Crop Agriculture: A Ricardian Approach*. CEEPA Discussion Paper

No. 12. Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, South Africa.

Maddison, D. 2000. "A hedonic analysis of agricultural land prices in England and Wales". *European Review of Agricultural Economics*, 27: 519-32.

Mendelsohn, R., W. Nordhaus and D. Shaw. 1994. "The impact of global warming on agriculture: A Ricardian analysis". *American Economic Review,* 84: 753–71.

Mendelsohn, R. and W. Nordhaus. 1996. "The impact of global warming on agriculture: Reply". *American Economic Review,* 86: 1312-15.

Mendelsohn, R. and A. Dinar. 1999. "Climate change, agriculture, and developing countries: Does adaptation matter?" *The World Bank Research Observer,* 14: 277-93.

Mendelsohn, R. 2000. "Measuring the effect of climate change on developing country agriculture, two essays on climate change and agriculture: A developing country perspective". FAO Economic and Social Development Paper No. 145, FAO, Italy.

Mendelsohn, R., A. Dinar and A. Dalfelt. 2000. *Climate Change Impacts on African Agriculture.* At http://www.ceepa.co.za/Climate_Change/pdf/(5-22-01)afrbckgrnd-impact.pdf

Mendelsohn, R., ed. 2001. *Global Warming and the American Economy: A Regional Assessment of Climate Change on Pacific Rim Countries*. Cheltenham: Edward Elgar Pub. UK.

Mendelsohn, R. 2003. "The impact of global warming on Pacific Rim Countries". In C. Chang et al, eds., *Global Warming and the Asian Pacific*. Cheltenham: Edward Elgar Pub. UK.

Mendelsohn, R. and A. Dinar. 2003. "Climate, water, and agriculture". *Land Economics,* 79(3): 328-41.

Mendelsohn, R., J. Arellano-Gonzalez and P. Christensen. 2010. "A Ricardian analysis of Mexican farms". *Environment and Development Economics,* 15: 153-72.

Molua, E.L. 2002. "Climate variability, vulnerability and effectiveness of farm-level adaptation options: The challenges and implications for food security in Southwestern Cameroon". *Environment and Development Economics,* 7: 529-45.

Molua, E.L. and C.M. Lambi. 2006. *The Economic Impact of Climate Change on Agriculture in Cameroon*. CEEPA Discussion Paper. Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, South Africa.

Molua, E.L. and C.M. Lambi. 2007. "The economic impact of climate change on agriculture in Cameroon". World Bank Policy Research Working Paper No. 4364. The World Bank, Washington, D.C.

Odingo, R.S. 2008. "Climate change and economic development: Issues, challenges and opportunity for Africa in the decades ahead". AERC Seminar Paper, 2008.

Omolaja, S.S. et al. 2009. "Rainfall and temperature effects on flowering and pollen productions in Cocoa". *African Crop Science Journal*, 17(1): 41-48.

Onyeji, S.C. and G. Fischer. 1994. "An economic analysis of potential impacts of climate change in Egypt". *Global Environmental Change and Policy Dimensions,* 4(4): 281-99.

Ouedraogo, M., L. Some and Y. Dembele. 2006. *Economic Impact Assessment of Climate Change* on Agriculture *in Burkina Faso: A Ricardian Approach*. CEEPA Discussion Paper No. 24. Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, South Africa.

Parry, M.L. 1990. *Climate Change and World Agriculture.* London: Earthscan Publication.

Reilly, J. 1994. "Crops and climate change". *Nature,* 367: 118-19.

Reilly, J. 1995. "Climate change and global agriculture: Recent findings and issues". *American Journal of Agricultural Economics,* 77: 727-33.

Reinsborough, M.J. 2003. "A Ricardian model of climate change in Canada". *Canadian Journal of Economics*, 36: 21-40.

Ricardo, D. 1817. *The Principles of Political Economy and Taxation*. London: John Murray.

Rosenzweig, C. and M. Parry. 1994. "Potential impacts of climate change on world food supply". *Nature*, 367: 133-38.

Sanghi, A., R. Mendelsohn and A. Dinar. 1999. "The climate sensitivity of Indian Agriculture". In A. Dinar et al, eds., *Measuring the Impact of Climate Change on Indian Agriculture.* World Bank Technical Paper No. 402. Washington, D.C.: The World Bank.

Seleka, T.B. 1999. "The impact of Botswana's traditional arable agriculture: Growth rates and the impact of the accelerated rainfed arable programme (ARAP)". *Agricultural Economics*, 20: 121-33.

Sene, M.I., M. Diop and A. Dieng. 2006. *Impacts of Climate Change on the Revenues and Adaptation of Farmers in Senegal*. CEEPA Discussion Paper No. 20. Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, South Africa.

Seo, N.S.O., R. Mendelsohn and M. Munasinghe. 2005. "Climate change and agriculture in Sri Lanka: A Ricardian valuation". *Environment and Development Economics,* 10: 581-96.

Seo, N.S.O. and R. Mendelsohn. 2006. *The Impact of Climate Change on Livestock Management in Africa: A Structural Ricardian Analysis*. CEEPA Discussion Paper No. 23. Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, South Africa.

Sylla, M.B., N. Elguindi, F. Giorgi and D. Wisser. 2015. "Projected robust shift of climate zones over West Africa in response to antropogenic climate change for the late 21st Century". *Climatic Change*. Forthcoming

Taylor, K.E., R.J. Stouffer and G.A. Meehl. 2012. "An overview of CMIP5 and the Experiment Design". *Bulletin American Meteorological Society*, 93: 485-98.

Tobey, J., J. Reilly and S. Kane. 1992. "Economic implication for global climate change for world agriculture". *Journal of Agricultural and Resource Economics*, 17:

195-204.

World Bank. 2008. *World Development Report 2008*. Washington, D.C.: The World Bank.

World Bank. 2010. "Agricultural insurance". Primer Series on Insurance, Issue 12. Washington, D.C.: The World Bank.

World Bank. 2014. *World Development Indicators*. Washington, D.C.: The World Bank.

Notes

1 Adams, et al (1989, 1990, 1993 and 1999), Parry (1990), Tobey et al (1992), Easterling et al (1993), Kaiser et al (1993), Rosengweig and Parry (1994), Darwin et al (1995), Darwin (1999), Bruce et al (1996), Reilly (1994 and 1995), Cline (1996), Mendelsohn et al (1994), Mendelsohn and Nordhaus (1996) Mendelsohn and Dinar (1999), Iglesias and Minguez (1997), Iglesias et al (1999), Maddison (2000), etc., were among the first researchers to initially assess climate change impacts on agriculture in industrial countries.

2 Other studies used land value for the dependent variable. However, because of the absence of land value in most developing countries due to the lack of well-functioning land markets, annual net farm revenue per hectare is often used (Mendelsohn et al, 2009). This, however, introduces a potential problem since the net revenue in one year is influenced by the weather in that year as observed by Mendelsohn et al (2009).

3 To account for this weakness, other important variables such as soil quality and market access are included in the model (Mendelsohn and Dinar, 1999).

4 This was after several trials of different definitions of seasonal climate.

5 The set of RCMs used are from: (i) the CANRCM of the Canadian Centre for Climate Modelling and Analysis (CCCMA); (ii) the CCLM of the Climate Limited-area Modelling Community (CLM-C); (iii) the RACMO of the Royal Netherlands Meteorological Institute (KNMI); (iv) the RCA of the Swedish Meteorological and Hydrological Institute (SMHI); (v) the RegCM of the International Centre for Theoretical Physics (ICTP), Italy; and, (vi) the HIRHAM of the Danish Meteorological Institute (DMI).