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A Ricardian valuation of the impact of climate change on Nigerian Cocoa production: Insight for adaptation policy

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A Ricardian valuation of the impact of climate change on Nigerian Cocoa production

Insight for adaptation policy

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Abstract

Purpose – The purpose of this study is to examine the relative importance of climate normals (average long-term temperature and precipitation) in explaining net farm revenue per hectare (NRh) for supplementary irrigated and rainfed cocoa farms in Nigeria.

Design/methodology/approach – NRh was estimated for 280 cocoa farmers sampled across seven Nigerian states. It was regressed on climate, household socio-economic characteristics and other control variables by using a Ricardian analytical framework. Marginal calculations were used to isolate the effects of climate change (CC) on cocoa farm revenues under supplementary irrigated and rainfed conditions. Future impacts of CC were simulated using Six CORDEX regional climate model (RCM) ensemble between 2036-2065 and 2071-2100.

Findings – Results indicate high sensitivity of NRh to Nigerian climate normals depending on whether farms use supplementary irrigation. Average annual temperature increases and precipitation decreases are associated with NRh losses for rainfed farms and gains for supplementary irrigated cocoa farms. Projections of future CC impacts suggest a wide range of NRh outcomes on supplementary irrigated and rainfed farm revenues, demonstrating the importance of irrigation as an effective adaptation strategy in Nigeria.

Originality/value – This paper uses novel data sets for simulating future CC impacts on land values in Nigeria. CORDEX data constitute the most comprehensive RCMs projections available for Africa.

Keywords Nigeria, Climate change, Climate change projections, Net Revenue per farm hectare, Ricardian valuation

Paper type Research paper

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1. Introduction

Agriculture is a very climate-sensitive sector, and climate-smart agriculture is the way forward to increase agricultural productivity in a sustainable manner. According to the *Fifth Assessment Report* of the Intergovernmental Panel on Climate Change, climate change (CC) will amplify existing stresses on agricultural systems, particularly those in Africa for several reasons (IPCC, 2014). First, about 80 per cent of African agriculture is still mainly rainfed and therefore highly vulnerable to changes in climatic conditions such as droughts, higher temperatures and reduced precipitation levels (World Bank, 2008; Hassan, 2010). Second, African agriculture is mostly extensive and practiced on relatively fragile environments and poor quality soils, with little use of modern inputs and farming methods to cope with CC impacts (Mendelsohn and Dinar, 1999; Mano and Nhemachena, 2006). Third, the presence of multiple stresses such as endemic poverty, weak institutions, inadequate health services, limited access to capital and markets, poor infrastructure and technology and conflicts over natural resources reduce farm households' adaptive capacity to manage the numerous vagaries of CC (IPCC, 2007; Odingo, 2008; Hassan, 2010). Finally, most African governments devote meager financial resources to their agricultural sectors, thereby reducing investment in scientific research needed to better understand and respond to CC impacts (Hassan, 2010). This investment neglect is persistent across many African countries despite the well-recognized poverty-reducing impact of agriculture (Christiaensen *et al.*, 2006).

There is growing concern that CC will be more severe in the west African region because of the problems of huge spatio-temporal rainfall variability, population pressure and limited adaptation and mitigation capacities (Berg *et al.*, 2009; Ibrahim *et al.*, 2014; IPCC, 2014). The impact is expected to be even more severe for a country like Nigeria, where rainfed agriculture is the main source of livelihood for about 50-60 per cent of the population and accounts for over 25.5 per cent of the nation's gross domestic product in real terms (National Bureau of Statistics, 2017). Most of the agricultural value added in Nigeria is mainly from the plantation tree crops sub-sector (i.e. cocoa, rubber, coffee and palm produce) which is highly climate-sensitive. For instance, between 2006 and 2012, a total of about 1.2 million tons of output from plantation tree crops were exported from Nigeria, representing over 40 per cent of the total export value derived from agricultural exports alone (Central Bank of Nigeria, 2014). Cocoa's contribution to the nation's economic development is not in doubt. No other agricultural export commodity has earned more foreign exchange than cocoa. The sub-sector offers substantial employment, both directly and indirectly, and supplies significant volumes of raw materials to cocoa-producing states, as well as revenue to their respective provincial governments. Because of its importance, the Federal Government of Nigeria, concerned with diversifying the nation's export base, has identified cocoa as the most important export tree crop.

However, there are growing concerns that CC may be impacting negatively on cocoa production in Nigeria. The first real evidence of CC impacts on cocoa production was during the 1972/73 drought, when production declined from about 216,000 metric tons to less than 150,000 metric tons (Central Bank of Nigeria, 2014). Thereafter, the production trend has consistently declined despite the agricultural conditionality of the structural adjustment program that 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 follows:

Q1. What proportion of change in cocoa production is due to the impacts of CC?

Q2. What are the economic implications of CC on cocoa production in Nigeria?

Q3. How do cocoa farmers in Nigeria adapt to changing climatic conditions?

Q4. As climate variables worsen, what is the likely future for this important plantation tree crop in the country?

The academic literature on CC impact on Nigerian cocoa agriculture in general is still very scanty, despite the importance of cocoa as a major export earner. In fact, a review of the extant literature suggests that there are few peer-reviewed documented studies for Nigeria. These include the works of Lawal and Emaku (2007), Omolaja *et al.* (2009), Ajewole and Iyanda (2010), Ajayi *et al.* (2010), Fonta *et al.* (2011), Nwachukwu *et al.* (2012) and Oyekale (2017). Lawal and Emaku (2007) find that while temperature is positively correlated with cocoa yield, rainfall and relative humidity are negatively correlated with cocoa yield. Omolaja *et al.* (2009) find that increasing precipitation and favorable temperature promote the flowering intensity of cocoa in Nigeria. For Ajewole and Iyanda (2010), cocoa yield is less sensitive to decreasing rainfall 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 to temperature increases. Contrastingly, Nwachukwu *et al.* (2012) finds cocoa productivity to be more rainfall-sensitive. Similar findings were obtained by Fonta *et al.* (2011) and Oyekale (2017). In both papers, net cocoa revenue per household farm hectare and yields was more sensitive to increasing precipitations.

Given the dearth of empirical literature on the impacts of CC on Nigerian agriculture, this study seeks to contribute to the academic literature by investigating the economic impacts of CC on Nigerian cocoa agriculture. It intends to do so by using a climate-land value analytical framework (i.e. a theoretical Ricardian cross-section model). The framework is applied to seven different Nigerian cocoa-producing states to:

- assess the potential economic impacts of CC on Nigeria cocoa agriculture under supplementary irrigated and rainfed farming conditions;
- evaluate the importance of irrigation (supplementary) as an alternative pathway to CC mitigation in Nigeria; and
- examine the likely future impacts of CC on cocoa farming in Nigeria.

The rest of the paper is structured as follows. In Section 2, the authors present the Ricardian model (RM) developed for the analysis; Section 3 describes the data and methodology, followed by a description of empirical results in projections with climate scenarios in Section 4. Section 5 concludes the paper with potential policy implications of the findings and suggests policy response options or recommendations to help mitigate the effects of CC on Nigerian tree crop agriculture.

2. Analytical framework

In his pioneering work on the theory of "economic rents" in 1817, David Ricardo (1817) observed that land values reflect land productivity at a site under a perfectly free competition market structure without monopoly. This invariably implies that any factor of production (e.g. capital, labor, technical progress, conducive weather or their combination) that influences land productivity will be reflected in sale value of land or land rent. As climate affects land productivity through cultivation, it is intuitive to assume that the value of land (rents) contains information about the value of climate as one attribute of land productivity. This is the theoretical basis of the Ricardian approach pioneered by Mendelsohn *et al.* (1994), which is adopted to predict the potential economic damage to US agriculture from CC. Specifically, Mendelsohn *et al.* (1994) showed that by regressing land value (rents) on climate, household covariates and other environmental control variables, it is possible to measure the marginal contribution of each variable to land rents as capitalized in land value. However, in specific cases like in most developing countries where land values (rents) are difficult to compute because of the absence of well-functioning land markets, Dinar *et al.* (1998) and Mendelsohn *et al.* (2001, 2009) suggest the use of net revenue per farm hectare (NRh). Hence, this principle is usually captured through a net farm revenue equation (Mendelsohn *et al.*, 2009) of the form:

$$\mathrm{NRh} = \sum \mathrm{P_i Q_i (X, C, S, Z)} - \sum \mathrm{P_x X} \tag{1}$$

where, NRh represents the net annual profit from the production crop $Q_{i,}$ 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 socio-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 RM is a reduced form model that examines how exogenous variables such as C, S and Z affect farmland values or, in this case, NRh. Note that the product of price and quantity gives revenue, and all the variables in the parentheses are critical factors affecting the output or quantity of the crop under consideration (i.e. cocoa). As it is intuitively portrayed in equation (1) above, the difference between total revenue (first term on the right-hand side of the equation) and total costs (second term on the right-hand side of the equation) gives us profit.

Because values far above or below preferred climatic conditions reduce crop productivity, the relationship between NRh and the climatic variables (C) is non-linear and postulated to be inverted U-shaped (Reinsborough, 2003; Seo *et al.*, 2005; Kurukulasuriya and Mendelsohn, 2008; Deressa and Hassan, 2009; Mendelsohn *et al.*, 2009). To control for this potential non-linear relationship in the empirical specification of the NRh function, the authors adopt a quadratic functional form on the CC indicator variable, C:

$$\mathrm{LnNRh_i} = \alpha_0 + \alpha_1 \mathrm{C} + \alpha_2 \mathrm{C}^2 + \alpha_3 \mathrm{S} + \alpha_4 \mathrm{Z} + \varepsilon, \tag{2}$$

where ε represents the error term which is normally distributed with zero mean and constant variance and α_i represents the regression coefficients to be estimated, including the intercept term. The marginal impact of a single climate variable (c_i) on NRh evaluated at the mean of that variable is given as:

$$\mathrm{E}\left[\frac{\mathrm{dNRh}}{\mathrm{dc_i}}\right] = \alpha_{1,\mathrm{i}} + 2 * \alpha_{2,\mathrm{i}} * \mathrm{E}[\mathrm{c_i}]. \tag{3}$$

One major advantage of using NRh is that it accounts for the direct impacts of climate on yields of different crops, as well as the indirect substitution of different inputs, the introduction of different activities and other possible adaptations by farmers to different climatic shocks (Mendelsohn and Dinar, 1999). However, the RM has been extensively criticized on several grounds, first because crops evaluated under the method are not subject to controlled experiments across farms as with the production function model, the agro-economic model or the agro-ecological zone model (Hassan, 2010). To control for this concern, the authors included other important variables such as soil quality and market access in the model, as suggested by Mendelsohn and Dinar (1999). Second, it fails to account for future change in technology, policies and institutions (Mendelsohn *et al.*, 2009). Third, it assumes that input and output prices remain constant, introducing a potential bias in the analysis (Mendelsohn *et al.*, 2009), and fourth, it does not account for the effect of factors consistent across space, e.g. carbon dioxide concentrations being beneficial to crops (Seo *et al.*, 2005; Mendelsohn *et al.*, 2009; Hassan, 2010). Finally, the model may overestimate potential damage caused by CC to farmland values when irrigation is not factored into account (Reinsborough, 2003; Seo *et al.*, 2005).

This study recognizes the various problems highlighted above and attempts to address them to generate reliable results. However, one also should not expect drastic price changes due to CC. Equally, to make the analysis less prone to potential empirical concerns, one can include carbon dioxide exogenously in the analysis, new technology and irrigation as important control variables.

3. Data and econometric procedure

3.1 Data description

Temperature and precipitation data are key to climate-land value analysis. Because CC involves long-term trends, the use of monthly climate normals is usually preferable (Reinsborough, 2003). To determine seasonal temperatures and precipitations, this study used January-December monthly means from 1981 to 2010 from 32 weather stations around the country from Nigeria's Meteorological Agency. 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 exists four types of soil in the respective states, and all of them were used in the analysis. Farm-level data on NRh and its determinants were collected from 280 cocoa farmers spread over the various agro-ecological zones of the seven selected states – Cross River, Abia, Edo, Ondo, Ekiti, Oyo and Ogun (Figure 1). These states represent the major cocoa-producing regions in the country with significant variations in temperatures and precipitations driven primarily by elevation. Four enumeration areas (EAs) were used in each state, for a total of 28 EAs. From each EA, ten farmers were randomly selected from farmers with a cocoa production record of more than 20 years (i.e. long enough to have experienced the CC effects). To collect data, enumerators with extensive fieldwork experience were recruited through Nigeria's National Bureau of Statistics.

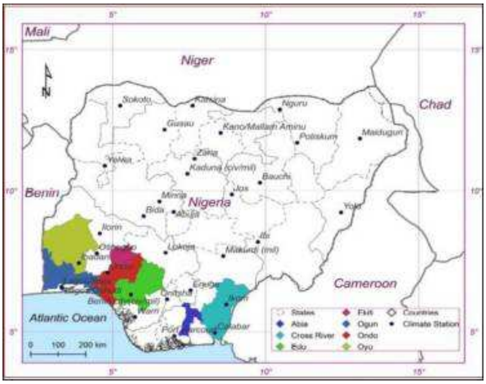

Figure 1.
Cocoa-producing states used for the study

The questionnaire contained seven sections that gathered information on household demographic characteristics, the employment status of the household head, land tenure and household labor composition for farming activities, including labor costs. In the fourth section, responses from more in-depth questions concerning farming activities were collected, such as primary crops grown, harvested and sold in the past twelve months; average yields obtained in a normal year; water source for farming, including the specific irrigation system used for farming; 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; and 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) and the cost of farm buildings. The last sections of the questionnaire helped to collect data on access to sources of information on farming activities and costs involved in obtaining information; estimates of the household's total income (for both farming and non-farming activities), taxes paid and subsidies received and farmers' perceptions of short- and long-term CC effects and their adaptation strategies in response to these changes.

Based on the answers to these questions, it was possible to calculate, for each of the 280 sampled households, the net farm revenue per cocoa hectare (NRh), defined as the difference between gross revenue per farm hectare and the per hectare costs of production, which includes seeds, fertilizer, pesticide, insecticide, herbicide, farm labor, depreciation on machineries and other farming costs.

3.2 Econometric procedure

In the empirical estimation procedure, NRh was regressed on climate, household socioeconomic characteristics and other environmental and control variables. As none of the explanatory variables (e.g. climate variables, household socio-economic condition variables and soil type variables) are endogenous, a log-linear ordinary least squares technique was used to generate the coefficient estimates. Therefore, the data at hand and the nature of the variables considered do not necessitate the use of instrumental variables (IVs) or other econometric models that are designed to account for potential endogeneity for identification of estimated coefficients. Following Reinsborough (2003) and Seo *et al.* (2005), after several trials and iterations of different definitions of seasonal climate, 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 October-March), the rainy season (average precipitation and temperature data for April-September) and the Harmattan period[1] (average precipitation and temperature data for December-February).

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 and account for a potential non-linear relationship between CC and net farm revenue. When the coefficient of the quadratic term is positive with a negative linear term, the climate response function is U-shaped, and when the linear term is positive and the quadratic term is negative, the function is hill-shaped or bell-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 whether climate effects on NRh are dependent on the season under consideration. Hence, the analysis includes interacting dry season temperature with precipitation, rainy season precipitation with temperature and *Harmattan* temperature with precipitation. With regards to other 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 CC alone (Reinsborough, 2003; Seo *et al.*, 2005; Ouedraogo *et al.*, 2006; Kurukulasuriya and Mendelsohn, 2006; Mendelsohn *et al.*, 2009). For instance, to account for demographic and other important factors in the empirical specification of the climate response function [equation (2)], population density was incorporated to capture urban/rural characteristics, main source of water (irrigation or not) and farm altitude.

Furthermore, two sets of climatic scenarios were used to examine the likely future impacts of CC on Nigerian cocoa agriculture. The first set, comprising two representative concentration pathways, i.e. RCP4.5 and RCP8.5 (Moss *et al.*, 2010), and two future time slices (2036-2065 and 2071-2100), was generated from a multimodel ensemble of regional climate models (RCMs) run under the recent coordinated regional climate downscaling experiment (CORDEX) initiative (Giorgi *et al.*, 2009). The CORDEX RCMs downscale many global climate models (GCMs) from the Coupled Model Intercomparison Project, Phase 5 (Taylor *et al.*, 2012; Sylla *et al.*, 2016). The RCMs are run over the whole of Africa at 50 km resolution. To date, the CORDEX data constitute the most comprehensive RCMs projections available for the continent. The authors are not aware of any African application that has utilized CORDEX projections.

Figure 2 shows 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), which produces a substantial decrease for the RCP8.5 during 2071-2100. The highest precipitation increase of more than 1 mm d-1 is simulated by RegCM4 of the International Centre for Theoretical Physics, 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.

Because the CORDEX ensemble data (Table I), which show increases in all variables (rainfall and temperature) regardless of the scenarios (RCP4.5 and RCP8.5), balance out the decreases in precipitation predicted by the regional climate model CCLM, the authors not only use CORDEX but also base the second set of scenarios on hypotheses of 2.5°C increase in temperature and 5 per cent decrease in precipitation from the historical observations (1981-2010). Similar hypotheses (i.e. +2.5 to 5°C and 7 to 14per cent decrease in precipitation) were tested earlier for African croplands by Kurukulasuriya and Mendelsohn (2006) and Mano and Nhemachena (2006). The projected changes from the different climate scenarios generated are summarized in Table I.

4. Results and discussion

4.1 Sample statistics

The summary statistics of the key variables used in the analysis are reported in the Appendix. On average, the NRh was Nigerian Naira 42,558.9 (hereafter NGN) for all farms, NGN45,339.12 for supplementary irrigated farms and NGN31,386.7 for rainfed farms. Mean temperatures and precipitations corresponding to the three seasons were 32.4°C and 47.7 mm for the hot dry season, 25.7°C and 169 mm for the heavy rainy season and 19.6°C and 12.7 mm for the Harmattan season. The soil type on which the farmers operate is a function of geographical location. The soil types are:

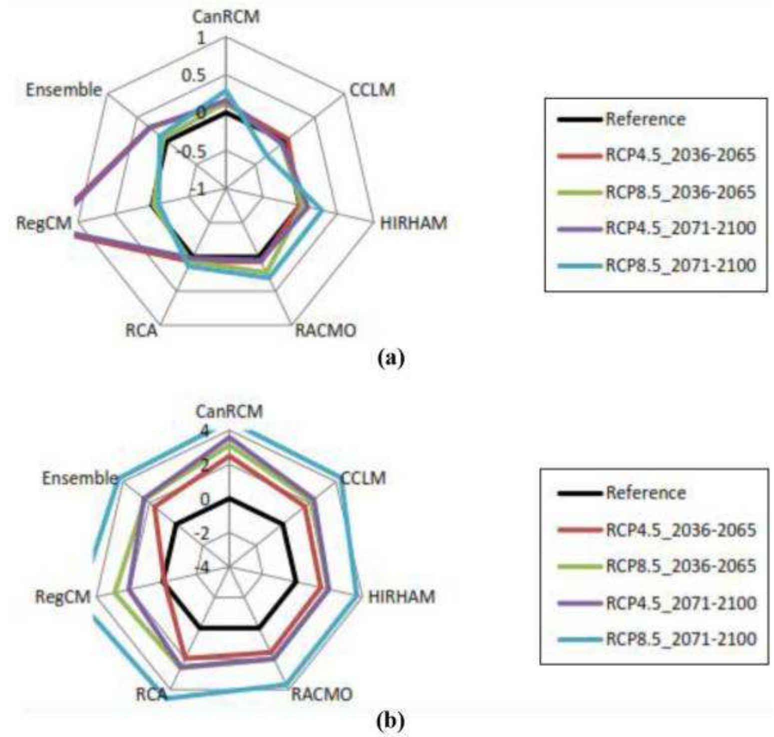

Figure 2. Absolute temperature and precipitation changes (in °C and mm d^{-1}) for both the climate scenarios RCP4.5 and RCP8.5 and for two future time windows 2036-2065 and 2071-2100

Notes: *Note that 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)

- *La*: These are ferralitic soils of the coastal plain sand and escarpment; dominant color is yellowish brown (not differentiated).
- *Jc*: These are ferruginous tropical soils on crystalline acid rocks.
- *Li*: These are ferrallite soils, and the dominant color is red on loose sandy sediments.
- *LVf*: These are ferric luvisol soils, which are seen as reddish sandy clay loam.

More than 42.9 per cent of the sampled farmers cultivated on La soil type, about 28.7 per cent of them farmed on the Jc soil type and about 28.4 per cent of the farmers were split between the Li and LVf soil types.

The average area devoted to cocoa cultivation was about 2.4 hectares from a total average household farm size of 6.5 hectares, suggesting that a non-negligible proportion (about 31 per cent) of the total available farming land is dedicated to cocoa. Men-headed

Table I. Monthly seasonal temperature and precipitation levels

	Scenario 1 (1)					Scenario 2 (2)		
(a) *CORDEX (temperature projections)*						2.5% precipitation decrease from observations (see Table II)		
	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	(1981-2010)	(2036-2065)	(2071-2100)	(2036-2065)	(2071-2100)	(2050-2100)	(2050-2100)	(2050-2100)
Dec-Feb	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
(b) *CORDEX (precipitation projections)*						5% precipitation decrease from observations (see Table II)		
	Historical	RCP4.5	RCP4.5	RCP8.5	RCP8.5	Pb: 5% (all farms)	Pb: 5% (rainfed farms)	Pb: 5% (irrigated farms)
Period	(1981-2010)	(2036-2065)	(2071-2100)	(2036-2065)	(2071-2100)	(2050-2100)	(2050-2100)	(2050-2100)
Dec-Feb	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

Notes: N.B., where Tb: baseline temperature: Pb: baseline precipitation; (a) monthly seasonal temperature (in °C) as generated from CORDEX and hypotheses of +2.5°C from observations (baseline period of 1981-2010); (b) monthly seasonal precipitation (in mm/month) as generated from CORDEX and hypotheses of −5% precipitation decrease from observations (baseline period of 1981-2010) households dominated the sample (95 per cent), with an average age for the entire sample of about 55 years, with 22 years of farming experience and about 9 years of schooling (i.e. junior secondary school). On average, nearly three household members worked in cocoa farming as their primary occupation from a total household size of about seven members. Only about 20 per cent of sampled farmers reported using irrigated farming (i.e. supplementary irrigation); the rest relied only on rain-fed agriculture. Less than 33 per cent of the farmers acknowledged having access to any form of credit facilities; on the other hand, about 14 per cent reported receiving farm subsidies. Yearly average use of fertilizer came to about 776 kg for the whole farm, and more than 93 per cent of farmers reported using pesticides. Average farm visit time from an agricultural extension worker was estimated to be less than 2 h a week; however, more than 66 per cent of sampled farmers reported having received advice from an agricultural extension worker in the last 12 months preceding the survey. More than 72 per cent of farmers reported using multiple farmlands for cocoa farming, and about 74 per cent reported practicing mixed farming. Finally, more than 52 per cent sold their cocoa produce in urban areas, with a mean market distance of about 90 km.

4.2 Ricardian estimates

Table II presents three log linear regressions or models on determinants of NRh for Nigerian cocoa farms. In Column two (Model 1), NRh 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 does not account for the effects of household socio-economic characteristics on NRh, an important category of independent variables reflecting farmlands' potential for alternative uses (Reinsborough 2003). Notwithstanding, Model 1 highlights the direction and magnitude of climate impacts on NRh. The implications of these findings are taken up later.

In the second regression or Model 2 (i.e. Column 3 of Table II), net farm revenue is regressed on climate and climate interaction effect variables conditional on seasons (dry, rainy and *Harmattan*). Note that many of the climatic variables which were statistically significant in the first model are dropped because of multicollinearity. Equally, it was also observed that many of the squared terms for temperature and precipitation remained statistically significant as in the first model and unchanged in sign and 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, NRh 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. The former suggests 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.

Column 4 or Model 3 corresponds to the climate response function [equation (2)], where NRh is regressed on climate variables (C), their squared terms (C^2), soil types and three important control variables (S), including household socio-economic characteristics (Z). This model, which comprehensively includes as many determining variables as possible, provides the best fit, with results one would expect, and is therefore used for all subsequent climate calculations. The adjusted R^2 for the model has a higher goodness of fit value of 0.46. The effects of some of the significant variables from the climate "only" Model 1 are unchanged in sign and quite similar in magnitude. Dry season temperatures and

Variables	Climate only (2) Coef.	*t*-stat.	Climate with CC interaction[a] (3) Coef.	*t*-stat.	Full model without interaction[b] (4) 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	
Adjusted R^2	0.29		0.27		0.46	
Observations	280		280		280	

Notes: [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); all figures in italic signifies statistical significance of variables at 1% and 5% levels of confidence

Table II. Loglinear specification results of ricardian model for all farms

precipitations are significant, with large negative effects on NRh as in Model 1. The squared terms for dry and rainy season remained significant and unchanged in sign as in Model 1, indicating that above optimal levels of temperature–precipitation NRh decreases. The four soil types all have a large significant negative effect on net revenue per cocoa farm hectare as expected and consistent with most previous Ricardian findings in Africa. This is perhaps so because African farmers often make extensive use of chemical fertilizers and pesticides, including agricultural practices that enhances soil degradation and worsens soil infertility. This partly explains why net farm revenue is often negatively correlated with poor quality soils in Africa (Kurukulasuriya and Mendelsohn, 2006; Mano and Nhemachena, 2006; Mendelsohn *et al.*, 2009).

Of control and socio-economic variables, irrigation, population density, access to credit and distance to urban markets are significant as expected. Farmers with greater access to credit facilities have higher NRh, a predictable empirical finding considering the capital-intensive nature of cocoa farming. This has an important policy implication with regard to the financial resource allocation by the banking sector for agriculture. Similarly, farmers closest to urban markets have higher NRh, probably because of market proximity and lower transportation cost. Hence, distance to urban markets has a statistically significant negative coefficient. Irrigation has a beneficial effect on NRh, suggesting its potential use as an adaptive intervention to mitigate the impact of CC. On the other hand, population density was found to be detrimental to NRh, as its significant negative coefficient shows.

Column 2 of Table III reports the marginal impacts of climate on NRh of the full model (i.e. Model 3) reported in Table II (i.e. Column 4). The marginal analysis simply shows the effect of an infinitesimal change in temperature and precipitation on cocoa farming in Nigeria. As observed (i.e. Row 6 of Column 2 in Table III), the annual temperature impact is close to NGN−5,698.4 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 NGN40 or about US$0.30 increase in net revenue per mm/month, and the most harmful precipitation effect is largely due 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 can be profound for Nigeria and other African and developing countries, and we discuss it in the subsequent paragraphs.

Table IV presents a comparison of cocoa farms with supplementary irrigation versus rainfed farms. In the irrigated farm model, the inclusion of the quadratic terms complicated the estimation as many climatic variables were dropped because of collinearity. Similarly, inclusion of the temperature–precipitation interaction effect and control variables produced unrealistic confidence intervals for the estimates. By omitting the C^2 and S variables, more sensible and precise estimates for irrigation and rainfed farms were obtained; these are presented in Column 2 and Column 3, respectively. Many significant differences are

Table III. Marginal impacts of climate on cocoa NRh (Naira)

Variables	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

Note: N.B. Marginals of each climate variable calculated at the mean of the sample

Variables	Irrigated model (2) Coef.	*t*-stat.	Rainfed model (3) 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	
Adjusted R^2	0.87		0.56	
Observations	56		224	

Note: All figures in italic signifies statistical significance of variables at 1% and 5% levels of confidence

Table IV. Loglinear specification of rainfed and supplementary irrigated farm samples

obtained between the estimates of the two models. The irrigated model, for example, shows that high temperatures in the rainy and *Harmattan* seasons are best for NRh, whereas dry season precipitations are best for rainfed farms. Irrigated NRh is significantly affected by Li soil types and rainfed NRh is significantly affected by La, whereas both farm types are affected by Jc soil types. Of the socio-economic variables, number of years of farming cocoa is more influential for irrigated farm revenues than rainfed farms, while distance to urban markets significantly influences rainfed NRh more than irrigated NRh, as does farm altitude.

The marginal calculations of Columns 3 and 4 of Table III show the marginal impacts of climate on the irrigated and rainfed regression models based on the results of Table IV. The annual temperature marginals for rainfed farms are much larger than those for supplementary irrigated farms, with an impact of NGN5,747 per degree celsius, in constrast to NGN10,393.3 per degree celsius for rainfed farms. Harmful temperature effects are associated with rainfed farms in all the three seasons, while in the irrigated model, they occur largely in the dry season, with beneficiary effects in the rainy and *Harmattan* seasons. Similarly, annual changes associated with increased precipitation impacts show net gains of NGN191.6 per mm per month for irrigated farms and NGN128.9 per mm per month for rainfed farms. In general, irrigated farms are more sensitive to increased precipitation during the rainy season, while rainfed farms are most vulnerable to decreased precipitation during both dry and rainy seasons.

4.3 Projections with climate scenarios

There are many contentious issues surrounding the use of estimated Ricardian results to predict how temperature and precipitation will affect future net farmland revenues (Reinsborough, 2003, p. 31-32). First, estimating beyond the range of observed data may be problematic, especially when the estimated relationships are not exactly as expected. For instance, one expects negative square terms of the climatic variables, assuming cocoa has optimum temperature and precipitation levels. However, while the squared terms of dry and rainy season temperature and precipitation variables exhibit a hill-shaped relationship, *Harmattan* temperature and precipitation squared exhibit a U-shaped relationship, possibly making an accurate forecasting of future CC effects on the cocoa farms' NRh problematic. Second, variables such as soil types and farmers' socio-economic characteristics, which are assumed to be constant with temperature and precipitation changes, will certainly be affected in reality. For instance, increased rainfall and sunshine affect soil moisture content and hence plant growth and productivity (Deressa and Hassan, 2009). However, as the changes to be estimated are quite moderate, using the results of the full model (i.e. Table II, Column 3) and those of Table IV to predict future climate impacts on NRh for all farms, irrigated and rainfed, should be not be too problematic. The aim of the projection is not to examine how NRh actually changes, but it is simply to isolate the statistically significant effect of CC on NRh, assuming all other conditions (e.g. price changes investment, population and the use of technology) are held constant **(**Mendelsohn *et al.*, 2009).

The first set of CC scenarios (i.e. Column 1 of Table I), generated from the CORDEX Ensemble of six RCMs, were fitted into the results of Table II's full model (Column 4) and those of Table IV (Columns 2 and 3) to examine how future CCs would affect NRh under both irrigated and rainfed conditions. The simulated results are reported in Tables V and VI. Annual and seasonal impacts vary a great deal between the different farms. In the RCP4.5 scenario, the calculations reveal marked variations in NRh across the different farms. Both scenarios predict drastic dry season declines in NRh between 2036-2065 and 2071-2100 for rainfed farms. Seasonal losses range from NGN−58.0 to −83 for all farms and from NGN−110.9 to 148.8 for rainfed farms. A striking prediction from the CORDEX Ensemble suggests that irrigated farm revenues will increase across all 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 future NRh decline, with expected losses of NGN−25.2 and NGN−29.1 for 2036-2065 and 2071-2100, respectively. The projections suggest that the increase in benefits to farmers can be gained incrementally via adaptive interventions such as irrigation.

In the second scenario (Table VI), first, a 2.5°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 six CORDEX RCMs ensemble. Second, reducing rainfall by 5 per cent is equally associated with net farm revenues loss of NGN−108.5 ($−0.72) for all farms and NGN−151.2 ($−1.0) for rainfed farms during the dry season per hectare of farmland. Similar seasonal losses are associated when a simultaneous 2.5°C increase in temperature and a 5 per cent reduction in rainfall are considered. The combined effect is a reduction in NRh 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

Table V. Impacts of CORDEX ensemble (six RCMs) scenarios on cocoa NRh

Seasonal variables	Historical (1981-2010)	CORDEX scenarios RCP4.5 (2036-2065)	RCP4.5 (2071-2100)	RCP8.5 (2036-2065)	RCP8.5 (2071-2100)
All farms					
Dec-Feb (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-Feb (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*
Supplementary irrigated farms					
Dec-Feb (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*

Table VI. Impacts of +2.5°C and −5% changes in temperature and precipitation on cocoa NRh

Seasonal variables	Baseline Tb and Pb (1981-2010)	IPCC Scenarios based Tb + 2.5°C and Pb (2050-2100)	Tb and Pb −5% Pb (2050-2100)	Tb + 2.5°C and Pb − 5% Pb (2050-2100)
All farms				
Dec-Feb (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-Feb (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*
Supplementary irrigated farms				
Dec-Feb (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*

Notes: N.B: Tb: baseline temperature; and Pb: baseline precipitation

are, in general, less sensitive to any of these changes, as was predicted by the six CORDEX RCMs ensemble. However, note that while the six CORDEX RCMs ensemble predicts that future net revenues decline only for rainfed farms, the second-case climate scenarios considered in the paper predict that annual net revenues decline for all farms and rainfed farms.

5. Conclusions

Using 20 years of data, this paper assesses the economic implications of CC (i.e. average long-term temperature and precipitation changes) on NRh in Nigerian cocoa farms under rainfed and irrigated (supplementary) conditions. The results indicate a high sensitivity of NRh to climate normals, dependent on whether cocoa farms are irrigated. In general, rainfed farms' revenues were more sensitive to marginal changes in both temperature and precipitation than irrigated farms. For instance, the annual temperature marginals for irrigated cocoa farms is about NGN5,747 ($38.3) per degree celsius compared to NGN−10,393.3 ($−69.3) per degree celsius for rainfed farms. Similarly, the annual changes associated with precipitation change are a net gain of NGN191.6 ($1.3) per mm per month for irrigated farms compared to NGN128.9 ($0.86) per mm per month for rainfed farms. Furthermore, the marginal analysis reveals that irrigated farms are sensitive to decreased precipitation only during the rainy season, whereas rainfed farms are most vulnerable in both dry and rainy seasons.

Two sets of future climate impact projections are included in the analysis. The first set of scenarios, based on the CORDEX ensemble, suggests a wide range of outcomes on NRh for all farms between 2036-2065 and 2071-2100. Dry season losses range from NGN−110.9 ($−0.74) to NGN−148.8 ($−1.0) for rainfed farms and from NGN−58.0 ($−0.39) to NGN−83 ($−0.55) for all farms. Irrigated farms are generally less sensitive to the different CORDEX scenarios. The results suggest the need to disaggregate farms by type for a reliable CC impact analysis so that policy can be directed where impacts are felt strongly.

The second hypothesized scenario set also predicts drastic declines in NRh per hectare for rainfed farms and all farms between 2050 and 2100. The combined effect of a simultaneous 2.5°C temperature increase and a 5 per cent rainfall reduction are associated with reduction in NRh of NGN−173.9 ($−1.2) for rainfed farms and about NGN−125.8 ($−0.84) for all farms, and again, irrigated farms are generally less sensitive to any changes. It is not surprising to find similar impacts for rainfed and all farms as there are more rainfed farms (224) in the overall sample farms compared to irrigated farms (56). Hence, the statistical results of all farms are mainly driven by the results that pertain to rainfed farms. A study on larger number of sampled irrigated farms will be beneficial in future.

The results clearly demonstrate the importance of supplementary irrigation as an adaptation strategy to reduce harmful CC effects on Nigerian cocoa agriculture. Serious neglect by the national and sub-national Nigerian governments of irrigation farming systems may be partly responsible for the country's declining trend in cocoa productivity. As a concrete future policy direction, this demands for more investment (not less investment) in irrigation to support local farmers' management of CC uncertainty. The regression results suggest that access to credit/working capital and proximity to markets by improving the road infrastructure that minimize the distance to final destination of agricultural output create the right developmental incentives for cocoa farmers to generate better farm revenues and improve their welfare. In irrigated farms, the experience of farmers was found to be beneficial. In addition to policy measures that increase investment in irrigation, extension services can be used as a vehicle to share experiences among farmers on best practices of cocoa production and environmental management. This may include pilot initiatives such as weather index-based crop insurance that can support farmers in mitigating adverse and heterogeneous effects of CC and natural catastrophes encountered during farming activities (Barnett, 2014; Barnett and Mahul, 2007; Kunreuther, 1996; FAO, 2011; IFAD, 2011; World Bank, 2010). The results clearly demonstrated the detrimental impact of distance to markets. Therefore, the obvious policy implication is the urgent need to provide conducive market infrastructure by improving access to market nodes such as urban areas. This enhances farmers' productivity, the welfare of their respective households and the dynamism of the cocoa sub-sector in Nigeria, with potential implications for farmers in other African and other developing countries across the globe.

In conclusion, the authors want to highlight the fact that they are not arguing that irrigation is the only adaptation strategy among other alternative adaptation strategies (e.g. developing drought resistant crops) that can be deployed to cushion the impact of CC. However, the authors believe that irrigation in the Nigerian context has advantages, is manageable in terms of technological capability of the farmers and is relatively cost-effective route to adapt to CCs compared to, for instance, breeding new crops that can withstand climate stresses such as water shortage and drought. Generating and using new breed of crops is based on long-term research and development investments. However, high yielding varieties are not readily available for farmers who cannot wait for many years or decades of field experiments which are required to validate the new crops. In this context, irrigation provides a practically feasible alternative to the harsh CC that Nigerian farmers find themselves in.

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Note

1. The Harmattan season is peculiar to the West African subcontinent. It usually occurs between the month of December and early March and signifies the beginning of the dry season. It is often characterized by harsh weather conditions such as cold, dry and dust-laden wind, very low humidity and relatively lower temperatures.

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Appendix

Table AI. Summary statistics of the sampled cocoa farms

Variable definition and measurement	All farms Mean	All farms SD	Rainfed Mean	Rainfed SD	Irrigated Mean	Irrigated SD
Socioeconomic variables						
NRh (in Naira)	42,558.9 ($283.7)	46,774.8 ($311.8)	31,386.7 ($209.2)	17387.2 ($115.9)	45,339.1 ($302.3)	51,202.7($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 experience (cocoa)	22.8	10.8	23	3.95	21.9	5.0
Household size (number 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 (number)	2.5	2.6	2.6	2.9	2.2	2.4
Farm labor (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. (°C)	32.4	4.82	28.6	1.12	28.9	1.05
Monthly rainy season temp. (°C)	25.7	1.13	25.1	0.91	24.5	0.82
Monthly Harmattan temp. (°C)	19.6	6.5	25.0	3.0	25.9	3.41

(*continued*)

Table AI.

Variable definition and measurement	All farms		Rainfed		Irrigated	
	Mean	SD	Mean	SD	Mean	SD
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)	1,238.8	139.3	1,217.3	146.3	1,332.8	110.2
Number of observations	280			224		56