Macrothink Institute™

Journal of Agricultural Studies
ISSN 2166-0379
2020, Vol. 8, No. 2

The Economic Impact of Climatic Variations on Ivorian Rice Farming

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Received: May 20, 2019 Accepted: Aug. 26, 2019 Published: Dec. 8, 2020

doi:10.5296/jas.v8i2.14798 URL: https://doi.org/10.5296/jas.v8i2.14798

Abstract

This study analyzes the economic impact of climatic variations on rice cultivation in Côte d'Ivoire. It attempts to respond to the lack of academic study at the national level and then to introduce a new approach that corrects the bias of the traditional Ricardian approach. We estimate an endogenous switching regression model to control for the effect of irrigation using a survey data from a national sample of 895 rice farmers. The results of our estimates show that Ivorian rice cultivation is significantly affected by variations and dispersion of rainfall. The elasticity of farmers' net income in relation to rainfall is 0.47 in rain-fed systems and 2.89 in irrigated systems. A decrease in the annual rainfall volume affects negatively the yield of farms both in rain-fed and irrigated systems. However, irregular rainfall or greater annual dispersion of precipitation has a negative impact only on the yield of rain-fed farms. Indeed, irrigation practices make it possible to respond effectively to highly dispersed precipitation during the year. The results suggest that farmer training, support services, and irrigation practices are the relevant options to better adapt rice farming to climatic variations.

Keywords: climatic variation, economic impact, endogenous switching regression, ricardian model

Jel Classification: Q12; Q54; C34.

1. Background and Rationale

Agriculture occupies a central place in the Ivorian economy due to its contribution to the GDP (20%) and the workforce it employs (PND, 2016). Agriculture, however, remains dependent on a climate characterized by highly erratic inter-annual and spatio-temporal rainfall. The climatic uncertainties affect the stability of production and weaken the agricultural economy (Yao et al., 2013).

According to climatic and oceanic observations, the West African zone has experienced a temperature rise 0.6 to 0.7 ℃ higher than the global average. Future trends further predict a drop in rainfall of up to 20 to 30%, particularly in the Sahelian zone (BOAD, 2010). Current and projected climate data indicate that the West African region is one of the most affected in the world. The expected consequences include severe drought, a decrease in available water reserves, and an increase in drylands (BOAD, 2010).

The effects of global warming on agriculture will cost developing countries more than industrialized countries (IPCC, 2007). The majority of developing countries will find it more difficult to adapt than rich countries. Most are located the warmest parts of the world, where temperatures are close to or above thresholds beyond which agricultural production tends to decline rather than increase (BOAD, 2010). This situation reinforces the need to assess the economic costs of climate change on agriculture in developing countries. This assessment is necessary for the implementation of effective adaptation policies to climatic variations.

In this study, rice is highlighted among other important crops for two main reasons. First, the cultivation of rice plays a crucial role in national policy to combat food insecurity in Côte d'Ivoire (PND, 2016). With a steady growth in demand of 6% per year, rice is a staple food for a growing urban population whose rice needs are steadily increasing. Second, Ivorian rice cultivation is more vulnerable to climatic hazards than other crops because it is predominantly rain-fed (90% of rice-growing areas are rain-fed).

Climatic variations are a threat to rice production and food security in Côte d'Ivoire. Thus, there is an important dual obligation to: establish the relationship between climatic variations and the productivity of farms and propose strategies to adapt to climate change.

The general objective of the study is to analyze the economic impact of climatic variations on Ivorian rice cultivation. Specific objectives include the following:

i. to assess the economic impact of climatic variations on rice farming;

ii. to examine farmers' response to climatic variations and

iii. to identify the most effective adaptation strategies.

2. Literature Review

Literature seeking to evaluate the impact of climate variability on the agricultural sector first emerged in the 1980s. Since then, several methods have been explored in order to model the impact of climatic variations on this sector as realistically as possible.

Geographical differentiation categorized the first approaches used (Da Silva, 2009). Since then, large research efforts focus on the effects of climate change in the agricultural sector at the global level. This work shows that climate change has impacted agriculture but the impacts not of sufficient magnitude to jeopardize global food supply (Bosello and Zhang, 2005).

Studies that examine the impact of climatic variations on agriculture in a specific region or country have concluded, in the majority of cases, that agriculture in developed countries would be only slightly affected (Mendelsohn et al., 1994; Deschênes and Greenstone, 2007). These results can be attributed to the structural resilience of agriculture in industrialized countries (Lewandrowski and Schimmelpfennig, 1999). However, these same studies also demonstrated a high heterogeneity across regions of the same country. In fact, the actual impact on a specific region varies according to several factors, including current and future climatic conditions, as well as soil conditions and land use (crop types).

Fundamentally, there are two broad approaches to assessing the impact of climate change on agriculture. They are differentiated primarily by their methodology; one focuses on agronomy, while the other focuses on the economy. The agronomic approach, generally referred to as the production function approach, is an experimental approach that attempts to measure the direct effects of climate change on different crops and their input needs (light, pesticides, herbicides, fertilizers, etc.) using biophysical simulation models of plants.

The agronomic model has the advantage of being able to very precisely measure plants' response mechanism to the climate by observing their behavior individually and by controlling all other variables likely to influence the growth of the plants. On the other hand, it is unable to take into account the indirect effects of environmental change in which crops evolve. For example, the increase in pests due to warmer weather, the deterioration of land quality or the increase in climatic variability.

The economic model approach simulates market dynamics and captures farmers' adaptation decisions. In fact, unlike the production function approach, economic models incorporate the farmer's response, which cannot be assumed to be passive in the face of climate change. In view of the fact that climatic variations will lead to major changes in the climatic equilibrium, which will in turn affect agricultural incomes, it is logical to assume that the farmer will employ adaptation strategies that reduce the negative impact of climate change on his income. The assumption of a rational economic agent leads to the hypothesis that the farmer makes adaptation choices that maximize his profits in the context of climate change.

The Ricardian approach provides a response to the limitations of the production function approach. Essentially, the Ricardian approach attempts to directly measure the effect of climatic variations on land value and agricultural yield (Bozzola et al., 2017; Di Falco, Veronesi and Yesuf, 2011).

This method is based on the assumption of market efficiency and thus on the fact that the value of farmland reflects the present value, including future income from the most productive land use. By focusing on the price of farmland in different environments, this approach implicitly examines the full range of farmer adaptation strategies. In fact, by analyzing farmers' behavior in their respective environments, we observe how they adapt to changes in this environment.

In the Ricardian model, farmers are assumed to maximize land rents given climatic variables and other production factors. The model estimates the impact of the climatic variables on the net productivity of agricultural land controlling for socioeconomic factors.

Kurukulasuriya and Mendelsohn (2013) reported different results based on a Ricardian model according to the farm system (irrigated or dryland). The divergence is explained by a selection bias issue. Indeed, farmers and farm characteristics in irrigated systems differ from those in dryland system. Therefore, farmers in irrigated systems and those in dryland systems are affected by the climatic shocks in different manner and their adaptation strategies are different. Indeed, the potential bias from omitted unobservable variables or characteristics is one of the weakness of the Ricardian model (Zhang et al., 2017). Kurukulasuriya et al. (2011) and Chatzopoulos and Lippert (2016) investigate this issue by implementing separate models that explicitly address the choice of irrigation.

Here, we analyze separately dryland and irrigated land systems but we treat the choice of irrigation by rice farmers as endogenous.

3. Methodology

3.1 Theoretical Framework

This study is based on the Ricardian analysis that the evolution of income reflects the net productivity of agricultural land (Deschênes and Greenstone, 2007). Using a transversal approach, we seek to understand how profits have reacted to climate variations in the various agroecological regions of the country.

Formally, we can write:

$$V = \int RN.e^{-\delta t}dt$$

$$V = \int [\sum P_i Q_i(X, C, Z, G) - \sum P_X X]\, e^{-\delta t}dt$$

Where

V represents the present value of future land productivity;

RN= net income per hectare;

P_i= market price of the crop;

Q_i= quantity produced;

C= vector of climatic variables;

Z= set of edaphic variables;

G= set of socio-economic variables;

X = vector of factors of production other than the land;

$Y =$ method of rice cultivation;

P_X= vector of the factors of production;

t= time and δ= discount rate.

Following (Mendelsohn and Dinar, 2003), the farmer is expected to choose the input levels X that maximize his net income given the agro-climatic characteristics of the farm and the market prices. The reduced form specification of the Ricardian model examines the impact of all exogenous variables C, Z and G on the discounted net income of the operator. The quadratic formula of the standard Ricardian model is as follows:

$$V = \beta_0 + \beta_1 C + \beta_2 C^2 + \beta_3 Z + \beta_4 G + \beta_5 X + \beta_6 Y + u \qquad (1)$$

The quadratic term (C^2) reflects the non-linearity of the net income function in relation to climatic variables. Indeed, based on agronomic experiments, we hypothesize a negative quadratic term reflecting an "inverted U" relationship between agricultural production and the level of temperature or precipitation (Mendelsohn and Dinar, 2003).

The marginal impact of climate variables on net income is therefore defined as:

$$E\left[\frac{\delta V}{\delta C_i}\right] = E[\beta_{1i} + 2\beta_{2i} C_i] \qquad (2)$$

The model captures the farmer's resilience to climate, that is, his or her ability to absorb unforeseen shocks related to climate. It describes the response of the farmer who faces climate fluctuations and opts for adaptation strategies such changing his use of fertilizers and/or pesticides, modifying the rice cultivation system or increasing irrigation levels, etc.

3.2 The Econometric Model

3.2.1 Econometric Specification

The economic evaluation of the impact of climatic variations on the net income of the farmer is hampered by the endogeneity of the choices of different types of rice cultivation practiced (rain-fed or irrigated). The impact of climatic variations differs principally depending on whether the crop is rain-fed or irrigated.

The problem of endogeneity of irrigation has been raised in several econometric applications (Eid et al., 2007; Mano and Nhemachena, 2007; Mendelsohn and Seo, 2007; Kurukulasuriya and Mendelsohn, 2013). Furthermore, Kurukulasuriya and Mendelsohn (2013) emphasize that the selection mechanism of the type of farm (rain-fed or irrigated) must be taken into account to estimate, in an unbiased way, the effect of climate variables on the net income of the farm. Thus, the proposed econometric model aims to estimate the impact of climatic variations on farmers' net income by controlling for the effect of irrigation.

The distribution of sampled individuals across different types of rice cultivation is not random but follows an endogenous selection rule. The question of endogenous selection emerges in the sense that the decision to invest in an irrigation system depends on the specific characteristics of the farmers who are influenced by both the rice farming system and income. The problem is isolating the effects of the rice farming system being used and the climatic variables on the farmer's net income. An assessment of these effects requires a preliminary determination of the factors that influence the choice of an irrigated or rain-fed system.

This article uses an Endogenous Switching Regression to explicitly model the interdependence of the net income equation and the choice of irrigation system.

According to Kurukulasuriya and Mendelsohn (2013), the underlying theoretical model assumes that each producer maximizes his profit:

$$\max \Pi = PQ^*(X,E) - WX \tag{3}$$

Where Π is the profit, P is the price of the output, Q^* is the quantity of output produced, X is the vector of the inputs, E is the vector of the environmental factors and W the price of the inputs.

The behavior of the farmer is analyzed on the basis of two equations: a profit equation and a selection equation that describe the choice of system (irrigated or rain-fed). It is assumed that the farmer makes the rational choice of an irrigation system if this approach is profitable compared to a rain-fed system.

- *The selection equation*

In the first step, a dichotomous model is specified to describe the choice of an irrigation system or rainwater system. The binary variable Y takes the value 1 if it is an irrigated system and the value 0 if it is rain-fed.

$$y^* = \beta X + \mu \tag{4}$$

y^* is a latent variable explaining the choice of irrigation:

$$Y = 1 \quad \text{si} \quad y^* = \beta X + \mu > 0 \tag{5}$$

$$Y = 0 \quad \text{si} \quad y^* = \beta X + \mu \leq 0 \tag{6}$$

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Journal of Agricultural Studies
ISSN 2166-0379
2020, Vol. 8, No. 2

- *The double-phase equation*

The second step specifies for each type of system, a profit function explained by a set of exogenous variables *Z*:

$$\begin{cases} \text{phase 1:} & \Pi_I = \gamma^I Z^I + \varepsilon_1 \quad if \quad Y = 1 & (7) \\ \text{phase 2:} & \Pi_p = \gamma^P Z^P + \varepsilon_2 \quad if \quad Y = 0 & (8) \end{cases}$$

Π_I is the net income per hectare (profit per hectare) of the irrigated farm and Π_p, the net income per hectare of the rain-fed farm; X is the vector of the explanatory variables of the binary model; Z^I is the vector of regressors of net income per hectare under irrigation and Z^P the vector of regressors of net income per hectare under rain-fed conditions.

The error terms, ε_1 and ε_2 follow a multivariate normal distribution of zero mean with the following matrix of variances and covariances:

$$\Omega = \begin{pmatrix} \sigma_u^2 & \sigma_{1u} & \sigma_{2u} \\ \sigma_{1u} & \sigma_1^2 & . \\ \sigma_{2u} & . & \sigma_2^2 \end{pmatrix}$$

Where σ_u^2 is the variance of the error term in the selection equation, σ_1^2 and σ_2^2 are the variances of the error terms in the profit equations. The covariance between ε_1 and ε_2 is not defined because Π_I and Π_2 are not observed simultaneously.

3.2.2 Estimation Method

Since the founding article by Heckman (1979), the consideration of endogenous selection bias has taken center stage in econometric analysis. The problem of self-selection was examined in the work of Heckman and Rob (1985) and Manski (1989). A summary of the different estimation methods is presented in the article by Vella (1998).

The general principle on correcting for selection bias is to specify a joint distribution for both the error terms of the selection equation and the process one wishes to study. The estimation is then done either in one step according to the method of maximum likelihood or in two steps, if the distributional hypotheses allows for it.

However, the two-step method is likely to overestimate the standard deviations of the parameters associated with the explanatory variables for net income. An efficient parameter estimator is derived from the endogenous switching regression model with one-step endogeneity processing using the full-information maximum likelihood method.

3.3 Evolution of Climatic Parameters in Côte d'Ivoire

The evolution of meteorological parameters over the last 50 years in Côte d'Ivoire reveals a change in the trend of climatic data (Yao et al., 2013). This data was analyzed across the main agro-climatic zones of Côte d'Ivoire.

3.3.1 Agro-Climatic Zoning

The agro-climatological map of Côte d'Ivoire (Figure 1) delineates four zones from south to north:

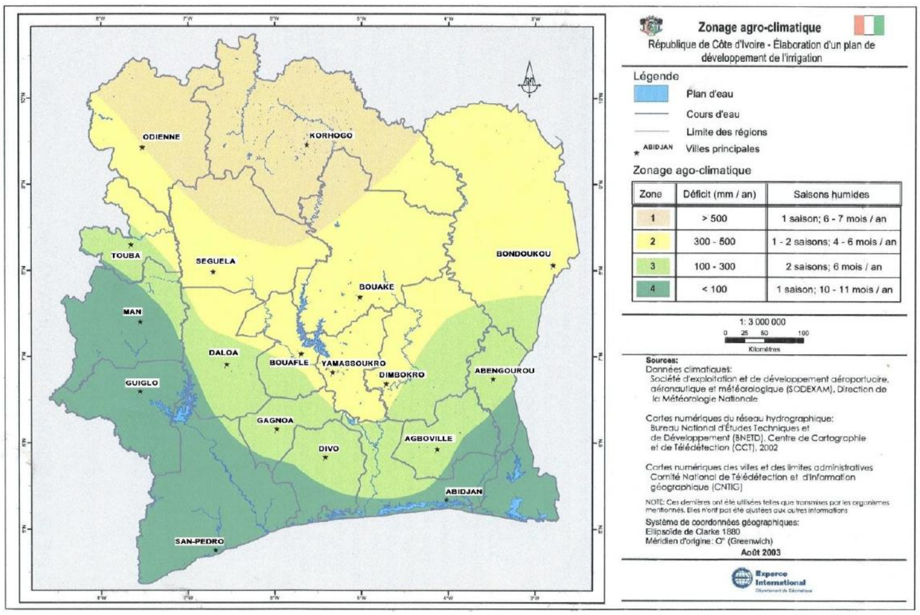

Figure 1. Agro-climatic zoning in Côte d'Ivoire

- -a very humid coastal forest zone (agro-climatic zone 1);
- a vast forest region inland, strongly affected by deforestation and experiencing two seasons of variable rainfall, from March to July and from September to November (agro-climatic zone 2);
- a wooded savanna zone (agro-climatic zone 3) and finally;
- a southern grassland savanna area, warmer and drier with a single rainy season from July to October (agro-climatic zone 4).

The calculated aridity index [1] (less than 1) in agro-climatic zones 3 and 4 makes it possible to integrate them into the Guinean zone. With an aridity index between 1 and 2, agro-climatic zone 2 is situated in the Sudano-Guinean zone. The agro-climatic zone 1 whose aridity index exceeds 2 is part of the Sudan zone (Yao et al., 2013).

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[1] Budyko-Lettau Aridity Index (IABL)

3.3.2 Evolution of Climatic Parameters

The evaluation of rainfall data indicates great intra-annual variability in the four agro-climatic zones of Côte d'Ivoire (Yao et al., 2013). The spatialization of the average annual rainfall over the last three decades shows that rainfall in Côte d'Ivoire varies and ranges from 900 mm/year in the North-East to 2200 mm/year in the South-West (Yao et al., 2013). Rainfall is decreasing from the southwest to the northeast, which corresponds to the dominant wind axis in Côte d'Ivoire (Figure 2). The wettest areas are the west and south where rainfall amounts vary from 1400 to 2200 mm/year. The least humid areas are the north and the northeast, where the rainfall ranges between 900 and 1300 mm/year (Yao et al., 2013).

The average interannual temperature from 1960-1969 varied from 24 to 26 ℃ in the northern half of Côte d'Ivoire and from 27 to 28 ℃ in the southern half (Yao et al., 2013). The decade from 1990-1999 witnessed a general rise in the average interannual temperature throughout the eastern half of the country, ranging from 27 to 28 ℃, while in the western half, it remained relatively low, ranging from 24 to 26 ℃ (Yao et al., 2013). In general, the temperature has remained higher than normal since 1978 and can be explained in part as an effect of greenhouse gas emissions.

3.4 The Data

The analysis of the effect of climatic variations on rice production requires detailed data on rice production systems and climate. Data on rice farming systems comes from a national survey conducted in 2016 and covering all rice ecologies and the diversity of rice growing systems practiced in Côte d'Ivoire.

A three-stage stratified probability survey, based on administrative divisions, was used to select the sample. In the first stage, 13 Ivorian states containing more than 60% of national rice production were selected (Figure A1 in Appendix). In the second stage, 21 villages were selected. The third stage consisted of a random selection of 895 rice farmers, 356 in rain-fed systems, 180 in lowland systems without water control and 359 in irrigated systems with partial or complete control of water.

The survey provided information on the socio-economic characteristics of the farmers and the management of rice farms. The primary data collected provide information on production, the factors of production used and their costs, the characteristics of the soil and the socio-economic environment of the farmer.Our primary data allows for the calculation of the net income of the rice farm expressed per hectare as follows:

$$Net\ income/ha = \frac{monetary\ value\ of\ rice\ produced - total\ operating\ expenditures}{area\ under\ cultivation}$$

This captures the profit margin of the land and serves as a key dependent variable. The climatic data is secondary. It comes from nine SODEXAM[2] stations selected in accordance

[2] Société d'Exploitation et de Développement Aéroportuaire, Aéronautique et Météorologique

with the areas covered by the survey. The climatic data provides the monthly rainfall for the year 2016 in the surveyed regions.

3.4.1 Descriptive Analysis of Types of Rice Cultivation

The characteristics of the production systems are presented by type of rice cultivation. Four types of rice cultivation are predominant in the study area: rain-fed rice grown on the plateaux, lowland rice cultivation using natural reservoirs of water without water management (traditional), irrigated rice cultivation of lowlands or trays carried out on perimeters managed with partial water control and irrigated rice cultivation of lowlands or trays with complete water control allowing the possibility of two cycles throughout the year.

3.4.2 Distribution of Farms by Rice Farming Systems

Table 1. Distribution of rice farming systems

Rice farming systems	Number	Frequency (%)	Cum (%)
Rain-fed upland	356	39,78	39.78
Traditional lowland	180	20,11	59.89
Irrigated rice with partial water control	223	24,92	84.80
Irrigated rice with complete water control	136	15,20	100.00
Total	895	100.00	

Source: Survey data reported by PASRES, 2016

Table 1 indicates that rain-fed rice is practiced on 40% of farms. Irrigated rice cultivation managed with partial control of water is practiced on 25% of the farms while unmanaged lowland rice growing constitutes 20% of the farms. Rice cultivation on irrigated perimeters managed with complete control of water is the least practiced with only 15% of farms.

3.4.3 Distribution of Rice Growing Systems by Agro-Climatic Zone

The Sudanese and Sudano-Guinean zones host the majority of rice farms of all types, 42% and 33% respectively. The Guinean zone hosts only 25% of the rice farms (Table 2).

Journal of Agricultural Studies
ISSN 2166-0379
2020, Vol. 8, No. 2

Table 2. Distribution of rice growing systems by agro-climatic zones

Agro-climatic zone	Rain-fed upland (%)	Traditional lowland (%)	Irrigated with partial water control (%)	Irrigated with complete water control (%)	Total %
Guinean	15,17	21,67	37,22	32,35	25%
Sudano-Guinean	39,33	41,11	48,88	39,71	42%
Sudanian	45,51	37,22	13,90	27,94	33%
Total	356	180	223	136	895

Source: Survey data reported by PASRES, 2016

Rain-fed upland rice cultivation is predominant in the Sudanian and Sudano-Guinean regions. These two agro-climatic zones include 45.5% and 39.3% of the rain-fed farms, respectively, while the Guinean zone represents only 15% of the farms of this type. Lowland rice farming is concentrated in the Sudano-Guinean zone. In fact, 41% of traditional lowland farms, 48% of lowland farms with partial water control and 39% of lowland farms managed with complete water control are located in the Sudano-Guinean area. The Guinean zone has the second highest concentration (after the Sudano-Guinean zone) of irrigated farms managed with partial (37.2%) or complete control of water (32.3%). The Sudanian zone hosts only a small portion of the managed irrigated farms, 13.9% with partial water control and 24.9% with complete water control. 37.2% of traditional lowland systems are concentrated in the Sudanian zone.

3.4.4 Distribution of Farms by Size and Type of Rice Cultivation

The productive system of Ivorian rice cultivation is largely based on small farms of less than two hectares. These farms represent more than 60% of the rice farming areas. The distribution of farms according to size and type of rice cultivation presented in Table 3 show a predominance of small farms (61.45% of all rice-growing areas) and rain-fed rice cultivation. Rain-fed rice farms represent 33% of small farms, 46.18% of medium farms and 67.14% of large farms. Lowland (traditional) rice cultivation accounts for 18.7% of small farms, 23.6% of medium farms and 17% of large farms.

Developed irrigated systems with partial water control represent 30% of small farms, 18.5% of medium farms and 8.5% of large farms. However, only 18% of small farms, 11.6% of medium farms and 7% of large farms have irrigated areas managed with complete water control.

Table 3. Distribution of farms by size and type of rice cultivation

	Size of Farm		
Rice Farming System	Small (< 2ha)	Average [2ha , 5ha[	Large (≥ 5ha)
Rain-fed	182 (33.09%)	127 (46.18%)	47 (67.14%)
Traditional lowland	103 (18.73%)	65 (23.64%)	12 (17.14%)
Irrigated farm with partial water control	166 (30.18%)	51 (18.55%)	6 (8.57%)
Irrigated farm with complete water control	99 (18%)	32 (11.64%)	5 (7.14%)
Total	550 *(61.45%)*	275 *(30.73%)*	70 *(7.82%)*

Source: Survey data reported by PASRES, 2016

3.4.5 Use of Inputs and Average Yield by Rice Farming System

- Rain-fed rice

The average yield of this method of rice cultivation is 925 kg/ha. These yields are obtained on farms with an average size of 2.11 hectares. The assessment of the labor input indicates that, on average, 211.37 man-days are carried out for one hectare. On average, rain-fed farms use relatively more fertilizer than traditional lowland farms, they use 66.85 kg/ha and 44.59 kg/ha respectively. Finally, we note a more intensive use of seeds (729 kg/ha) on rain-fed farms (Table 4).

- The traditional lowland system and the irrigated system

Traditional lowland rice cultivation has an average yield of 1.027 tonnes per hectare, while irrigated rice cultivation systems with partial or complete control of water have an average yield of 1.852 tons per hectare.

It is important to highlight the differences in the use of resources (labor, fertilizers and improved seeds) between the two rice systems. In terms of labor, the traditional lowland farmer works an average of 136 man-days compared to 115 man-days in a developed irrigated system. In the managed irrigated areas, work time is 15% less than that of traditional lowland rice areas. Farms with irrigated systems use on average, more fertilizer than those in traditional lowlands, with 78.42 kg/ha and 44.59 kg/ha respectively. The utilization rate of seeds is on average higher in irrigated systems than in traditional lowlands, using 622 kg and 557 kg respectively (Table 4).

Table 4. Use of inputs and average yield by rice farming system

	Rice Farming System			
	Rain-fed	Unmanaged lowland	Managed irrigated	Average
Quantity of inputs used per ha				
Seed (kgs)	729,37	557,2801	622,013	585,73
Fertilizer (kgs)	66,856	44,599	78,429	55,563
Insecticide (liters)	3,492	1,209	1,046	1,475
Herbicide (liters)	2,433	2,713	2,624	2,655
Labor				
Work time (m-d[1]/ha)	211,376	136,216	115,07	141,24
Land				
Area under cultivation (ha)	2,11	2,26	1,55	2,07
Average Production (Kg/ha)	**925,331**	**1027,073**	**1852,197**	**1072,961**

m-d[1] = man-day: a working day of an adult man between the ages of 16 à59 ans.

Source: Survey data reported by PASRES, 2016

3.4.6 The Socio-Demographic Characteristics of Rice Farmers

Socio-demographic characteristics include: gender, age, household size, level of education, rice cooperative membership, and land ownership status. Table 5 summarizes the socio-demographic characteristics of farmers by type of rice cultivation.

Table 5 shows that almost all farm managers (84.24%) are male and 64.84% are of Ivorian descent. The average age in the sample surveyed is 46 years old. A large proportion of farm managers consists of adults (83.28%), followed by farmers over the age of 59 (11.90%), and finally, young people under the age of 16 (4.82%).

Only 36% of rice farmers completed primary school, primarily farmers from irrigated systems. Additionally, about 71% of rice farmers are members of a rice cooperative and only 24% own the land they farm. The land ownership assessment showed that the majority of rice farm managers (75.76%) rent their land.

Table 5. Sociodemographic characteristics of surveyed rice farmers

	Rice Farming Systems			
Variable	Rain-fed	Traditional lowland	Irrigated	Total
Sex of farm manager				
Male (%)	90.91	79.81	92.31	84.24%
Female (%)	9.09	20.19	7.69	15.76%
Age	47.63	47.32	44.94	46.8
Size of household	13.31	12.51	8.2	11.6
Nationality of farm manager				
Ivorian	27.28	70.19	71.79	64.84%
Other	72.72	29.81	28.21	35.15%
Education level of farm manager				
Illiterate (%)	86.36	65.38	43.59	63.03%
Primary school (%)	4.55	12.5	41.03	18.18%
Secondary school (%)	9.09	16.35	15.38	15.15%
Higher education (%)	0	5.77	0	3.64%
Rice farming cooperative membership status				
Member (%)	100	72.12	51.28	70.9%
Nonmember (%)	0	27.88	48.72	29.1%
Land ownership status				
Renter	86.36	66.35	94.87	75.76%
Owner	13.64	33.65	5.13	24.24%

Source: Survey data reported by PASRES, 2016

4. Results and Discussion

Estimation results of the two-phase approach: the selection equation and net income equations are presented in Tables 6 and 7 in Appendix 2.

4.1 The Selection Equation

The dependent variable in the selection equation is a binary variable describing the adoption or lack of adoption of an irrigated system with complete or partial water control. Table 6 presents the estimation of the probit model of adoption of an irrigated system. Variables introduced into the selection equation include: agro-climatic zone, cooperative membership, soil quality, area under cultivation, land ownership, and level of education.

The probability of adopting an irrigation system is significantly influenced by the agro-climatic zone, the soil characteristics, and the size of the farm.

- The agro-climatic zone

The probability of adopting an irrigation system with water control (partial or total) is significantly higher in the Guinean zone (forest zone) than in the Sudanian zone (savanna zone). This can be explained by the higher irrigation costs in the savanna zone relative to the forest area. In fact, irrigation in the savanna zone requires large and expensive investments in hydro-agricultural infrastructure. On the other hand, the prevalence of lowlands in the forest zone makes it possible to set up irrigation systems at relatively lower costs.

- Soil characteristics

Negative coefficients associated with semi-wet and arid soils indicate that the probability of adopting an irrigation system is negatively affected by soil aridity. This result can be explained by the greater profitability of irrigation on wet soils because it requires less water and generates a relatively higher agronomic yield. This result confirms that of Kurukulasuriya and Mendelsohn (2013) which shows that, across Africa, the wettest regions with lower annual average temperatures are more likely to adopt soil irrigation practices that the driest and hottest regions.

- Farm size

Estimates reveal a significant positive relationship between the size of the farm and the likelihood of adopting an irrigation system. The ease of access to financial services for large farms may explain the means for them to develop irrigation projects. Additionally, the adoption of fixed irrigation technologies, such as pumps, makes it possible to achieve economies of scale on large farms.

Table 6. Results of the probit model of adoption of an irrigated system

	Coef.	Std. Err.	P>|z|
Agro-climatic zone			
Guinean zone (ref)			
Sudano-Guinean zone	-0.226559	0.1426629	0.112
Sudanian zone	-0.7026645***	0.1635365	0.000
Member of a group	0 .0192603	0.1017333	0.850
Size of household	0 .0016066	0.0066307	0.809
Soil characteristics			
Humid (ref)			
Semi-humid	-0.9527557***	0.1063297	0.000
Arid	-1.396937***	0.2380763	0.000
Farm size	0.153232***	0.0361164	0.000
Ownership status			
Owner/renter(ref)	0.03773	0.1098703	0.731
Education			
Literate/ No education (ref)	-0.0050983	0.1048128	0.961
_cons	0.8558628***	0.1730115	0.000

(***) Significant at the 1% threshold; (**) significant at the 5% threshold.

Source: Created using survey data from PASRES, 2016

4.2 Estimates of Net Farm Income

The results of the endogenous switching regression model are shown on Table 7. The variables introduced in the net income equations include climatic variables (average annual rainfall and its distribution over the year) and control variables (age, membership in a cooperative group, level of education, gender of the head farmer, land ownership status and household size).

The correlation coefficient ρ (-0,12) between the error terms of the net farm income equation for the rain-fed system and the selection equation is not statistically significant. However, it was noted that the correlation coefficient ρ_1 (0.406) between the error terms of the net income equation for the irrigated system and the selection equation is positive and statistically significant. This positive correlation implies that the unobservable characteristics that positively influence the adoption of an irrigation system are also positively correlated with those that improve the net income of the farmer.

Of the control variables introduced, the education level of the farmer proved relevant in the explanation of the net farm income in the rain-fed system. Several empirical studies conducted in Africa highlight the positive effect of education on agricultural productivity (Kaboré, 2010). Indeed, because it leads to informed decision-making, education plays a vital role in the ability of farmers to adapt to climate change. This includes enhancing farmers' ability to use climate information effectively to adapt the cultivation timelines to new climatic data.

The net income equations provide insight into the sensitivity of rice farms to climatic variations. In fact, both in rain-fed cultivation systems and in irrigated systems, farms are clearly affected by variations in rainfall.

The linear and quadratic terms of annual rainfall are significant, implying a nonlinear effect of rainfall on agricultural income in the rain-fed system. An inverted U relationship between rainfall and net farm income is described by the positive and negative signs of the respective linear and quadratic terms. Net farm income in rain-fed farms is thus an increasing function of rainfall up to a maximum threshold beyond which net income declines. This result is consistent with agronomic forecasts and the forecasts of the majority of studies in Africa using the Ricardian approach (Molua and Lambi 2007, Mano and Nhemachema 2007, Kabuko-Mariara and Karanja 2007, Eid et al. 2007). Indeed, rainfall tends to increase agricultural incomes following decreasing marginal yields to a maximum point beyond which the flooding of plots negatively impacts the production of farms in rain-fed system.

On the other hand, in the irrigated system, the quadratic term of annual rainfall is not significant, indicating a linear relationship between rainfall and net income of farmers. This result can be explained by the capacity of the irrigated system to better adapt to the intense rainy seasons, and by the more efficient conservation of water that will be used for irrigation during periods of drought.

The negative and significant coefficient of variation of rainfall indicates a high sensitivity of rain-fed rice to the annual dispersion of rainfall. On average, the net income in rain-fed systems decreases with the dispersion of rainfall throughout the year. A strong dispersion of the rainfall pattern over the year increases the water deficit, which reduces the yields of rain-fed rice (Diomandé and Kouassi, 2014). On the other hand, the practice of irrigation is an effective answer to the dispersion of the rains. Indeed, the impact of rainfall dispersion on the irrigated system is insignificant.

Table 7. Estimated net farm income for rain-fed and irrigated systems

Net farm income equation	Rain-fed cultivation system		Irrigated cultivation system	
	Coef.	T-Stud.	Coef.	T-Stud.
Age	0.0164	0.83	0.00886	0.40
Age^2	-0.0001	-0.81	-0.00017	-0.76
Member of a group	0.0854	0.96	-0.11342	-1.12
Education				
Literate/No education (ref)	0.32***	3.39	-0.02456	-0.24
Gender				
Female/male (ref)	-0.1624	-1.34	-0.12772	-0.80
Land ownership				
Owner/renter (ref)	-0.066	-0.68	-0.14719	-1.40
Size of household	0.0074	1.33	0.00334	0.48
Log (rainfall)	0.60369***	2.58	2.89291***	7.06
Log (rainfall) Sq	-0.0159***	-6.53	-0.22322	-1.37
Dispersion of rainfall (CV)	-0.6023***	-2.80	-0.000833	-0.71
Constant	5.8597***	3.12	29.12368***	12.70
	0.92744***	31.54	0.9004674***	18.56
	-0.1209917	-0.796	0.4066962**	2.41
Log-likelihood	-1634.7717			
Number of observations	895			

(***) Significant at the 1% threshold; (**) significant at the 5% threshold.

Source: Created using survey data from PASRES, 2016

- Marginal impact of climate change on net income of rice farmers

The impact of climatic variations on farm profit is evaluated by calculating marginal effects. The estimated coefficients of climatic variables (Table 7) cannot be directly interpreted but are used for the calculation of marginal effects (Table 8).

Marginal effects of climate variability on farmers' net income are calculated at the average point of each sample and expressed in terms of elasticity. The results show that rainfall has a significant impact on rice productivity in both the rain-fed and irrigated systems. The elasticity of producers' net income in relation to rainfall is 0.47 in rain-fed systems and 2.89 in irrigated systems. This implies that farmers' net income would increase by 0.47% in rain-fed systems and 2.89% in irrigated systems following an increase in the annual rainfall volume by one percentage point.

In addition, irregular rainfall during the growing season creates water deficits that negatively impact the productivity of rain-fed farms. Indeed, a greater annual dispersion of precipitation (increase in the coefficient of variation of one point) would reduce the net income of farmers in rain-fed systems by 0.6%. On the other hand, the marginal effect of rainfall dispersion on net farm income in irrigated systems is not significant. Indeed, irrigation is a response to the dispersion of precipitation.

Table 8. Marginal effects and elasticities

Variable	Elasticities	
	Rain-fed	Irrigated
Rainfall	0,47*** (0,001)	2,89*** (0,000)
Dispersion of rainfall (Coefficient of variation)	-0,6023*** (0,000)	-0,0008 (0,479)

(***) Significant at the 1% threshold; (**) significant at the 5% threshold.

Source: Created using survey data from PASRES, 2016

5. Conclusion

This study assesses the impact of climate change on Ivorian rice cultivation using a new Ricardian approach. This approach examines rain-fed and irrigated systems separately and treats the choice of irrigation as endogenous. It corrects the selection bias of the traditional Ricardian approach.

The results of this study establish a positive and significant relationship of rainfall on the net income of rice farmers in both rain-fed and irrigated systems. In fact, the elasticity of farmers' net income in relation to rainfall is 0.47 in rain-fed systems and 2.89 in irrigated systems. Furthermore, a decrease in the annual volume of rainfall will lead to a decrease in crop yields both in rain-fed and irrigated systems. The decrease in annual rainfall will have a negative impact on lowland water availability, causing a greater loss of yield for irrigated crops.

The study shows, on the other hand, that the practice of irrigation makes it possible to respond effectively to excess rainfall and to highly dispersed precipitations during the year.

There is a significant quadratic relationship between rainfall and yields in rain-fed systems. This result indicates the existence of a maximum threshold beyond which the impact of rainfall on crop yields in rain-fed systems is negative. On the other hand, the quadratic term is not significant in the irrigated system, reflecting a consistently positive linear effect of rainfall on the productivity of irrigated rice cultivation. Rainfall dispersion negatively affects the yield of farms in rain-fed systems with an elasticity of -0.6 while the impact is insignificant in irrigated systems.

These results confirm the greater capacity of the irrigated system to adapt to seasonal water deficits and heavy rainfall by methods of conserving or storing water resources.

In an effort to better adapt Ivorian rice cultivation to climatic variations, the study suggests the following recommendations:

- Improve the collection, dissemination and analysis of climatic data. In point of fact, the development of adaptation and mitigation measures requires regular collection of agro-climatic data in order to better understand the linkages between agriculture and climate;
- Invest in farmer training and in extension services focused on adaptation strategies;
- Promote irrigation by investing in lowland development. Effective irrigation techniques are essential to mitigate the negative effects of climatic variations.

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