Analysis of the Impact of Irrigation on the Nutritional Status of Rice Farming Households in the Iffou Region of Côte D'ivoire

Allou Nazaire N'DRI

Assi J.C. KIMOU

Working Paper 039-2026

Bringing Rigour and Evidence to Economic Policy Making in Africa

CONSORTIUM POUR LA RECHERCHE ÉCONOMIQUE EN AFRIQUE

ANALYSIS OF THE IMPACT OF IRRIGATION ON THE NUTRITIONAL STATUS OF RICE FARMING HOUSEHOLDS IN THE IFFOU REGION OF CÔTE D'IVOIRE

By:

Allou Nazaire N'DRI,

University Alassane Ouattara
Bouaké

Assi J.C. KIMOU,

University Félix Houphouët Boigny
Abidjan Cocody

AERC Research Paper 039-2026
African Economic Research Consortium, Nairobi
February 2026

Disclaimer: The findings, opinions and recommendations are, however, those of the author, and do not necessarily reflect the views of the Consortium, its individual members or the AERC Secretariat.

Published by: The African Economic Research Consortium

P.O. Box 62882 - City Square
Nairobi 00200, Kenya

Abstract

This paper investigates the impact of irrigation on the nutritional status of rice farming households in M'Bahiakro, which is an irrigated rice-producing area. It utilizes data from a survey of rice farmers conducted by the Ivorian Centre for Economic and Social Research (CIRES) and the International Initiative for Impact Evaluation (3ie). The empirical strategy first estimates a Probit model to determine drivers of participation in the irrigation system. Second, it assesses the impact of irrigation on rice production and rice income using an Endogenous Switching Regression (ESR). Descriptive statistics show that producers participating in the irrigation system have higher productivity levels and higher income compared to non-participant farmers. Similarly, the Household Dietary Diversity Score (HDDS) is higher among households that use irrigation compared to non-participating households. The results of the probit model estimation show that education, training, extension services, off-farm activities, and membership in an agricultural cooperative are the main determinants of participation in irrigation. The results of the impact assessment indicate no significant effect of the irrigation system on food diversity. The impact estimation on rice production and household income shows that participation in the irrigation system has a positive effect on both income and rice production for participants. These findings reveal a positive effect of irrigation on beneficiaries, which implies an interest in the irrigation program for policymakers and rice farmers.

Keywords: Nutrition; impact evaluation; Probit; Endogenous Switching Regression; Côte d'Ivoire

1. Introduction

Food security and nutrition remain significant social issues worldwide, particularly in developing countries. Millions of people continue to be affected by hunger and undernourishment. In 2017, the number of undernourished people was estimated at 821 million, while stunting among children affected nearly 151 million and reached 50 million among children under five years old (FAO et al, 2018). Despite the efforts made to ensure access to a regular and balanced diet for all, hunger persists in the Global South. An estimated 8.2 percent of the global population may have faced hunger in 2024, down from 8.5 percent in 2023 and 8.7 percent in 2022. It is estimated that between 638 and 720 million people, corresponding to 7.8 and 8.8 percent of the global population, respectively, faced hunger in 2024. The number of people unable to afford a healthy diet in the world fell from 2.76 billion in 2019 to 2.60 billion in 2024. However, the number increased in Africa from 864 million to just over 1 billion in this period (from 64 to 66.6 percent). In low-income countries (almost in Africa), the number increased from 464 million in 2019 to 545 million (72 percent of the population) in 2024 (FAO et al., 2025)

In Côte d'Ivoire, the proportion of the population in a state of undernourishment is estimated at around 15% in 2019[1]. Households' limited access to food is due to several factors, including insufficient agricultural production, and originates from a lack of market supply and low purchasing power. Food availability is also constrained by both low food storage and poor processing capacities, with post-harvest losses ranging from 30% to 40% (National Nutrition Council, 2015). The result of this situation is malnutrition, which, through its adverse effects on labour productivity, contributes to limiting economic and social development. An analysis of the National Multisectoral Nutrition Plan 2016-2020 on the consequences of malnutrition in Côte d'Ivoire reveals an economic loss linked to the fall in labour productivity of more than 972 million dollars (nearly 486 billion CFA francs).

In 2014, nearly 21% of the Ivorian population did not reach the minimum level of calorie intake, and the diet remains poorly diversified in all age groups. The average calorie intake per inhabitant is 2534 kcal per person a day, compared with the 2806 kcal per person a day recommended by the WHO (World Bank, 2014). Malnutrition also affects child mortality and hurts intellectual development and learning capacities. It contributes to 33% of child mortality with an estimated 128,354 deaths of children under five each year (Tahmeed et al., 2012). Like most socio-economic indicators, the nutritional situation of the population, particularly children under five and women, deteriorated significantly during the decade of instability (2002-2011) in Côte d'Ivoire. Despite the sustained economic growth due to the restoration of socio-political stability and the effort made by the Government and its partners, the nutritional situation remains worrisome in most regions of Côte d'Ivoire.

The country remains affected by various forms of malnutrition. Stunting is the most widespread. Its prevalence is considered serious at the national level. It shifts from 29.8% in 2012 (PND, 2012-2015) to 21.6% in 2016 (Early Childhood Matters and Bernard Van Leer Foundation, 2019). Despite the decrease, Côte d'Ivoire dwells in a serious nutritional situation. To address this issue, the country aims to become self-sufficient in several key products. Rice is among these products. Chaudhari et al. (2018) reveal that rice contains 80% carbohydrates, 7-8% protein, 3% fat, and 3% fibre. In addition, rice is a food that is easy to cook. However, local rice production covers only half of national consumption

[1] Website of the World Bank 2022 and WORLD DATA ATLAS IVORY COAST FOOD SECURITY

needs, requiring massive rice imports of more than 200 billion CFA francs a year to make up the shortfall. Indeed, rice has become the main cereal consumed by the Ivorian population, particularly in urban areas, due to growing urbanisation and population growth. Its consumption has risen to more than 1.3 million tonnes per year, representing 70 kg/capita/year (PNIA/SARA, 2014).

To overcome this situation, Côte d'Ivoire has embarked on a rice development policy that is part of the revised National Rice Sector Development Strategy (SNDR). The SNDR is broken down into various programmes and strategies implemented in the rice sector, consisting of the construction of infrastructure and irrigation equipment. Through the cultivation of irrigated rice with a two-year production cycle programme, the Government envisions increasing production and achieving self-sufficiency in rice and improving the nutritional status of the population. Increasing domestic rice production to meet growing consumption and reduce imports has been a priority since independence, as Côte d'Ivoire has a potential of 475,000 hectares of irrigable land, i.e., over three-quarters of the national territory (Namara & Sally, 2014). Irrigation policy should be intensified through various rice development programs and strategies in several regions of the country, primarily in the northern, western, and central regions.

It is within the framework of implementing this policy that the hydro-agricultural development of M'Bahiakro, located in the center of the country, was carried out. This area is part of the old Cocoa Belt that has nowadays moved to the southwest of the country. Today, rainfall in this region has become low and highly variable. The fertility and productivity of the land are widely affected, reducing food production and increasing the level of poverty, food insecurity, and malnutrition in the region. The State of Côte d'Ivoire developed the M'Bahiakro hydro-agricultural programme to address these issues. Indeed, the rice growing perimeter has been developed for total water control. It has a 5-metre high inflatable dam, two pumping stations, tracks, and buildings. Tractors, tillers, and threshing machines are available to the beneficiaries. Financed within the framework of a public-private partnership, the project's objective is to contribute to food security and improve the living conditions of the population in the middle N'Zi Valley by increasing rice and market garden product production. The project covers an area of 450 hectares for a rice production of 4,200 tonnes of paddy per year. The production activities are financed by a firm selected for this purpose. The firm provides inputs (such as ploughs, fertilisers), carries out phytosanitary treatment, and finally harvests. The services of the firm, as well as the electricity costs for pumping water for irrigation, are withdrawn from the farmer's revenue from the sale of their products.

Unlike this area, which has all the facilities for irrigated rice production, in the control area (i.e., non-irrigated area), production is also carried out in lowlands. The development is done traditionally and by producers. The agronomists chose the control area because it meets several criteria, including the cultivation of rice as one of the main activities, a suitable distance between the two areas to avoid risks of spillover, the presence of groups, the existence of lowlands, and farmers' experience in rice production. The distance between the two areas is estimated at more than 90 kilometres. The two areas have similar agro-climatic conditions with lowlands favourable for rice production.
Since the implementation of the hydro-agricultural facilities in the different regions of the country, there is a paucity of research related to the impact of these initiatives on rice-farming households. Most of the studies carried out on rice in Côte d'Ivoire have provided a general description or monograph of the food security situation (INS, 2012; 2013; Ministry of Agriculture, WFP & FAO, 2012; Ducroquet et al., 2017). Other studies have highlighted trends in the nutritional situation in the country, such as those carried out by Tano et al. (2010), the Fair Labor Association (2015), Kenkhuis (2016), Agbo et al. (2017), and Zahe et al. (2017). However, these studies did not focus on rice and did not rigorously provide evidence about the impact of irrigation on household nutrition. This paper aims to contribute

to the search for economic gains from water management by investigating the impact of irrigation on the nutritional status of rice-producing households. The study, therefore, provides answers to the following questions:

Is there a significant difference in nutritional status between producers who practice irrigation and those who do not? What factors influence participation in irrigation? Moreover, what is the impact of irrigation on the nutritional status of households?

2. Objectives

The overall objective of this study is to assess the impact of irrigated rice cultivation on the nutritional status of rice-producing households.

Specifically, the research aims to:

- Characterise the nutritional profile of rice-producing households.
- Determine the factors that influence household participation in the irrigation programme.
- Assess the impact of participation in the irrigation programme on the nutritional status, rice yield, and income of rice-producing households.

3. Literature review

Several studies have highlighted the impact of irrigation on poverty, food security, and nutrition through various methods. Studies such as Hussain and Wijerathna (2004), Huang et al. (2005), and Van den Berg and Ruben (2006) have used simple methods to compare impact results between irrigation participants and nonparticipants. Hussain and Wijerathna (2004) assess the impact of irrigation on households in six countries (Bangladesh, China, India, Indonesia, Pakistan, and Vietnam) using multistage sampling methods. They use dichotomous variable models (Probit and Logit) to estimate the impact of irrigation. Huang et al. (2005) analyzed the impact of irrigation on agricultural productivity in Indonesia using econometric estimation and simulation based on the results. In Ethiopia, Van den Berg and Ruben (2006) capture the effect of irrigation on households through ordinary least squares (OLS) model estimation. All these studies show positive results. However, there are some limitations in using these methods to analyse the impact of irrigation. The problem of endogeneity and selection bias is included. Estimation results may be biased due to unobserved factors that are simultaneously correlated with access to irrigation (or improvement of irrigation services) and outcome indicators/dependent variables. Robust econometric impact models are recommended to address these problems.

Nkhata et al. (2014) used Propensity Score Matching (PSM) techniques to show that, in Malawi, irrigation has a positive impact on participants' daily caloric intake. Overall, the bias-corrected estimate using nearest neighbour matching showed that irrigation increases the daily caloric intake of participants by 103 kilocalories. This consumption would represent an average increase of 10% more than what participants would consume if they were not participating in the irrigation system. Gebrehiwot et al. (2017) used the Endogenous Switching Regression (ESR) model to measure the impact of micro-irrigation development on the welfare of households in Ethiopia through two variables: household income and household fixed assets. Their results indicate that the income of households that adopted irrigation increases by 8.8% and asset formation by 186% compared to non-users. Hagos et al. (2012) note, in a study spanning four regions in Ethiopia, that access to water management technologies for agriculture has a significant impact on poverty reduction. Sinyolo et al. (2014) used a treatment effect model to assess the effect of access to irrigated agriculture on the welfare of rural households in the province of KwaZulu-Natal in South Africa. The results showed a positive effect of irrigated agriculture on overall household consumption. They justify public investment in smallholder irrigation. Dillon (2011), using the panel method on household data in northern Mali, finds a positive and significant effect of access to irrigation on household consumption. The results show that irrigation increased household consumption by 27% to 30%. In China, a comparison between irrigation participants and nonparticipants contributes to increased yields for most crops and high income for farmers in all regions (Huang et al., 2005). In Mali, Burney et al. (2010) assessed the impact of solar-powered irrigation. They conclude that irrigation improves both food security through a significant increase in income and nutrition in beneficiary households.

The practice of irrigation can improve nutritional outcomes through multiple pathways. Among such pathways, one may include increased productivity, improved food availability, and enhanced food quantity and quality (Domènech, 2015). In Bolivia, a study carried out by Salazar et al. (2015) uses the Local Average Treatment Effects (LATE) method that relies on instrumental variables to analyse the impact of irrigation technology on productivity and food security. It shows that irrigators increase production by 92%, sales value by 360%, household income by 36%, per capita income by 19% and their food security level by 32% compared to non-irrigators. These econometric models, despite their robustness and sophistication, contain shortcomings. The Propensity Score Matching (PSM) requires a reasonably large sample size and quality data. Therefore, it is unable to control for biases between the two groups (Pufahl & Weiss, 2009). The double difference requires a reference database for both groups and can produce measurement bias if the selection changes over time (Ravallion, 2009b). For the instrumental variable method, it is not evident to find good instruments. Sometimes, they are available, but their quality is weak. If the instrument is weak (correlated with unobservable variables), it can potentially increase the bias and affect the outcome of the intervention (Stern et al., 2012). The use of panel data models assumes that the same types of data are collected. In our case, however, not all farmers produced irrigated rice during the first interviews due to water drainage constraints. As a result, the application of panels is not appropriate.

Models that suffer less from these weaknesses, and which allow selection bias and the endogeneity problem to be corrected, are the two-stage method proposed by Heckman (1979) and the Endogenous Switching Regression (ESR) developed by Lee (1978). The last model is suitable for our study because we lacked quality instruments to apply the instrumental variable method. Plus, the absence of a reference study does not allow us to apply the difference in difference. The problems of selection bias could also affect the use of PSM. Several authors have used this method to analyse the impact on participation or technology adoption in the agricultural sector (Di Falco et al., 2011; Anang, 2017).
Although studies on the impact of irrigation on nutritional status have existed in West Africa, very few studies have been devoted to this issue in Côte d'Ivoire, despite the country's commitment to numerous hydro-agricultural development projects for rice production. Such a lack makes this study interesting.

4. Conceptual framework

Irrigation appears nowadays as a technology capable of mitigating the adverse effects imposed by natural factors in the pursuit of increased productivity and food diversity, thereby achieving an adequate nutritional status. Water control technologies appear to be one of the options for increasing food production and achieving both food security and good nutritional status. These techniques make it possible to carry out several production cycles during a year, as opposed to rain-fed agriculture, which provides only one production cycle. According to Norton et al. (2010), the adoption of new technologies, such as irrigation, is the primary driver of agricultural growth and poverty reduction.
Within this conceptual framework, expressed in Figure 1, water control is achieved through technological innovations such as irrigation. Participation in the irrigation system opens three possible avenues leading to increased production. The first possibility is the increase in the productivity of capital, which in turn leads to an increase in output, leading to increased production. The second path is labor productivity growth that improves rice production. The third possibility is the intensive use of the land, thus increasing rice production. All three paths lead to the same conclusion, that is, production increase.

There are three options available to the household when food production increases. These include: (i) self-consumption, (ii) sale of production, and (iii) consumption and sale (Figure 1). First, the household may decide to consume the production directly. That is self-consumption or production exclusively for consumption. Thus, self-consumption is partly related to the substitution effect, which allows the household to consume food that improves their diet. This channel enables the capture of the direct effect or substitution effect (Leroy, 1967). This first option raises the issue of the relationship between irrigation and nutrition. To this end, each of the three routes just mentioned makes it possible to establish the link between irrigation and the improvement of nutritional status.

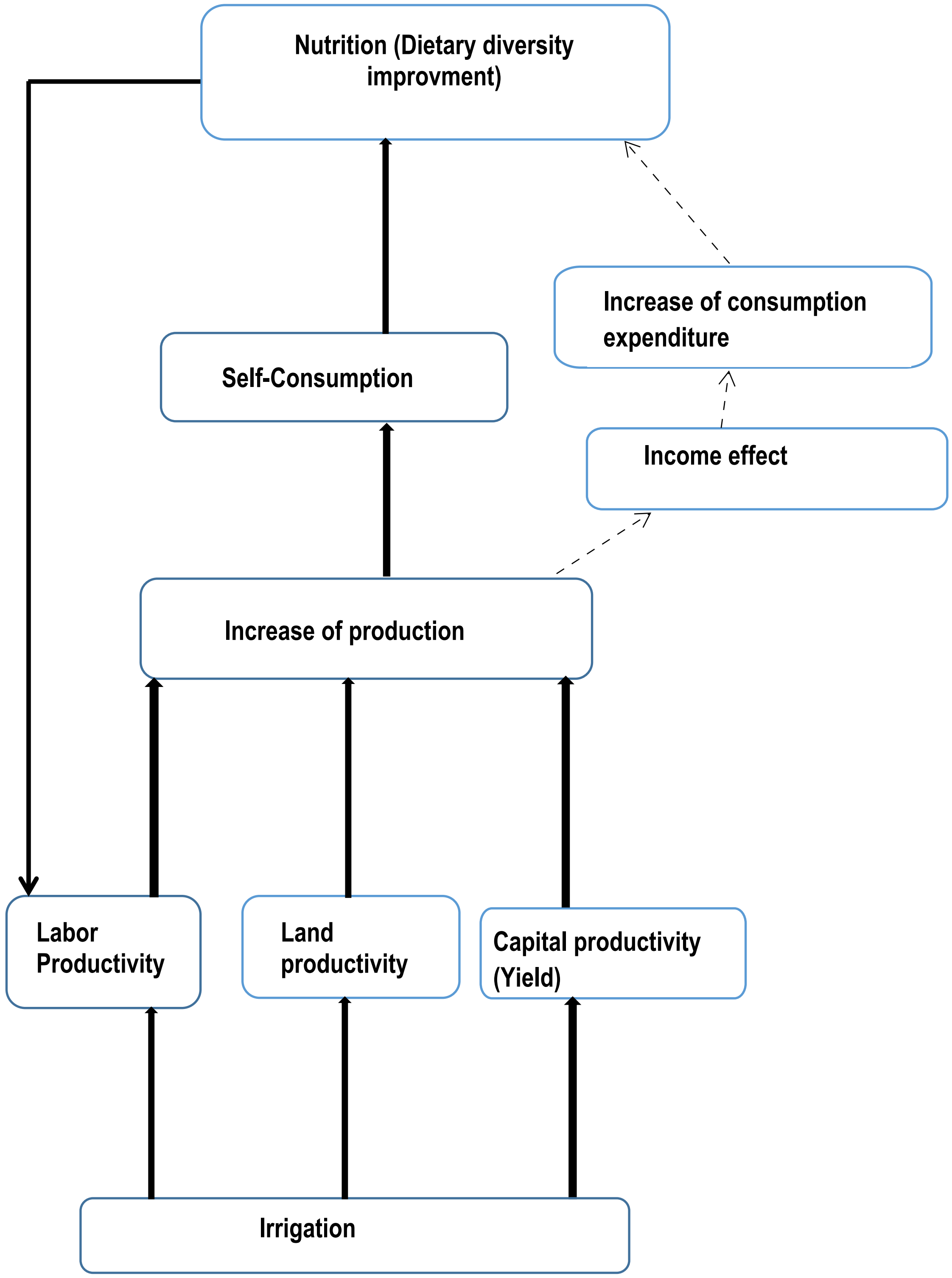
Consequently, irrigation allows the improvement of capital productivity, which leads to increased yields, which in turn drives increased rice production. The self-consumption of rice provides nutrients directly to the body, contributing to an improvement in nutritional status. The improvement in nutritional status may also be because of labour productivity. The idea of a relationship between nutrition and labour productivity is not new. This hypothesis, known as the wage efficiency hypothesis, has been discussed for decades by authors such as Leibenstein (1957), who is considered a precursor (Mazumdar, 1959; Stiglitz, 1976; Bliss & Stern, 1978). In this relationship, it is the impact of nutrition on worker productivity that is measured. However, recent studies highlight the impact of labour productivity on nutrition. Most authors show that the adoption of new technologies (such as irrigation in our case) increases labour productivity, which contributes to an increase in rice production. Therefore, it aims to improve nutritional status. Furthermore, land availability provides a link between irrigation and nutrition because intensive land use promotes increased rice production that allows households to consume their production and then ensure good nutritional status.

The second option stems from the fact that producers can improve their nutritional status through exclusive production for the market (income channel). In this case, the household uses part of the income for food expenditure, including expenditure on animal protein and other nutrient-rich foods (Domènech, 2015). This case could represent the indirect or income effect (Leroy, 1967). This effect is caused by an increase in income through the sale of production (Parent et al. 2002). The household could increase its utility, i.e., its nutritional status, by purchasing food products with high nutritional value. This option corresponds to our case. In fact, in the context of M'Bahiakro hydro-agricultural development, a firm bought paddy directly from the producers at a remunerative price compared to what the market offers. Households are therefore forced to turn to the market to obtain the goods they need to balance their diet. In such a case, the arrangements for implementing the project allow only the income effect to be highlighted since almost all production is directly intended for the market.

Finally, for the third option, the household can combine the first two options by consuming part of the production and selling the surplus to obtain micronutrients and other macronutrients that can both improve their diet and ensure their good nutritional status. The option to consume part of the food and sell the excess seems advantageous for the household because it allows it to make up for calorie deficits by buying nutritious foods that are absent from the diet. It is in this sense that Passarelli et al. (2018) indicate that irrigation, through its contribution to compensating for the lack of water regardless of season, increases crop yields, which leads to an increase in household income and/or an improvement in household food availability. Thus, in households where the increase in yields or income is used to meet food needs, the result is an improvement in nutritional status.

The works of several authors, such as Masset et al. (2012), Carletto et al. (2015), and Pandey et al. (2016), have linked irrigation and nutrition, highlighting that the increase in production resulting from irrigation leads to a corresponding increase in income. That income increase enables the supply of nutrient-rich products to households, which contribute to the improvement of their nutritional status. Mekonnen et al. (2019) also demonstrate in their analysis a strong relationship between household nutritional status and access to irrigation, leading to increased production and income.

Figure 1: Linkages between irrigation, productivity, and nutrition



Source: Adapted from Tsegaye & Tamene (2005)

5. Methodology of the study

5.1. Source of data

The data for this study were collected from a survey conducted by the International Initiative for Impact Evaluation (3ie) and the Ivorian Centre for Economic and Social Research (CIRES) as part of the impact assessment of the M'Bahiakro hydro-agricultural development project. This project is one of the three modern irrigation programmes financed by the West African Development Bank (BOAD). It is also part of the implementation of the two-cycle production irrigation policy, aimed at increasing rice production to achieve both rice food security and improve the nutritional status of rice-farming households. This department includes two major administrative regions (Iffou and N'Zi) in Côte d'Ivoire. The area of the developed perimeter is 450 hectares wide, of which 350 hectares are devoted to irrigated rice cultivation and 50 hectares to the production of market garden crops (vegetables).

Prior to the implementation of the hydro-agricultural infrastructures, interested populations were invited to register freely on lists that were signed by the prefectural authority. Project promoters retained two exclusion criteria. The first is not to be a public or private worker and to be resident in one of the seven localities concerned by the development project. Based on these lists, the plots were allocated by the Project Implementation Unit (UEP). The irrigable plain chosen for irrigation is the property of the village communities, which they have freely conceded for the common cause. This area belongs to six villages and to the town of M'Bahiakro, located on the banks of the N'Zi River. All these localities are beneficiaries, and the producers are from these localities. Accordingly, access to land is not contested and cannot be a source of land conflict. Prior to their installation, the rice producers benefited from a set of technical training on rice cultivation itineraries, application of fertilisers, herbicide application, etc. The first beneficiaries settled in 2012.

As for the control zone, six localities were surveyed. The criteria for selecting a zone include the cultivation of rice as one of the primary activities, the distance between the two zones (beneficiary zone and control zone), the presence of groups, the existence of lowlands, and farmers' experience in rice production. To avoid the risk of contamination, planners chose a control zone far from the beneficiary zone. Thus, the distance between the two zones is estimated at more than 90 kilometres. The two zones have similar agro-climatic conditions with lowlands favourable for rice production.
For the study, the sample size consists of 329 producers, divided as follows: 175 in beneficiary villages and 154 in control villages. The survey covers thirteen localities: six villages and the town of M'Bahiakro in the beneficiary area, as well as six villages in the control zone.

The data collected are related to the main objective of contributing to the revival of agricultural production, increasing producers' income, combating poverty, and creating jobs. The data include socio-demographic characteristics, agronomic data (surface area, production, etc.), rice technical itineraries, water management, fertilizer use, income, consumer spending, and other relevant information. The data are also used to develop a new agricultural policy. For the measurement of food security and the analysis of nutritional status, data were collected on the types (groups) of food consumed in the 24 hours prior to collection and the type of food consumed in the last seven days. These data allow analyses but have shortcomings. For example, it is not possible to distinguish the quantity consumed by a consumer from the quantity sold, as data on self-consumption were not collected. The reason why the data have not been collected is the marketing system set up under this programme. Indeed, producers received pre-financing from a firm so that they could finance their production activities. A contract linked the two parties (producers and firm). In this relationship, the firm pre-financed all the rice-growing activities, which included the supply of fertilizers. In return, the producers deliver all the production to the firm. In this context, all the activities are meticulously carried out by the firm in such a way that post-harvest losses and self-consumption are negligible.

5.2. Descriptive analysis

5.2.1. Demographic characteristics of farmers

Table 1 shows the demographic characteristics of farmers. The analysis indicates no significant difference between participants and nonparticipants as far as gender is concerned. Rice farmers are predominantly male in both the participant (84.57%) and control groups (91.56%). A greater number of participants (66.13%) received training compared to nonparticipants (13.41%). Concerning the extension services, participants get more extension services (16.18%) than nonparticipants (0.07%). The implication is that a greater number of participants (66%) benefit from the extension services. The participants (57.35%) are better educated than nonparticipants (42.15%). This difference means that participants are more likely to use technologies such as irrigation.

For the analysis of farmer business organization, data show beneficiary farmers (64.71%) belong to an Farmer Based Organization (FBO) compared to non-beneficiaries (16.48%). That highlights more propensity for technology adoption for beneficiaries. Non-beneficiaries' farmers (67%) sow more quality seed than the beneficiary group (54%). This situation can be explained by the interest of nonparticipants to increase their productivity because they do not have the same infrastructure and other inputs as the participants. The highest quality of seed can lead to an increase in rice production. There is a statistically significant difference at the 1% level between beneficiary farmers (88.23%) and non-beneficiaries (71.26%) in the use of mobile phones. Beneficiary farmers use mobile phones to receive information about rice prices, rice cultivation, and other relevant details related to rice production.

Table 1: Socio-demographic characteristics of participants and non-participants of rice irrigation farming

Variables	% Participants (a)	% Non-participants (b)	Difference of proportion (b-a)
Gender : male	84.57	91.56	0.032
Training	66.18	13.41	-0.52***
Education	57.35	42.15	-0.15**
Married	75	82.38	0.07
Extension services	16.18	0.07	-0.15***
Improved seed	54.41	67.43	0.13**
Belong to FBO	64.71	16.48	-0.48***
Access to credit	8.82	7.66	0.003
Off-farm activities	16.17	13.02	-0.031
Access to market	22.05	20.68	-0.013
Mobile phone	88.23	71.26	-0.16***

Significance Reference: * = 10%, **= 5%, *** = 1%.

5.2.2. Farmers' farm characteristics

Table 2 presents descriptive statistics for the continuous household variables in the study. For the descriptive analysis of these variables, the t-test or tests of difference in proportion of means are used to show the difference between irrigation participants and nonparticipants. The statistics indicate a significant difference at the 1% level between participants and nonparticipants regarding cultivated land size (ha), as participants have larger rice farms than nonparticipants. There is a significant difference of 1% in rice production between the two groups, as participants produce more rice than nonparticipants. This gap has a direct impact on income, with an equally significant income difference of 5% between the two groups. Differences also exist between the two groups regarding fertilizer use. The table shows that participant farmers apply slightly more fertilizer than nonparticipant farmers. Additionally, there are no significant differences between the two groups in terms of age, household size, and experience.

Table 2: Farmer and farm characteristics of participants and nonparticipants of rice irrigation farming

Variabes	Cultivated land area for rice (ha)		Rice production (kg/ha)		Rice income in FCFA		Fertilizer (kg/ha)		Producer's age in years		Size of household		Experience in year	
	Partici Pant(a)	Non-Parti pant (b)	Partici Pant (a)	Non-parti pant (b)	Participant (a)	Non-parti Pant (b)	Partici pant (a)	Non-Parti pant (b)	Partic ipant (a)	Non-parti pant (b)	Parti cipant (a)	Non-parti pant (b)	Partici Pant(a)	Non-Parti pant (b)
Mean	0.95	0.65	2,060.75	1,337.76	690,250.9	438,076.4	111.85	104.27	44.7	46.2	6.31	5.7	9.77	10.12
Standard deviation	1.09	0.69	1,020.31	618.45	1,301,242	862,933.1	49.79	25.68	11.21	13.70	2.97	3.001	8.33	8.71
Minimum	0.3	0.25	453.6	400	250,000	100,000	100	25	25	25	1	1	1	1
Maximum	8.33	6	4,500	4,200	10,300,000	11,200,000	400	300	75	75	16	17	25	25
Difference (b-a)	-0.30***		-722.99***		-252174.4**		-7.58*		1.45		-0.6		0.056	

Significance: * = 10%, **= 5%, *** = 1%. Standard errors in parentheses.

5.3. Empirical Strategy

This part of the paper describes our empirical approach. It defines the framework for measuring nutritional status and the econometric model supporting the research work.

5.3.1. Measuring nutritional status by the Household Dietary Diversity Score (HDDS)

The Household Dietary Diversity Score (HDDS) is used as a proxy for measuring the nutritional status of the household. The HDDS was developed in 2006 under the Food and Nutrition Technical Assistance Project (FANTA II) as an indicator of household access to food. It has been popularised by FAO and USAID (FANTA, 2006; FAO, 2010). Agronomists define Household Dietary Diversity as the number of food groups consumed by a household in each reference period. It is a crucial indicator of food security for several reasons. The HDDS indicator provides an outline of a household's ability to access food as well as its socio-economic status based on the previous food consumed in 24 hours (Kennedy et al., 2011). It is a proxy for measuring household access to food. It indicates the acquisition of food in sufficient quantity and quality, serving as a proxy for household access to food at the population level (Swindale & Bilinsky, 2006; FAO, 2011). As Household Dietary Diversity generally increases with increasing income, this indicator is sometimes used as a proxy for the dimension of access to food insecurity. It is one of the indicators frequently used to assess the effect of increasing household income on food consumption following interventions (Swindale & Bilinsky, 2006).

The HDDS has strengths and weaknesses. One of its strengths is that it is revealed through simple questions that both interviewers and respondents can easily understand. However, this indicator has weaknesses. One of its drawbacks is that the data are collected at the household level, which does not provide information on the consumption of different food groups or the overall dietary diversity of individuals within the household. Therefore, the HDDS does not provide information on intra-household food distribution. The indicator has not been validated against any adequacy standard to determine whether the number of food groups in a diet constitutes a "sufficiently diverse" or an "insufficiently diverse" diet at the household level. Notwithstanding its limitations, this indicator is a good proxy for capturing the nutritional status of households.

The HDDS is between 0 and 12. A score is assigned to each food group, which is either 1 (if consumed) or 0 (if not consumed). The household score is between 0 and 12 and is equal to the total number of food groups consumed by the household (see table in Annex 1). The HDDS is calculated by summing the groups consumed by the household over 24 hours. The value of the HDDS should not exceed 12.
HDDS = $(A + B + C + D + E + F + G + H + I + J + K + L)$

where A, B, …, L = Food groups and A+ B+………………..+L = Number of food groups consumed

5.3.2. Household Nutritional Profile

Table 3 presents the nutritional profile of beneficiaries and control households. To construct the nutritional profile, the different foods consumed by the households during the week were documented. Each food consumed is counted according to the frequency of consumption by the household during the week. As these foods are classified according to the different food groups defined in the literature, the number of foods consumed is calculated according to the groups. To determine the proportion of each food group, the ratio of the total amount consumed per group to the number of people consuming that food group is calculated. The results indicate that the nutritional profiles do not differ significantly between the groups, except for the consumption of cereals and tubers. Households participating in irrigation have a high propensity to consume cereals (27%), while non-participating households consume more tubers (nearly 27%). Both types of households are likely to consume meat and fish, with 15% of nonparticipants and 13% of participants. Dairy products are consumed more by participants (over 5%) than by nonparticipants (3%).

Table 3: Comparison between household-level food consumption

Foods	Food groups	Participants (%)	Non-participants (%)
1. maize, rice, sorghum, millet, bread and other foods made from maize, rice, sorghum	Cereals	27.28	21.74
2. Casava, potatoes, yams, and other foods made from roots or tubers	Roots and tu-bers	23.65	26.56
3. Beans, peas, peanuts, lentils, or nuts	Pulses	5.45	7.24
4. Vegetables, leaves	Vegetables	1.82	3.86
5. Fruits	Fruits	1.82	4.35
6. Beef pork, goat, chicken, duck, egg, fish	Meat and fish	12.73	15.45
7. Milk, yoghurt and other dairy products	Milk	5.45	2.90
8. Sugar, honey and other sugar products	Sugar and honey	7.27	2.90
9. Oil and fats	Oil	5.45	3.38
10. Spices, tea, coffee, salt, or other alcoholic beverages	Condiments	9.1	11.58

The proportion and difference of participants and non-participant households that consume the various food groups are shown in Table 4. The table shows that there is no difference in food consumption between the two groups. This table confirms the statistics obtained in Table 3.

Table 4: Comparison of proportions in food group consumption

Variables	Participants (a)	Non-participants (b)	Difference between (b) and (a)	Z-stat	P-Value
Cereals	0.21	0.27	-0.05	0.44	0.41
Roots and tubers	0,26	0,23	0.03	0.44	0.32
Pulses	0.07	0.05	0.02	0.47	0.32
Vegetables	0.04	0.02	0.02	0.74	0.22
Fruits	0.04	0.02	0.02	0.87	0.19
Meat and fish	0.15	0.13	0.02	0.51	0.30
Milk	0.03	0.06	-0.03	- 0.93	0.17
Sugar and honey	0.03	0.07	-0.04	-1.50	0.06
Oil	0.03	0.05	-0.02	-0.71	0.23
Condiments	0.22	0.27	-0.05	0.53	0.70

Table 5 shows the HDDS test comparison between participants and nonparticipants. In this study, we use the Dietary Diversity Score to establish the link between irrigation and nutrition. Many authors used this approach to measure the nutritional status of households. Passarelli et al. (2018) investigated the link between irrigation and nutrition through dietary diversity in Ethiopia. In Ghana, Mekonnen et al. (2019) also assessed the impact of irrigation on dietary diversity and nutrition. Thus, using the same approach, significant differences are observed between the two groups in dietary diversity scores. The statistics indicate that beneficiary households consume eight (8) groups compared to seven (7) among non-beneficiary households.

Table 5: Results of tests of comparison between the HDDS beneficiaries and non-beneficiaries

Variables	Beneficiaries (a)	Non-beneficiaries (b)	Difference (b-a)
Dietary diversity score	8.00	7.00	-1.19*

Significance: * = 10%, **= 5%, *** = 1%.

5.3.3 Econometric approach

We use an Endogenous Switching Regression (ESR) for the estimation. The ESR model was developed by Lee (1978). The model provides two types of results. The first part is a Probit model that gives the determinants of participation in the irrigation scheme. The second presents the impact (the impact of irrigation on rice-farming households). ESR models are closely related to instrumental variable (IV) approaches. As with instrumental variables, ESR models require an instrument that explains participation in the programme for correct identification. Unlike PSM and IV approaches, ESR models do not assume that the two schemes (participation in the irrigation system or rice cultivation practice) are similar. Moreover, these models empirically verify whether the marginal yield of observable characteristics differs between the two schemes. This approach requires a larger sample size because it involves more parameters to estimate the impact of irrigation adoption accurately. In addition, the estimation of effect sizes is more sensitive to specification errors. The model can be applied to instruments, using the same criteria (Narayanan, 2014; Escobal & Cavero, 2012).

The main advantage of the ESR models is the joint estimation of the selection and outcome equations using an FIML estimator (Asfaw et al., 2012). Another advantage is that the ESR allows counterfactual analyses. Additionally, the ESR models enable the consideration of both observable and unobservable characteristics. Due to its advantages, ESR models have been utilized for impact assessment in the agricultural sector, notably through the work of Di Falco (2011), Gebrehiwot et al. (2017), and Anang (2017). So, the ESR approach is used in this study. This model provides the results of a Probit analysis of rice farmers' participation in irrigation. The specification of the Probit model is presented in the next section.

5.3.4 ESR model specification

According to Gebrehiwot et al. (2017), microeconomic assessments of the impact of an intervention (the use of irrigation) on the outcome (the nutritional status of the household) are based on the model developed by Becker and Mincer. However, the decision to adopt new technology, in our case an irrigation system, is voluntary. As a result, the well-known problem of sample selection bias may result. Producers who practise irrigation are likely to be the ones who find it profitable. Other unobservable or uncontrolled factors may remain. Such a difference could pose the problem of self-selection in the use of irrigation perimeters, which would be a source of endogeneity. Failing to consider this problem could exaggerate the actual impact of irrigation (Alene & Manyong, 2007).

To address the problem of selection bias and endogeneity, Lee (1978) developed a model estimation approach called Endogenous Switching Regression (ESR). In this approach, the decision is modelled by standard models of limited dependent variables. Then the second-stage outcome variables are estimated separately for each group (irrigators and non-irrigators). This holds under the condition that the decision has been made. Since the decision to adopt irrigation is a dichotomous choice, a producer will decide to use irrigation when there is a positive difference between using the irrigation system and not using it.

The ESR provides the results of the Probit model of participation in the irrigation system. To identify the factors that influence a rice farmer's decision to participate in an irrigation program, we estimate a binary Probit model.

The dependent variable Y_i^* takes the value 1 if the farmer participates in the irrigation program and 0 otherwise.

Formally, the decision to participate is assumed to be determined by an unobserved latent variable Y_i^* representing the net benefit associated with participation:

$$Y_i^* = X_i^{'}\beta + \varepsilon_i, \quad \varepsilon_i \sim N(0,1)$$

$$Y_i^* = \begin{cases} 1 & \text{if } Y_i^* > 0 \text{ (farmer participates)} \\ 0 & \text{Otherwise} \end{cases}$$

So,

$$P(Y_i = 1 \mid X_i) = \Phi(X_i^{'}\beta)$$

Where $\Phi(.)$ the Cumulative Distribution Function (CDF) of the standard normal distribution

X_i is a vector of explanatory variables or independent variables (gender, training, marital status, experience, extension services, farmer business organization, mobile phone, market access, off-farm activities, fertilizer (kg/ha)).

β is a vector of parameters to be estimated.

The estimation is performed using the Maximum likelihood ratio, and marginal effects are employed for interpretation. However, ESR provides the results of Probit model estimation and allows the calculation of marginal effects. So, the ESR model is used for estimation.

Theoretically, a producer decides to adopt irrigation when the expected benefit of adoption, z_{i1}, is greater than the utility received from non-adoption, z_{i0}. The expected utility is not observed, but adoption is observed, so the decision to adopt $(Zi*)$ is treated as a dichotomous choice:

$Z_i = 1$ if $z_{i1} > z_{i0}$ and $Z_i = 0$ if $z_{i0} > z_{i1}$

Thus, using an underlying latent variable model, the participation decision can be modelled as follows:

$Z_i^* = \gamma X_i + \varepsilon_i$

$$z_i = \begin{cases} 1 \; si \; z_{i*} > 0 \\ 0 \; si \; z_{i*} < 0 \end{cases} \qquad (1)$$

Where Zi is a binary variable with the value 1 in case of participation and 0 in case of non-participation. The outcome variables (HDDS) are considered as a linear function of the binary variable of participation in irrigation, with the other explanatory variables. Similarly, the following equation can be used to measure the impact on household income (in FCFA) and rice yield (in kg/ha).

$$Y_i = \lambda X_i + \beta Z_i + \mu_i \qquad (2)$$

Where Y_i is an outcome indicator, λ and β are vectors of parameters to be estimated, x_i is the vector of explanatory variables, and the error term μ.

Variables and their unit of measure for x_i are:
Sex (1 = male ; 0 = Female)
Training (1 = Yes ; 0=No)
Household size (number of persons)
Married (1=Yes ; 0 = No)
Experience (in years)
Education (1 = Yes ; 0=No)
Credit access (1 = Yes ; 0=No)
Extension services (1 = Yes ; 0=No)
Farmers Business Organisation (FBO) (1 = Yes; 0=No)
Mobile phone (1 = Yes ; 0=No)
Market access (1 = Yes ; 0=No)
off_farm_activities (1 = Yes ; 0=No)
Fertilizer (kg/ha)

The estimation of the ESR model involves separate estimates for participants and nonparticipants. This difference suggests that the adoption of irrigation becomes the selection criterion, indicating the regimes faced by each producer. The pattern of participation in the irrigation system is defined by equation (1). Following this equation, nutritional outcomes are observed for both diets (Maddala, 1983; Di Falco et al., 2011).

Regime 1: $Y_{1i} = \alpha_1 X_{1i} + v_{1i}$ if $Z_i = 1$ (participants) (3)

Regime 2: $Y_{2i} = \alpha_2 X_{2i} + v_{2i}$ if $Z_i = 0$ (non participants) (4)

Variables and their unit of measure for x_i are:
Sex (1 = male ; 0 = Female)
Age (years)
age^2 (years)
Household_size (number of persons)
Married (1=Yes ; 0 = No)
Extension services (1 = Yes ; 0=No)
Education (1 = Yes ; 0=No)
Experience (years)
Off_farm_activities (1 = Yes ; 0=No)

Mobile_phone (1 = Yes ; 0=No)
credit_access (1 = Yes ; 0=No)
Acces_market (1 = Yes ; 0=No)

In regimes 1 and 2, Y_{1i} is the potential outcome under treatment/participation,
$Y2i$ is the potential outcome under non-treatment/non-adoption,
$X1i$ is the explanatory variables that influence the outcomes of participants/adopters,
$X2i$ is the explanatory variables that influence the outcomes of nonparticipants,
$v1i$ measures the selection bias among participants,
$v2i$ measures the selection bias among non-adopters/nonparticipants.

Unobserved variables affecting the probability of participation in irrigation could also affect nutritional status, so the error term in equation (1) and those in equations (3) and (4) can be correlated. Equation (3) is the equation of participation in irrigation, and equation (4) is the non-participation in irrigation. To account for this, equations (1), (3), and (4) were simultaneously estimated using Full Information Maximum Likelihood (FIML). This technique remains an efficient approach and can be estimated using the Stata command "movestay" (Lokshin & Sajaia, 2004).[2]

Table 6 presents conditional results, treatment, and heterogeneity effects. It summarizes how participation affects outcomes and how these effects vary across groups. Thus, the expected outcomes of participants (a) and nonparticipants (b), and the expected outcomes in terms of nutritional status in cases of counterfactuals (c) that beneficiaries have not adopted and (d) that non-beneficiaries have adopted (Di Falco et al., 2011). These measures are essential to explain the differences in nutritional status outcomes between the two groups of producers.

Table 6: conditional Results, treatment and heterogeneity effects

Subgroups	Decision		Treatment effects
	Participants	Non-participants	
Participants	(a) E(y_{1i}|Zi = 1)	(c) E(y_{2i}|Zi = 1)	TT
Non participants	(d) E(y_{1i}|Zi = 0)	(b) E (y_{2i}|Z_i = 0)	TU
Heterogeneity effects	BH_1	BH_2	TH

Note: (a) and (b) represent the observed nutritional outcomes; (c) and (d) represent the expected nutritional outcomes of the counterfactual.

TT: Effect of treatment on the treated; TU: Effect of treatment on the untreated; BH1: Basic heterogeneity effect for participants; BH0: Basic heterogeneity effect for nonparticipants; TH: Transient heterogeneity effect.

The effect of treatment on the treatment group (TT) is expressed in equation (5) as the difference between cases (a) and (c):

$$TT = (y_{1i}|Z_i = 1) - (y_{2i}|Z_i = 1) \qquad (5)$$

Similarly, the effect of treatment on the untreated is defined as follows:

$$TU = (y_{1i}|Z_i = 0) - (y_{2i}|Z_i = 0) \qquad (6)$$

[2] Lokshin and Sajaia developed the movestay command applicable under stata

The study differentiates between treatment effects and the effects of baseline heterogeneity. The basic heterogeneity effect is expressed by equation (7) for producers who adopted irrigation. This equation represents the difference between cases (a) and (d):

$BH_1 = (y_{1i}|Z_i = 1) - (y_{1i}|Z_i = 0)$ (7)

For nonparticipants, the basic heterogeneity effect can be expressed as the difference between cases (c) and (b):

$BH_2 = (y_{2i}|Z_i = 1) - E\ (y_{2i}|Z_i = 0)$ (8)

Finally, the effect of transitory heterogeneity is calculated (equation 9). Such a calculation makes it possible to determine whether the impact of irrigation is more or less important for adopters and non-adopters compared to the counterfactual scenario.

$TH = TT - TU$ (9)

6. Results of the econometric analysis

6.1. Analysis of factors influencing participation in the rice irrigation scheme

The probit model was employed to examine the factors influencing participation in the rice irrigation scheme. The validity of the model is further ensured by conducting multicollinearity and heteroscedasticity tests. The test results are presented in Annex 5. The Variance Inflation Factor (VIF) helps detect multicollinearity. A small value of VIF indicates the absence of multicollinearity (Noora, 2020), while a high value of more than 5 indicates the presence of multicollinearity. In our case, the VIF value is between 1 and 5. Thus, the variables are weakly correlated. For the heteroscedasticity test, we used the Breusch-Pagan Test for Heteroskedasticity. The results indicate heteroscedasticity, as the null hypothesis of constant variance is rejected, with a probability of less than 0.001. We corrected the heteroscedasticity by using a *"robust* "option in Stata.

The results of the probit model appear in Table 7. The model is globally significant at 1%. That reflects the significance of the explanatory variables included in the irrigation participation model. The results reveal that the main determinants of participation in irrigation are membership in a FBO or a cooperative (social capital), cultivated land size, access to credit, off-farm activities, education, training, and extension services. Mentoring is an essential element in agriculture, as it is one of the key instruments to improve farm productivity. Indeed, every rice farmer supported by extension services is encouraged to adopt innovative technologies or practices such as irrigation. As a result, farmers who utilize extension services have a 40% chance of participating in the irrigation scheme. The positive and significant effects of agricultural extension are evident in the works of several authors, including Wheeler et al. (2016), Abdulai and Huffman (2016), and Gebrehiwot et al. (2017). Agricultural training remains a significant factor influencing participation in irrigation. Trained farmers have a strong propensity to use irrigation. Our result shows that trained farmers are likely to participate in the irrigation scheme with a probability of almost 18%. Training is likely to increase productivity through the adoption of good agricultural practices and enhanced water use efficiency. Indeed, increasing farmers' knowledge and skills through various training and extension programs contributes to enhancing water use efficiency and improving productivity (Panahi et al., 2009; Chuchird et al., 2017).

Education remains one of the best means for the retention and application of knowledge acquired during training. It guides the producer in the choice of irrigation practices. The level of education allows the adoption of technologies that improve productivity. When farmers are educated, their participation in irrigation is likely to increase by about 9%. More educated farmers are likely to understand the benefit of investing in the farm by adopting innovative farming methods due to expected higher returns on investment. The interest of education in irrigation is confirmed by authors such as Getacher et al. (2013b), Abdulai and Huffman (2016), and Tefera and Cho (2017). Similarly, membership and participation in farmer groups or associations contribute to the adoption of environmentally friendly, operationally viable, and economically viable irrigation schemes (He et al., 2007; Abdulai et al., 2011; Masuki et al., 2014). Differently, membership strengthens social capital and information sharing. It reduces costs by cost-sharing and improves peer motivation, among other benefits. In our work, the positive significance of Farmer-Based Organizations (FBOs) or membership in an economic interest group or cooperative society suggests a likely increase in irrigation participation, with a probability of 18%. These results confirm those found by Regassa (2015) and Azumah and Zakaria (2019).

Credit is essential. It helps farmers acquire all the necessary inputs in the correct quantity, quality, and at the right time. Access to credit is likely to increase the probability of participation in irrigation by about 9%. Nonvide (2016) confirms this result, Gebrehiwot et al. (2017), Getacher et al. (2013).

Similarly, the practice of an off-farm activity is also likely to increase the probability of participation in the irrigation scheme by 8%. This result aligns with Nonvidé (2016). However, access to the market and being married are both likely to reduce irrigation participation by 8% and 8%, respectively, since both variables indicate a negative relationship with irrigation participation.

Table 7: Results of Probit model estimation and marginal effects of participation in irrigation

Dependent variable Participation in irrigation = 1 ; 0 otherwise	Participation model	
	Coefficient	Marginal effects (dy/dx)
Sex (1 = male ; 0 = Female)	0.0757 (0.193)	0.0127 (0.0325)
Training (1 = Yes ; 0=No)	1.083*** (0.221)	0.1829*** (0.0322)
Household size	0.0433 (0.0402)	0.0073 (0.0068)
Married (1=Yes ; 0 = No)	-0.494** (0.228)	-0.0833** (0.0382)
Experience (in year)	0.00364 (0.0138)	0.0006 (0.0023)
Education (1 = Yes ; 0=No)	0.513*** (0.194)	0.0866** (0.0328)
Credit access (1 = Yes ; 0=No)	0.515** (0.220)	0.0870** (0.0362)
Extension services (1 = Yes ; 0=No)	2.385*** (0.472)	0.4028*** (0.0775)
Farmers business organisation (FBO) (1 = Yes; 0=No)	1.062*** (0.213)	0.1794*** (0.0336)
Mobile phone (1 = Yes ; 0=No)	0.408 (0.262)	0.0689 (0.0440)
Market access (1 = Yes ; 0=No)	-0.483** (0.222)	-0.0815** (0.0383)
off_farm_activities (1 = Yes ; 0=No)	0.489* (0.264)	0.0826** (0.0439)
Fertilizer (kg/ha)	-0.00127 (0.00163)	-0.0002 (0.00027)
Constant	-2.503*** (0.519)	

Note: Significance: * = 10%, **= 5%, *** = 1%. Standard errors in parentheses.

6.2. Impact of irrigation on the Household Dietary Diversity Score (HDDS)

The results of the Endogenous Switching Regression (ESR) model, assessing the impact of irrigation on HDDS, are presented in Table 8. The Wald chi2 value is significant at 1%. It shows that the model is globally significant. Thus, the model has a good fit with explanatory variables. The significance of the likelihood ratio test of independence between the equations confirms our choice of the ESR model.

The estimated coefficient of correlation between participation in irrigation and Household Dietary Diversity Score represented by the value of the term rho1 is positive and significantly different from zero. It suggests that self-selection occurred in the participation in irrigation schemes. This suggestion implies that the Endogenous Switching Regression is more appropriate than OLS regression because, under these conditions, OLS estimates would be biased. Table 8 also illustrates the factors that significantly influence the Household Dietary Diversity Score (HDDS). These are extension services, credit access, use of mobile phones for participants, use of mobile phones for nonparticipants, and marital status.

For the participation model, extension services, which are significant at 10%, have a positive effect on the nutritional status of participants. Extension services are an essential element in agriculture because it is one of the instruments to improve farm productivity. Indeed, every rice farmer supported by extension services is encouraged to adopt innovative technologies such as irrigation. This allows them to increase both their production and diverse consumption of food types. Additionally, through the sale of their production, they can improve their nutritional status by purchasing more nutritious food. Credit access also has a positive impact on HDDS because it enables households to secure essential inputs and food, thereby improving their nutritional status. Similarly, the use of a mobile phone helps to increase HDDS. The variable is significant at 1%. It suggests that farmers can get information about prices through the phone. For nonparticipants, the negative significance of marital status suggests that being married reduces HDDS among this group of farmers. However, ownership of phones by this group of farmers increases HDDS.

Table 8: Effect of participation in irrigation on the Household Dietary Diversity Score (HDDS)

Dependant variable	Models' outcomes	
Household Dietary Diversity Score (HDDS)	Participants	Non-participants
Sex	0.0642 (0.0765)	0.0156 (0.0385)
Age	-0.0103 (0.00978)	0.00194 (0.00549)
Age²	8.92e-05 (9.28e-05)	-2.05e-05 (5.37e-05)
Household_size	0.00327 (0.0113)	0.00243 (0.00563)
Married	-0.0832 (0.0720)	-0.0675* (0.0354)
Extension services	0.110* (0.0641)	-0.128 (0.146)
Education	-0.0262 (0.0406)	0.0134 (0.0244)
Experience	-0.000905 (0.00322)	-0.00140 (0.00176)
Off_farm_activities	-0.0265 (0.0543)	-0.0308 (0.0351)
Mobile_phone	0.923*** (0.0688)	0.767*** (0.0266)
credit_access	0.102** (0.0440)	-0.00362 (0.0257)
Acces_market	0.00244 (0.0494)	-0.0114 (0.0324)
Constant	3.177*** (0.277)	3.307*** (0.145)
rho_0	0.250 (0.347)	
rho_1	0.531 (0.252)**	
Log likelihoold : 7.2923	Wald chi2(14) =237.91	Prob > chi2 = 0.0000
Test of Wald indep. eqns. :	chi2(1) = 5.04	Prob > chi2 = 0.024

Note: Significance: * = 10%, **= 5%, *** = 1%. Standard errors in parentheses.

The expected dietary diversity under actual and counterfactual conditions is presented in Table 9. Cells (a) and (b) represent the expected nutritional outcomes observed under the real conditions, and (c) and (d) correspond to the counterfactuals. The dietary diversity for irrigation participants (a) is 4.021, and that of nonparticipants (b) is 3.85. The difference between the two groups is 0.17. However, this difference cannot be attributed solely to participation in irrigation. The last column of Table 9 presents the effects of participation in the irrigation system on dietary diversity. In counterfactual case (c), it is clearly shown that the treatment effect for irrigation participants is 0.001. This effect, however, is not significant. That implies that there is no difference in dietary diversity whether the farmer participates in or not in the irrigation system. Conversely, in counterfactual case (d), nonparticipants would decrease their dietary diversity by 9.4%[3]. This result highlights the indirect transmission mechanism by which irrigation affects dietary diversity. Indeed, due to the contractual nature of the relationship between the rice farmers and the firm, most of the rice produced is delivered to the firm. As a result, households may not use this income from the sale of rice to buy rich foods, but to spend on other items such as health and education. In this context, it is clear that irrigation does not affect household dietary diversity. Another explanation is that the data are cross-sectional rather than longitudinal, so findings should be interpreted as estimated causal associations rather than actual causal relationships (Passarelli, 2018).

The last column presents the effects of irrigation treatment on dietary diversity. The results show that participation in irrigation increases dietary diversity. The transient heterogeneity effect is positive. It implies that the effect of irrigation on nutritional outcomes is significantly higher for farmers who have participated in the irrigation scheme than for those who have not. It is therefore necessary to implement policies to facilitate participation in irrigation. The last row of Table 9, which considers the potential heterogeneity effect in the sample, reveals that farmers who adopt an irrigation system would have a higher HDDS than farmers who do not participate in irrigation in counterfactual cases (c) and (d). We conclude that there are important heterogeneity factors showing advantages in favour of participants compared to nonparticipants. The findings reveal that the practice of irrigation improves nutritional status through increased dietary diversity. They corroborate with the results found by Alaofè et al. (2016), Passarelli et al. (2018), and Mekonnen et al. (2019).

Table 9[4]: Conditional Results, Treatment Effects, and Heterogeneity of the Impact of Irrigation on Food Diversity Score

Sub-groups	Decision stage		Treatment effects
	Beneficiaries	Non-beneficiaries	
Beneficiaries	(a) 4.021 (0.0350)	(c) 4.020 (0.0306)	TT = 0.001 (0.01259)
Non-beneficiaries	(d) 3.76 (0.0263)	(b) 3.85 (0.0217)	TU = -0.09 (0.007) ***
Heterogeneity effects	BH1 0.25 (0.0546) ***	BH2 0.16 (0.0450) ***	TH = 0.09 (0.0068) ***

Note: Significance: * = 10%, **= 5%, *** = 1%. Standard errors in parentheses.

6.3. Impact of irrigation on household income

The results of the Endogenous Switching Regression (ESR) model assessing the impact of irrigation on household income are presented in Table 10. The Wald chi2 value is significant at 1%, reflecting that the model is globally significant. Thus, the model has a good fit with explanatory variables. The significance of the likelihood ratio test of independence between the equations confirms our choice of the ESR model. The estimated coefficient of correlation between participation in irrigation and household income, represented by the value of the term rho1, is positive and significantly different

[3] The treatment effect in this unit is interpreted as a percentage difference. Actually, when the outcome variable is log-transformed, multiplying the ATT by 100 is an approximation, and it is near enough only for differences <0.05. The exact percent difference is given by $100(e^{ATT}-1)$, where e is exponential and ATT is the average treatment effect provided by the analysis of the log-transformed variable.

[4] The results in this table stem from using the MSAT method and command developed by Aaar, A. (2015).

from zero, suggesting that self-selection occurred in the participation in irrigation schemes. It also implies that the Endogenous Switching Regression is more appropriate than OLS regression because, under these conditions, OLS estimates would be biased. Table 10 illustrates the factors influencing household income as well. These are the ages of farmers and their education level. Other factors influencing the household income are also reported in Table 10.

Age positively affects household income with a significance level of 1% for participants and is not significant for nonparticipants. However, the age square variable indicates a negative sign. Thus, it supports the life cycle hypothesis, which suggests a declining productivity for older persons. This result suggests that as farmers age, their income-earning skills are likely to decline. Education, which is significant at the 1% level, affects household income positively. Indeed, when the farmer is more educated, they can control and apply technology, so productivity increases and, in turn, income too.

Table 10: Effects of participation in irrigation on household income

Dependant variable	Models' outcome	
Household income	Participants	Non-participants
Sex	0.192 (0.223)	0.0837 (0.176)
Age	0.142** (0.0553)	-0.0124 (0.0397)
Age²	-0.00113** (0.000529)	8.58e-05 (0.000388)
Household_size	0.00284 (0.0453)	0.0360 (0.0326)
Maried	-0.0414 (0.284)	0.123 (0.251)
education	0.705*** (0.229)	-0.0591 (0.185)
Cultivated land size (ha)	0.117 (0.110)	-0.113 (0.129)
Training	0.246 (0.280)	0.305 (0.312)
Experience (year)	-0.0138 (0.0187)	0.0181 (0.0128)
Credit_access	0.298 (0.238)	-0.481** (0.192)
Distance_market (km)	0.129 (0.289)	0.205 (0.231)
FBO	-0.139 (0.266)	0.0407 (0.274)
Mobile phone	-0.457 (0.400)	0.0678 (0.189)
Constant	7.986*** (1.387)	12.44*** (0.965)
rho_0	-0.063 (0.330)	
rho_1	0.631 (0.276)**	
Log likelihood : -616.2302	Wald chi2(12) =31.36	Prob > chi2 = 0.003
Test of Wald indep. Eqns :	chi2(13) = 5.36	Prob > chi2 = 0.020

Note: Significance: * = 10%, **= 5%, *** = 1%. Standard errors in parentheses.

The expected household income under actual and counterfactual conditions is presented in Table 11. Cells (a) and (b) represent the expected income outcomes observed under the real conditions, and (c) and (d) correspond to the counterfactuals. The household income for irrigation participants (a) is 12.86, and that of nonparticipants (b) is 12.36. The difference between the two groups is 0.50. However, this difference cannot be attributed solely to participation in irrigation. The last column of Table 11 presents the effects of participation in the irrigation system on household income. In the counterfactual case (c), the income of farmers participating in the irrigation scheme increases by 0.45, equivalent to

56.8%. Conversely, in the counterfactual case (d), the income of nonparticipants would decrease significantly by 0.06, equivalent to 6.2%, if they adopted the irrigation system.
The transient heterogeneity effect is positive. It means that the effect of irrigation on income outcome is significantly higher for farmers who participated in irrigation than for those who did not. Such an outcome encourages the implementation of policies to pursue participation in irrigation. The last row of Table 11, which considers the potential heterogeneity effect in the sample, reveals that farmers who actually participated in the irrigation scheme would have a higher income than farmers who did not in counterfactual cases © and (d). We conclude that there are important heterogeneity factors showing advantages in favour of participants compared to nonparticipants.

Table 11: Conditional Results, Treatment Effects, and Heterogeneity of the Impact of Irrigation on Household Income

Sub-groups	Decision stage		Treatment effects
	Beneficiaries	Non beneficiaries	
Beneficiaries	(a) 12.86 (0.0759)	(c) 12.41 (0.0398)	TT = 0.45 (0.0857) ***
Non beneficiaries	(d) 12.30 (0,0424)	(b) 12.36 (0.0209)	TU = -0.06 (0.0473) ***
Heterogeneity effects	BH_1 0.56 (0.0917) ***	BH_2 0.05 (0.0458) ***	TH = 0.51 (0.0445) ***

Significance: * = 10%, **= 5%, *** = 1%. Values in brackets are standard errors.

6.4. Impact of irrigation on household rice yield

The results of the Endogenous Switching Regression (ESR) model assessing the impact of irrigation on the yield of rice are presented in Table 12. The Wald chi2 value is significant at 1%. It shows that the model is globally significant. Thus, the model has a good fit with explanatory variables. The significance of the likelihood ratio test of independence between the equations confirms our choice of the ESR model. The estimated coefficient of correlation between participation in irrigation and household rice production, represented by the value of the term rho1, is positive and significantly different from zero, suggesting that self-selection occurred in the participation in irrigation schemes. Hence, the Endogenous Switching Regression is more appropriate than OLS regression because in these conditions, OLS estimates would be biased. Table 12 also illustrates the factors influencing the household rice production. These are specifically related to the age of farmers and their education level. Other factors affecting rice production are also reported.

Age positively affects rice production with a significance level of 5% for participants and not significant for nonparticipants, indicating that young farmers work hard to increase their production. Moreover, as farmers age, their physical capacity decreases. However, the square of age is significant for the participants. That indicates a specific quadratic effect of age. The area positively influences participation in the irrigation system. It is significant at 1% for both groups. The ownership of a large farm favours production. These results are in line with those found by authors such as Adeoti (2009) and Bagheri and Ghorbani (2011). Membership in the association contributes to production as well. As previously highlighted, membership strengthens social capital and information sharing. It reduces cost when it is shared between the members and improves peer motivation. In our work, Farmer-Based Organization (FBO) or Membership of an economic interest group or cooperative society positively affects production by 10%.

Credit access is also an important factor of production because it allows for the secure input of resources such as fertilizers, pesticides, equipment, and the payment of the workforce to work in the field. Credit is essential as it helps farmers acquire all the necessary inputs in the right quantities and qualities at the right time. The coefficient associated with credit access is significant at 5%. This result confirms previous findings (Nonvidé, 2016; Gebrehiwot et al., 2017; Getacher et al., 2013). Extension services are an essential factor in agriculture, too, as it is one of the instruments to improve the productivity of the farm. Indeed, every rice farmer supported by coaching or extension services is encouraged to adopt innovative technologies such as irrigation. The coefficient of the variable extension services is positive and significant at 5% for the participant. The positive effects of extension services are evident in the works of authors such as Nonvidé (2016) and Gebrehiwot et al. (2017). With respect to household size, it hurts rice production among the participant group. Indeed, farmers involved in irrigation use technology than human resources. Also, large numbers of labourers may be a waste of human resources.

Table 12: Effects of participation in irrigation on rice production (kg)

Dependant variable	Models' outcomes	
Rice in kg	Participants	Non-participants
Sex	-0.00187 (0.166)	0.258 (0.191)
Age	0.0842** (0.0406)	-0.0334 (0.0562)
Age²	-0.000662* (0.000370)	0.000371 (0.000541)
Household_size	-0.0582* (0.0332)	0.00999 (0.0308)
Married	-0.238 (0.225)	0.641* (0.347)
Education	0.166 (0.167)	0.224 (0.204)
Fertilizer (kg/ha)	0.000105 (0.000433)	0.000156 (0.000691)
Cultivated land size (ha)	0.378*** (0.0679)	0.584*** (0.119)
FBO	0.394* (0.212)	-0.279 (0.278)
Credit_acces	0.398** (0.185)	-0.242 (0.228)
access_market	0.0790 (0.199)	0.198 (0.271)
Extension services	0.578** (0.270)	-0.344 (0.913)
Constant	4.019*** (1.197)	6.226*** (1.305)
rho_0	- 0.330 (0.363)	
rho_1	0.769 (0.441)*	
Log vraisemblance : -174.483	Wald chi2(12) =58.35	Prob > chi2 = 0.0000
Test Wald indep. Eqns :	chi2(1) = 114.90	Prob > chi2 = 0.000

Note: Significance: * = 10%, **= 5%, *** = 1%. Standard errors in parentheses.

The expected production under actual and counterfactual conditions is presented in Table 13. Cells (a) and (b) represent the expected production outcomes observed under the real conditions, and (c) and

(d) correspond to the counterfactuals. The production for participants in irrigation (a) is 7.10, and that of nonparticipants (b) is 6.96. The difference between the two groups is 0.14. However, this difference cannot be attributed solely to participation in irrigation. The last column of Table 13 presents the effects of participation in the irrigation system on production. In counterfactual case (c), production would decrease by 0.44 if producers did not use the irrigation system. Conversely, in counterfactual case (d), nonparticipants would decrease their production by 0.68 if they adopted the irrigation system. The last column presents the effects of irrigation treatment on production. The results show that participation in irrigation increases rice yield.

The transient heterogeneity effect is positive, indicating that the effect of irrigation on rice production is significantly higher for farmers who participate in irrigation than for those who do not. This result supports the implementation of policies to facilitate infrastructure access in the case of irrigation. The last row of Table 13, which considers the potential heterogeneity effect in the sample, reveals that farmers participating in the irrigation system would have a higher rice yield than those who do not in counterfactual cases (c) and (d). We conclude that there are important heterogeneity factors that show advantages in favour of participants as opposed to nonparticipants.

Table 13: Conditional Results, Treatment Effects, and Heterogeneity of the impact of irrigation on rice production (kg)

Sub-groups	Decision stage		Treatment effects
	Beneficiaries	Non Beneficiaries	
Beneficiaries	(a) 7.10 (0.0671)	(c) 6.66 (0.0902)	TT = 0.44 (0.1124) ***
Non beneficiaries	(d) 6.28 (0.0277)	(b) 6.96 (0.0304)	TU = - 0.68 (0.0490) ***
Heterogeneity effects	BH_1 0.82 (0,0642)***	BH_2 -0.30 (0.0810)***	TH = 1.12 (0.0452)***

Note: Significance: * = 10%, **= 5%, *** = 1%. Standard errors in parentheses.

7. CONCLUSION AND POLICY IMPLICATION

Irrigation remains a crucial factor in enhancing rice yields in the face of climate change, which is affecting water availability. The production of sufficient rice is both an indicator of food security and an improved nutritional status. This study investigated the effect of irrigation on the nutritional status of rice-producing households in Côte d'Ivoire, particularly in the M'Bahiakro department, a region formerly known for its cocoa production. In this work, we first show whether there is a difference in the Dietary Diversity Scores (HDDS) of producers who use irrigation and those who do not. The results indicate a significant and positive difference in favour of the irrigation participants.

Second, the analysis focused on the determinants that favour participation in irrigation. The main determinants are education, training, extension services, membership in a cooperative or economic interest group, credit access, and off-farm activities. Third, we analysed the impact of irrigation on the nutritional status of households using dietary diversity as a proxy. An analysis assessed the conditional (real and counterfactual), treatment, and heterogeneity effects. The results reveal that participation in the irrigation system does not affect dietary diversity. The counterfactual results are negative. This observation implies that the irrigation system has still not had positive effects on practitioners, as demonstrated in works such as the study carried out in Tanzania by Passarelli (2018). However, the transient heterogeneity is positive. Such results mean that the effect of irrigation on nutritional outcomes is significantly higher for farmers who participated in irrigation than for those who did not.

Fourth, the paper also analyzes the impact of the irrigation system on rice production, presenting conditional expected and observed results (real and counterfactual), as well as treatment and heterogeneity effects. The results reveal a positive and significant contribution of the irrigation system to rice production for the participants. However, the counterfactual results are negative, implying that the irrigation system does not have ot positive effects on users. However, the transient heterogeneity is positive, implying that the effect of irrigation on rice production is significantly higher for farmers who actually participated in irrigation than for those who did not.

The last analysis concerns the impact of irrigation on household income. The results show a positive and significant contribution of the irrigation system to household income for the participants. Hence, the irrigation system has positive effects on users. This result is consistent with those who found that irrigation increases household income.

Our results underscore the importance of irrigation in enhancing rice production and the income of farmers participating in the irrigation system. Nevertheless, irrigation does not affect the dietary diversity score of these rice-farming households. One of the primary objectives of irrigation, which is to increase production, is achieved. However, the impact of irrigation on the Dietary Diversity Score of households benefiting from the irrigation system is not significant. This low significance raises questions about the mechanism used to achieve this objective. The use of a single crop may not be sufficient to achieve this objective. It is imperative to implement the second component of the programme, which involves cultivating vegetable crops with high yield potential and adequate nutritional value. The implementation of this component will not only diversify the diet but also the sources of income. Furthermore, participants in the irrigation system must be sufficiently involved in the entire process. Similarly, the involvement of a firm in the implementation of the activities must be through a formal contract between the participants and the firm that defines the roles of each party, particularly regarding the distribution and role (consumption or sale) of the production.

Policy makers should consider irrigated rice as a strategic sector capable of reducing food insecurity because of its two-cycle production potential and its nutritional values. It is also a source of income and, therefore, a factor of poverty alleviation.

REFERENCES

Abdulai Awudu and Huffman Wallace (2014). The Adoption and Impact of Soil and Water Conservation Technology: An Endogenous Switching Regression Application. in *Land Economics* February 2014 DOI: 10.3368/le.90.1.26.

Abdulai, A.; Owusu, V.; Bakang, J.A. Adoption of safer irrigation technologies and cropping patterns: Evidence from Southern Ghana. Ecol. Econ. **2011**, 70, 1415–1423. [CrossRef]

Adeoti, A. I. (2009). Factors Influencing Irrigation Technology Adoption and its Impact on Household Poverty in Ghana. *Journal of Agriculture and Rural Development in the Tropics and Subtropics* Volume 109, No. 1, 2009, pages 51–63

Agbo Adouko Edith, Kouamé Christophe, N'Doua N'Doua Denos, Kouassi Allegra, and Brou Kouakou (2017). Assessment of Cocoa Producers' Children Nutritional Status in the Nawa Region, Côte d'Ivoire. *Journal of Food and Nutrition Research*, vol. 5, no. 8 (2017): 606-613. doi: 10.12691/jfnr-5-8-11.

Alaofè, H., Burney, J., Naylor, R. and Taren, D. (2016). Solar-powered drip irrigation impacts on crops production diversity and dietary diversity in northern Benin, *Food Nutr. Bull*. 37, 164–175

Alene, A. D. Manyong·V. M. (2007). The effects of education on agricultural productivity under traditional and improved technology in northern Nigeria: an endogenous switching regression analysis.

Al-Hassan, R. M., Egyir, I. S. & Abakah, J. (2013). Farm household level impacts of information communication technology (ICT)-based agricultural market information in Ghana, *Journal of Development and Agricultural Economics, 5* (4), 161-167.

Anang, B. T. (2017). Effect of non-farm work on agricultural productivity: Empirical evidence from northern Ghana. Working Paper ·

Asfaw, S., Kassie, M., Simtowe, F., Lipper, L., (2012). Poverty reduction effects of agricultural technology adoption: a micro-evidence from rural Tanzania. *Journal of Development Studies*. 48 (9), 1288–1305.

Azumah, S. B., Zakaria A. (2019). Fertilizer Subsidy and Rice Productivity in Ghana: A Microeconomic Study. *Journal of Agricultural Studies* ISSN 2166-0379 2019, Vol. 7, No. 1

Banque Mondiale (2014). World Development Indicator (WDI), Côte d'Ivoire, 2014.

Bagheri, A., and Ghorbani, A. (2011). Adoption and non-adoption of sprinkler irrigation technology in Ardabil Province of Iran. *African Journal of Agricultural Research* Vol. 6(5), pp. 1085-1089, 4 March, 2011 Available online at http://www.academicjournals.org/AJAR DOI: 10.5897/AJAR09.380

Bliss, C. and Stern, N. (1978). Productivity, wages and nutrition: 1. The theory; 2. Some observations, *Journal of Development Economic*, 5, 363-98.

Burney Jennifer et al. (2010). The case for distributed irrigation as a development priority in sub-Saharan Africa. *Proceedings of the National Academy of Sciences* 110(31).

Carletto Gero, Marie Ruel, Paul Winters and Alberto Zezza (2015). Farm-Level Pathways to Improved Nutritional Status: Introduction to the Special Issue, *The Journal of Development Studies*, 51:8, 945-957 http://dx.doi.org/10.1080/00220388.2015.1018908.

Chaudhari et al. (2018). Rice nutritional and medicinal properties: A review article. *Journal of Pharmacognosy and Phytochemistry* 2018; 7(2): 150-156.

Chuchird, R.; Sasaki, N. and Abe, I. (2017). Influencing Factors of the Adoption of Agricultural Irrigation Technologies and the Economic Returns: A Case Study in Chaiyaphum Province, Thailand. *Sustainability* 2017, 9, 1524; doi:10.3390/su9091524.

Conseil National de Nutrition (CNN) (2015). Politique Nationale de Nutrition

Coates, Jennifer, and Daniel Maxwell (2012). Reaching for the Stars?: Universal Measures Of Household Food Security. UN FAO International Scientific Symposium on Food Security and Nutrition Measurement, Rome, February 2012.

Coates, Jennifer, Beatrice L. Rogers, Patrick Webb, Daniel Maxwell, Robert Houser, and Christine McDonald. (2007). Diet Diversity Study. Final report to the World Food Programme. Medford, MA: Friedman School of Nutrition Science and Policy, Tufts University.

Di Falco, S., Veronesi, M. and Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American Journal of Agricultural Economics,* 93(3), 829-846.

Dillon Andrew (2011). Do Differences in the Scale of Irrigation Projects Generate Different Impacts on Poverty and Production? *Journal of Agricultural Economics*, Vol. 62, No. 2, 2011, 474–492 doi:10.1111/j.1477-9552.2010.00276.x

Domènech, L. (2015). Improving irrigation access to combat food insecurity and undernutrition: A review. *Global Food Security*, 6, 24–33. https://doi.org/10.1016/j.gfs.2015.09.001.

Ducroquet, H., Tillie, P., Louhichi, K. et Gomez-Y-Paloma, S. (2017). L'agriculture de la Côte d'Ivoire à la loupe: Etats des lieux des filières de production végétales et animales et revue des politiques agricoles. EUR 28754 FR, doi: 10.2760/126254

Early Childhood Matters and Bernard Van Leer Foundation (2019). Advances in early childhood development

Escobal, J. A., and Cavero, D. (2012). Transaction costs, institutional arrangements and inequality outcomes: Potato marketing by small producers in rural Peru. *World Development*, 40, 329–341.

FANTA (2006). Developing and Validating Simple Indicators of Dietary Quality and Energy Intake of Infants and Young Children in Developing Countries: Summary of findings from analysis of 10 data sets. Working Group on Infant and Young Child Feeding Indicators. Food and Nutrition Technical Assistance (FANTA) Project, Academy for Educational Development (AED), Washington, D.C.

FAO, IFAD, UNICEF, WFP & WHO (2025). The State of Food Security and Nutrition in the World 2025 –. Addressing high food price inflation for food security and nutrition. Rome.

FAO, FIDA, OMS, PAM et UNICEF (2018). L'État de la sécurité alimentaire et de la nutrition dans le monde 2018. Renforcer la résilience face aux changements climatiques pour la sécurité alimentaire et la nutrition. Rome, FAO)

FAO (2017). Information and Communication Technology (ICT) in Agriculture. A Report to the G20 Agricultural Deputies. Rome, 2017.

FAO (2013). Proceedings of the International Scientific Symposium on Food and Nutrition Security information: from Valid Measurement to Effective Decision Making. Rome, 17–19 January 2012. Rome: FAO.

FAO (2011). Guidelines for Measuring Household and Individual Dietary Diversity.

FAO (2010). Expert Consultation on Nutrition Indicators for Biodiversity 2. Food consumption. FAO. Rome, Italy (available at http://www.fao.org/infoods/ biodiversity/index_en.stm).

FAO (2003). Food energy –methods of analysis and conversion factors. Report of a technical workshop, Rome, 3-6 December 2002.

Fair Labor Association (2015). Situational assessment of women and youth farmers and family nutritional status in two cocoa producing communities in Côte d'Ivoire.

Gebrehiwot, K.G., Makina, D. and Woldu, T. (2017). The impact of micro-irrigation on households' welfare in the northern part of Ethiopia: an endogenous switching regression approach. *Studies in Agricultural Economics* 119 (2017) 160-167 https://doi.org/10.7896/j.1707

Getacher, T., Mesfin, A. and Gebre-Egziabher G.(2013). Adoption and impacts of an irrigation technology: Evidence from household level data in Tigray, Northern Ethiopia. *African Journal of Agricultural Research*. Vol. 8(38), pp. 4766-4772, 3 October, 2013 DOI:10.5897/AJAR2013.7014.

Hagos, F. et al. (2012). Agricultural water management and poverty in Ethiopia. Agricultural Economics 43 (2012) supplement 1–13.

He, X.; Cao, H.; Li, F. Econometric analysis of the determinants of adoption of rainwater harvesting and supplementary irrigation technology (RHSIT) in the semiarid Loess Plateau of China. Agric. Water Manag. **2007**, 89, 243–250. [CrossRef]

Heckman, J. J. (1979). Sample Selection Bias as a Specification Error ; Econometrica, Vol. 47, No. 1, pp. 153-161 Published by: *The Econometric Society Stable* URL: http://www.jstor.org/stable/

Hoddinott J & Yohannes Y (2002). Dietary Diversity as a Food Security Indicator. Washington, DC: Food and Nutrition Technical Assistance Project, Academy for Educational Development.

Huang L, et al. (2005). Cloning and identification of methionine synthase gene from Pichia pastoris. *Acta Biochim Biophys Sin (Shanghai)*37(6):371-8.

Hussain, I. and Wijerathna, D. (2004). Irrigation and Income-Poverty Alleviation: A Comparative Analysis of Irrigation Systems in Developing Asia; water Policy.

INS (2012). Evaluation de la Sécurité Alimentaire en Situation d'Urgence (ESASU) en Février 2012.

INS (2013). Evaluation de la Sécurité Alimentaire à l'Ouest (ESAO) en Novembre 2012 ; Enquête conjointe.

INS, FAO and PAM (2013). Enquête sur l'insécurité alimentaire et la vulnérabilité à l'ouest et au nord-ouest de la Côte d'Ivoire. Rapport final.

INS and ICF (2012). Enquête Démographique Et De Santé Et à Indicateurs Multiples De Côte d'Ivoire 2011-2012. Calverton, Maryland, USA: Institut National de la Statistique et ICF International.

Kenkhuis, MF (2016). Nutritional status among cocoa farming families and underlying causes in Côte d´Ivoire. *Global Alliance for Improved Nutrition* (GAIN).

Kennedy Gina, Terri Ballard and MarieClaude Dop (2011). Guidelines for Measuring Household and Individual Dietary Diversity

Kennedy, G., Berardo, A., Papavero, C.,Horjus P., Ballard T, Dop, M. C , Delbaere, J. and Brouwer,D. I. (2010). Proxy measures of household food consumption for food security assessment and surveillance: comparison of the household dietary diversity and food consumption scores. *Public Health Nutrition*: 13(12), 2010–2018. http://doi:10.1017/S136898001000145X

Kennedy, Eileen. (2002). Qualitative Measures of Food Insecurity and Hunger. Paper read at International Scientific Symposium on Measurement and Assessment of Food Deprivation and Undernutrition, 2002, Rome, Italy.

Katengeza, S. (2012). ICTS-Based Market Information Services, Operational Environment and Performance: The Case of Malawi Agricultural Commodity Exchange and Food and Nutrition Security Joint Task Force, *American International Journal of Social Science, 1* (2),34-43.

Lee, L.F. (1978). Unionism and Wage Rates: A Simultaneous Equations Model with Qualitative and Limited Dependent Variables. *International Economic Review* 19 (2), 415-433. https://doi.org/10.2307/2526310

Leibenstein, Harvey (1957). The Theory of Underdevelopment in Densely Populated Backward Area in Economic Backwardness and Economic Growth, ed Harvey Leibenstein. Wiley: New York.

Leroy, V. (1967). Effet de substitution, effet revenu, effet d'encaisse réelle : une présentation. *L'Actualité économique*, *43* (1), 19–38. https://doi.org/10.7202/1003305ar

Maddala, G. S. (1983). Limited-dependent and qualitative variables in economics. New York, NY: Cambridge University Press.

Masset, Edoardo, Lawrence Haddad, Alexander Cornelius, and Jairo Isaza-Castro (2012). Effectiveness of Agricultural Interventions that Aim to Improve Nutritional Status of Children: Systematic Review. *British Medical Journal* 344: d8222. https://Doi: 10.1136/bmj. d822

Masuki, K.; Mutabazi, K.; Mattee, A.; Tumbo, S.; Rwehumbiza, F.; Mowo, J. Factors influencing intensity of adoption of integrated water management innovation in the semi-arid areas of Northeastern Tanzania. Int. J. Environ. Eng. Nat. Resour. **2014**, 1, 227–234.

Maxwell, Daniel, Jennifer Coates, and Bapu Vaitla (2013). How Do Different Indicators of Household Food Security Compare? Empirical Evidence from Tigray. Feinstein International Center, Tufts University: Medford, USA.

Mazumdar, Deepak (1959). The Marginal Productivity Theory of Wages and Disguised Unemployment, *Review of Economic Studies* 26 (3) (1959), 190-197.

Mekonnen, D. K.; Choufani, J.; Bryan, E.; Abizari, A.; Ringler, C.; and Amikuzuno, J. (2019). Irrigation-nutrition linkages: Evidence from northern Ghana. IFPRI Discussion Paper 1887. Washington, DC: International Food Policy Research Institute (IFPRI). https://doi.org/10.2499/p15738coll2.133515

Ministère de l'agriculture Côte d'Ivoire, PAM et FAO (2012). Evaluation de la sécurité alimentaire en situation d'urgence : données de janvier et février 2012. Abidjan, Côte d'Ivoire.

Namara, R. E.; Sally, H. (Eds.) (2014). Proceedings of the Workshop on Irrigation in West Africa: Current Status and a View to the Future, Ouagadougou, Burkina Faso, December 1-2, 2010. Colombo, Sri Lanka: *International Water Management Institute* (IWMI). 373p. doi:10.5337/2014.218).

Narayanan Sudha (2014). Profits from participation in high value agriculture: Evidence of heterogeneous benefits in contract farming schemes in Southern India. *Food Policy* 44 (2014) 142–157.

Njelekela, C.; Sanga, C. (2015): Contribution of information and communication technology in improving access to market information among smallholder farmers: The case study of Kilosa District, The International Journal of Management Science and Information Technology (IJMSIT), ISSN 1923-0273, NAISIT Publishers, Toronto, Iss. 17, pp. 56-71.

Nkhata, R., C. Jumbe, and M. Mwabumba (2014). Does irrigation have an impact on food security and poverty? Evidence from Bwanje Valley Irrigation Scheme in Malawi. Malawi Strategy Support Program. Working Paper no. 4. Lilongwe: International Food Policy Research Institute.

Nonvide, G M A (2017). Effect of Adoption of Irrigation on Rice Yield in the Municipality of Malanville, Benin. *African Development Review*, Vol. 29, No. S2, 2017, 109–120

Noora Shrestha (2020). Detecting Multicollinearity in Regression Analysis. *American Journal of Applied Mathematics and Statistics*, vol. 8, no. 2 (2020): 39-42. doi: 10.12691/ajams-8-2-1.

Norton, G W. Alwang, J. Masters W A. (2010). Economics of Agricultural Development: world food systems and resource use. Second edition 2010 by Routledge.

Nzonzo, D. et Mogambi, H. (2016). An Analysis of Communication and Information Communication Technologies Adoption in Irrigated Rice Production in Kenya. *International Journal of Education and Research* Vol. 4 No. 12 December 2016.

Panahi, F.; Malek-Mohammadi, I.; Chizari, M.; Samani, J. The role of optimizing agricultural water resource management to livelihood poverty abolition in rural Iran. Aust. J. Basic Appl. Sci. **2009**, 3, 3841–3849.

Pandey, V. L., Dev, S.M, Jayachandran, U. (2016). Impact of agricultural interventions on the nutritional status in South Asia: A review. *Food policy* 62 (2016) 28–40. http://dx.doi.org/10.1016/j.foodpol.2016.05.002

Parent Gérard, Jean-Noël Poda, Noël-Marie Zagré, Renaud de Plaen, Georges Courade (2002). Irrigation, santé et sécurité alimentaire en Afrique quels liens? *Cahiers Agricultures* 2002 ; 11 : 9- 15.

Passarelli, S., Dawit Mekonnen, D., Bryan, E., Ringler, C. (2018). Evaluating the pathways from small-scale irrigation to dietary diversity: evidence from Ethiopia and Tanzania. *Food Security* (2018) 10:981–997. https://doi.org/10.1007/s12571-018-0812-5

Plan National de Développement de la Côte d'Ivoire (PND, 2012-2015).

Plan National de Développement de la Côte d'Ivoire (2016-2020). Plan National Multisectoriel de Nutrition 2016 – 2020.

PNIA/SARA (2014). Programme National d'Investissement agricole, fiches filières 2014. Documents préparés pour être diffusés au moment du SARA 2015 et disponibles sur le site : http://sara.ci/wp-content/uploads/2014/10/PNIA_fiches-fili%C3%A8res.pdf

Pufahl Andrea and Weiss Christoph (2009). Evaluating the effects of farm programmes: results from propensity score matching; *European Review of Agricultural Economics*, 2009, vol. 36, issue 1, 79-101.

Salazar, L., Aramburu, J., González-Flores, M. and Winters, P. (2015). Food security and productivity: impacts of technology adoption in small subsistence farmers in Bolivia / p. cm. — (IDB Working Paper Series; 567).

Sinyolo Sikhulumile et al. (2014). Water security and rural household food security: Empirical evidence from the Mzinyathi district in South Africa;PLAAS (Institute for Poverty,Land and Agrarian Studies).

Stern, E., Stame, N., Mayne, J., Forss, K., Davies, R., & Befani, B. (2012). Broadening the Range of Designs and Methods for Impact Evaluations. DFID Working Paper 38. UK Department for International Development.

Stiglitz, Joseph (1976). The Efficiency Wage Hypothesis, Surplus Labor, and the Distribution of Income in LDCs, Oxford Economic Papers, New Series 28 (2) (1976), 185-207.

Swindale A. & Bilinsky, P. (2006). Household dietary diversity score (HDDS) for measurement of household food access: indicator guide, Version 2. Food and Nutrition Technical Assistance Project, Academy for Educational Development, Washington, D.C.

Ravallion, Martin (2009b). Evaluation in the Practice of Development, World Bank Research Observer 24(1): 29-54.

Regassa Abdi Etafa (2015). Determinants of agro pastoralists' participation in irrigation scheme: the case of Fentalle Agro Pastoral District, Oromia regional state, Ethiopia. Int. J. Agril. Res. Innov. & Tech. 5 (2): 44-50, December, 2015.

Tahmeed A.; Muttaquina H.; Kazi I. S. (2012). Global Burden of Maternal and Child Undernutrition and Micronutrient Deficiencies. *Annals of Nutrition and Metabolism,* 61(s1), 8–17.

Tano O., Konan E.Y., Alimata J.D., Donnen P., Dramaix M., Kouamé K. and Dagnan N. S. (2010). Malnutrition chronique chez les enfants de moins de cinq ans au nord de la Côte d'Ivoire. Santé publique 2010, volume 22, n° 2, pp. 213-220.

Tefera, Eshetu and Cho, Young-Bohk (2017). Contribution of Small Scale Irrigation to Households' Income and Food Security: Evidence from Ketar Irrigation Scheme, Arsi Zone, Oromiya Region, Ethiopia. *African Journal of Business Management.* Vol. 11(3), pp. 57-68, 14 February, 2017 DOI: 10.5897/AJBM2016.8175.

Van Den Berg Marrit and Ruben Ruerd (2006). Small-Scale irrigation and income distribution in Ethiopia; *Journal of development studies*,vol. 42, 2006-issue 5.Pages 868-880 |https://doi.org/10.1080/00220380600742142

Weismann, Doris, John Hoddinott, Noora-Lisa Aberman, and Marie T. Ruel (2006). Review and Validation of Dietary Diversity, Food Frequency and Other Proxy Indicators of Household Food Security. Washington, D.C.: *International Food Policy Research Institute*.

Wheeler Sarah Ann, Alec Zuo, Henning Bjornlund, Makarius Victor Mdemu, Andre van Rooyen & Paiva Munguambe (2016). An overview of extension use in irrigated agriculture and case studies in south-eastern Africa, *International Journal of Water Resources Development*, DOI: 10.1080/07900627.2016.1225570

Young, Helen, and Jaspars, Susanne (2009). Review of Nutrition and Mortality Indicators for the Integrated Food Security Phase Classification (IPC): Reference Levels and Decision-making. Inter-Agency Standing Committee Nutrition Cluster.

Young, Helen, and Jaspars, Susanne (2006). The Meaning and Measurement of Acute Malnutrition in Emergencies: A Primer for Decision-Makers. HPN Network Paper 56.

Zahe Kyas, Méité Alassane, Ouattara H, Dally T, Kouame KG, et al. (2017). Diet, Nutritional Status and School Performance of Schoolchildren in the District of Abidjan: Case of Yopougon and Bingerville. *J Nutr Health Sci* 4(1): 102. doi: 10.15744/2393-9060.4.102.

ANNEXES

Annexe 1

Food groups used for HDDS calculation

A.	Cereals
B.	Roots and tubers
C.	Vegetables
D.	Fruits
E.	Meat, poultry, offal
F.	Eggs
G.	Fish and other seafood
H.	Pulses, legumes, nuts and seed
I.	Milk and milk products
J.	Oils and fats
K.	Sweets / honey
L.	Spices, condiments and beverages

Source : Food and Agriculture Organisation (2011)

Annexe 2
Endogeneity test on income and off-farm income

Endogenous test on income

VARIABLES	(1) Model 1	(2) Model 2
Sex	2.549	110,838*
	(2.947)	(62,469)
Age	0.0257	8,523
	(0.0728)	(12,531)
age²		-75.82
		(127.2)
Size-Households	0.147	17,176
	(0.346)	(13,804)
Marital-status	4.395*	27,461
	(2.608)	(95,606)
Experience		-308.5
		(6,718)
Supervision	0.214	501,251**
	(4.784)	(231,702)
Uneducated		-147,024
		(169,194)
Secondary education		-196,720
		(189,335)
Primary education		-77,389
		(180,965)
Nationality		-367,739***
		(122,008)
res_revenue		**-602.1**
		(1,553)
Rice production	-0.00105**	
	(0.000422)	
Rice -Revenue	3.23e-06***	
	(8.85e-07)	
Literate	0.689	
	(2.010)	
Origin	2.616	
	(2.472)	
Participation	6.404**	
	(2.559)	
Constant	43.76***	218,688
	(5.252)	(348,277)
Observations	329	329
R-squared	0.048	0.073

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Endogenous test on off-farm income

VARIABLES	(1) Model 1	(2) Model 2
Sex	1.671	0.289*
	(2.884)	(0.166)
Age	0.00133	0.00436
	(0.0698)	(0.00382)
Marital-status	3.880	-0.0181
	(2.543)	(0.136)
Level of education		-0.100**
		(0.0470)
Origin	3.139	0.161
	(2.448)	(0.153)
Experience		0.000438
		(0.00589)
Participation	5.242**	0.0454
	(2.502)	(0.151)
Agni		-0.774***
		(0.290)
Baoulé		-0.127
		(0.261)
Malinké		-0.960***
		(0.233)
Christianism		-0.0686
		(0.139)
Islam		-0.0567
		(0.253)
literate	0.518	0.194*
	(1.961)	(0.116)
Coran school		0.00352
		(0.164)
Member of an association		-0.102
		(0.129)
Residdent		0.196
		(0.190)
Land-ownership		0.227
		(0.194)
res_revenue_nonagric		**0.00261**
		(0.00304)
Rice production	3.83e-05	
	(0.000255)	
Non agricultural revenue	2.32e-06***	
	(5.04e-07)	
Size-Households	0.120	
	(0.338)	
Supervision	1.177	
	(4.828)	
Constant	38.42***	14.19***
	(5.319)	(0.450)
Observations	329	308
R-squared	0.107	0.157

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Annexe 3 : : Descriptive analysis of the qualitative variables of the households in the study

Variables	Description	Coding	Participants (a)	Non-participants (b)	Difference of proportion (b-a)
Sex	Gender of producer	1= Male 0= Female	84.57 15.43	91.56 8.44	0.032
Training	Producer training	1 = Yes 0 = No	66.18 33.82	13.41 86.59	-0.52***
Instruction	Level of education of the producer : 1= No level 2= Primary 3= Secondary	None 1 = Yes 0 = No	42.65 57.35	57.85 42.15	
		Primary 1= Yes 0 = No	41.18 58.82	27.20 72.80	-0.15
		Secondary 1= Yes 0= No	4.41 95.59	4.21 95.79	
Marital_status	Marital status of the producer	1 = Yes 0 = No	75 25	82.38 17.62	0.07
Extension services	Producer supervision	1 = Yes 0 = No	16.18 83.82	0.77 99.23	-0.15***
Improved seed	Quality of the seed used	1 = Yes 0 = No	54.41 45.59	67.43 32.57	0.13**
FBO	Farmer-Based Organization or member of an agricultural group or cooperative	1 = Yes 0 = No	64.71 35.29	16.48 83.52	-0.48***
Access_credit	Producer access to credit	1 = Yes 0 = No	8.82 91.18	7.66 92.34	0.003
water_access	Water access and management	1 = Yes 0 = No	61.76 38.24	11.11 88.89	-0.50***

Annexe 5: Test for multicollinearity

Variables	VIF	1/VIF
Training	1.36	0.732683
Household size	1.27	0.786581
FBO	1.24	0.807736
Married	1.16	0.859841
Extension services	1.16	0.862205
Credit access	1.15	0.866326
Market access	1.15	0.870989
Cultivated land rice	1.11	0.904824
Fertilizer	1.10	0.912943
Education	1.04	0.960320
Mobile phone	1.04	0.961768
Experience	1.03	0.967511
Sex	1.03	0.969525
Off-farm activities	1.02	0.981057
Mean VIF	1.13	

Annexe 6: Test for heteroskedasticity

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity

Ho: Constant variance

Variables: fitted values of participation

chi2(1) = 46.53

Prob > chi2 = 0.0000

Mission

To strengthen local capacity for conducting independent, rigorous inquiry into the problems facing the management of economies in sub-Saharan Africa.

The mission rests on two basic premises: that development is more likely to occur where there is sustained sound management of the economy, and that such management is more likely to happen where there is an active, well-informed group of locally based professional economists to conduct policy-relevant research.

Bringing Rigour and Evidence to Economic Policy Making in Africa

- Improve quality.
- Ensure Sustainability.
- Expand influence.

www.aercafrica.org

Learn More

www.facebook.com/aercafrica

www.instagram.com/aercafrica_official/

twitter.com/aercafrica

www.linkedin.com/school/aercafrica/

Contact Us
African Economic Research Consortium
Consortium pour la Recherche Economique en Afrique
Middle East Bank Towers,
3rd Floor, Jakaya Kikwete Road
Nairobi 00200, Kenya
Tel: +254 (0) 20 273 4150
communications@aercafrica.org