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Technical efficiency and constraints related to rice production in West Africa: The case of Benin Republic

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Abstract: Rice plays a major role in the fight against food insecurity in developing countries such as Benin. The objective of this research is to evaluate the determinants of technical efficiency, the factors influencing this efficiency, as well as the constraints related to rice production in Benin. The technical efficiency levels were obtained from the *Data Envelopment Analysis* (DEA) method and were regressed in a Tobit regression model to assess the determinants of the efficiency of rice producers. Production constraints were identified using Kendall's W concordance test and descriptive statistics. The technical efficiency rate obtained was 51%. Inferential analysis showed that parameters such as the age of the rice producer, household size, the amount of agricultural credit obtained, and the use of inputs impact the technical efficiency of rice production. In addition, most rice producers suffer from limited access to agricultural credit and adequate agricultural equipment, while their production is subject to climatic hazards. Agricultural development policies related to the determinants of the technical efficiency of rice production should be formulated in order to improve the efficiency of the producers in Benin Republic.

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PUBLIC INTEREST STATEMENT

Rice is one of the most consumed cereals in Benin, and its production makes it possible to actively fight against food insecurity. Although statistical data indicates a slight increase in production yields in recent years, the level of productivity of producers nevertheless remains very low and is falling drastically. In a context where the population of Benin is growing and rice production is strongly threatened by climatic variations, one wonders what will be the levels of production and the level of productivity of these farms by 2050. This study has identified the parameters on which it is necessary to act in order to optimize rice production. These main variables are related to access to agricultural credit, the use of the labor force and climatic parameters.Thus, it is important to define agricultural policies that will facilitate producers' access to agricultural credit and new technologies to reduce the impact of climate change on rice production in Benin.

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Subjects: Agricultural Development; Agricultural Economics; Agriculture and Food

Keywords: agricultural credit; food security; Food policy; staple food; subsidy; Tobit regression model

I. Introduction

Rice, on a global scale represents the third cereal produced after wheat and maize (Adégbola et al., 2014) and 20% of cereal consumption (Kouassi, 2019). Globally, it is one of the leading cereals for human consumption (Kinkpé et al., 2016). Constituted as one of the foodstuffs most consumed in the world, rice actively contributes to food security in Africa (Miassi et al., 2022; Ngom, 2016). As on other continents, rice plays an important role in household diets in Africa and represents a strategic product in the fight against food insecurity in the developing countries (Seck et al., 2013). However, in Africa, rice features as fourth in importance after millet, sorghum, and maize (MAEP, 2010).

In the sub-Saharan Africa, rice is counted among the fastest-growing food crops. Demand in the region is increasing by around six percent (6%) per year, but then the gap between demand and production also continues to grow (Mbétid-Bessane, 2014). The level of rice consumption is as high in Benin as in other countries of the sub-Saharan Africa (Todomé et al., 2018). Indeed, the agricultural sector in Benin, a West African country, is the primary source of wealth, contributing an average of 36% to the GDP (RNDH, 2015). Furthermore, rice production constitutes a portion of those sectors actively participating in the development of the Beninese economy (Nouatin et al., 2009).

In Benin, rice consumption and imports increased by 670% and 500% respectively between 1990 and 2010 (Demont et al., 2017). A low per capita consumption of 3 to 4 kg in the 1960s was reported by the National Strategy for the Development of Rice Production (SNDR) in 2011, and it gradually climbed to 12 kg in 2004 and between 25 and 30 kg in 2011. In 2017, reports indicated a per capita consumption of roughly 45.7 kg (PSDSA, 2017). But the expected amount of paddy rice produced in Benin in 2015 (234,145 tones) was much lower than the goal of 600,000 tones by that year (USDA, 2018). Since 2003, rice yield has been low (3 tones per hectare), even though, depending on the cultivars and production methods, a yield potential of roughly 4–10 tones per hectare can be reached (MAEP, 2009). On the other hand, these positive results cover only 23% of the national demand (Yabi et al., 2017). It is therefore imperative to develop agricultural policies to optimize the efficiency of producers for an improvement on the one hand in yields and on the other in the supply of rice (Kaboré, 2007). Moreover, national needs increased by 46.87% between 2001 and 2005, while the level of production increased by only 7.5% per year over the same period (ADRAO, 2007).

Thus, we deduce that the level of consumption is increasing faster than the level of production, while at the same time, the size of the Beninese population is also increasing. This population has increased from 6.8 million in 2000 to 11.4 million in 2018; i.e., a growth rate close to 100% (PRB, 2014). The projections made by PRB (2014) stipulate that the population of Benin could be estimated at around 15 million in 2030. There will, therefore, be very strong demographic pressure in respect of the demand for rice. Given the fact that cereals, including rice, and staple foods in Benin, there will be a significant demand for rice by 2030 (MAEP, 2010).

However, rice production is currently subjected to climate change, thus resulting in difficulties such as the effects of natural disasters, soil erosion and in accessing water (Ngom, 2016; Omotayo 2018). At the same time, producers also encounter difficulties related to accessing land suitable for rice production, an inadequate road infrastructure, declining soil fertility levels, and above all, a lack of agricultural inputs (Bessan et al., 2018; Nouatin et al., 2009). In general, the quantitative and qualitative needs of rice producers for inputs are still being poorly met (Demont et al., 2017).

Faced with these observed facts, it is therefore imperative to revitalize rice production systems so that they become technically efficient. According to Ngom (2016), rice production can be revitalized following

increase in production or by improving the efficiency levels of the inputs allocated to rice production. This revitalization of rice production systems should then be based on an evaluation of the models combining production factors (investment capital, labour, and land); identifying and then evaluating the determinants of technical efficiency in rice production, and subsequently acting upon them to improve the performance of the sector. In this study, technical efficiency measures the ability of a rice production unit to obtain the maximum possible output from a combination of production factors. Thus, efficiency is defined as the ability of the producer to produce the maximum quantity of rice with the minimum production factor. It is therefore to this end that this study aims on the one hand to analyze the economic performance, and on the other hand, to determine the factors influencing the technical efficiency of rice production in the northern Benin, specifically in the communes of Gogounou and Malanville. Based on parameters determining the efficiency of production, these factors will make it possible to better redirect the agricultural policies developed with a view to improving rice production in Benin.

II. Identification and evaluation of the determinants of technical efficiency

There is a panoply of scientific research that is part of the evaluation of the parameters determining the efficiency of agricultural operations. Work on the evaluation of technical efficiency is diversifying, but the results are generally dependent on the methodological approach (Bessan et al., 2018). Technical efficiency is a relevant and precise instrument in the analysis of the technical performance of farms, especially those producing cereals (Rached et al., 2018). Technical efficiency measures the efficiency of the use of resources and factors of production. In other words, it is interested in the allocation of inputs involved in the production process of a given output. Several studies have shown that certain parameters have an impact on the level of efficiency of farms. These factors can be the level of education, the size of the farm, the age of the head of the household, membership of a producer group, and access to credit (Nuama, 2006). Methods for evaluating productive efficiency are based on the famous non-parametric approach to data envelopment, commonly known as the DEA (Data Envelopment Analysis) method, developed by Charnes et al. (1978). Several studies have focused on studying the technical efficiency of farms using the DEA (Data Envelopment Analysis) method (Bhatt & Bhat, 2014; Hayran & Gül, 2020; Heidari et al., 2011). It involves linear programming that allows for the construction of a production frontier without any restriction on the functional form. Audibert et al. (2003) assessed the impact of malaria on the technical efficiency of cotton producers in north of Ivory Coast using the Data Envelopment Analysis method. The efficiency indices from the DEA model were considered as the dependent variable in a Tobit model. This explained the malaria morbidity rate among cotton farmers and their families, as well as cultural behaviors and social cohesion. It appears from the results obtained that the density of parasitic infection has a negative impact, both directly and indirectly, on efficiency in cotton production.

Helfand and Levine (2004), also used the same method of analysis to study the determinants of technical efficiency, as well as the relationships between farm size and the technical efficiency of producers in Brazil. This study led to the conclusion that the socio-economic and demographic characteristics of the producers, in particular the mode of access to land, the size of the farms, access to the market, modern inputs, and extensions were the parameters exerting an influence on the efficiency of Brazilian producers. Like previous authors, Abatania et al. (2012) evaluated the technical efficiency of farms in Ghana using the DEA approach. According to their research, they concluded that the average technical efficiency of farms is 0.77. They showed that parameters such as the age and sex of the producer, as well as the geographical location of the farms, and the hired labour significantly affect the technical efficiency of the farms.

Furthermore, Ndiaye (2018),also used the Data Envelopment Analysis technique to determine the degrees of technical efficiency of farms in Mauritius. Subsequently, the author used a Tobit regression model to identify the parameters influencing the technical efficiency of farms. The author concluded that the average technical efficiency of farms wass 0.726. In addition, the technical efficiency of farms is influenced by parameters such as the gender of the farm manager and the cultivated area. Ndiaye (2018) advocates that policies should be undertaken to improve

the formal education of producers, strengthen the capacities of their organizations, as well as their access to agricultural inputs and agricultural land.

The technical efficiency of the "rice-wheat" association was also evaluated by Javed et al. (2010) in Pakistan. These authors applied the DEA and Tobit analysis models. According to the results of this study, the average technical efficiency of farms is 32% and the quantities of inputs could be reduced by 17% without inducing a decline in the level of production. The age of the producers, the size of the farms, and the distances separating the fields from the places of sale of the harvested products have a positive impact on the technical efficiency of the producers. Rios and Shively (2005) measured the sizes and efficiency of coffee farms in Vietnam using a two-step approach (the DEA approach followed by regression analysis). According to these authors, large farms are technically and economically more efficient than small farms.

Chiona (2011), like Rios and Shively (2005), evaluated the technical efficiency levels of Zambian maize smallholders using the DEA method and an Ordinary Least Square (OLS) regression equation. According to his research results, the use of fertilizers, the mechanized tillage method, the use of certified seeds, participation in agricultural activities, and the formal education of the producer have a positive impact on technical efficiency. The DEA method is not the only approach used to determine the technical efficiency of a farm; it can also be conducted via the stochastic approach. The stochastic approach was initiated by Aigner et al. (1977). In some research studies, such as those of Ngom (2016), Kpenavoun Chogou et al. (2018), and Konan et al. (2014), the technical efficiency of farms has been evaluated by using the stochastic function of the Cobb-Douglas type.

The research results of Ngom (2016) state that the technical efficiency of rice producers in Senegal varies from 14 to 100%, with an average of 70%. An evaluation of the determinants of this level of efficiency was made from the stochastic function of the Cobb-Douglas type that showed that the area to which the producer belongs, his/her ethnicity and gender, the size of the household, the level of education, the distance between the farm and the home, and the number of plots owned by the producer have a significant impact on his/her efficiency. Kpenavoun Chogou et al. (2018) evaluated the financial performance and technical efficiency of rice seed production in southern Benin. This study led to the conclusion that rice seed production is a financially profitable activity. According to their research results, the production of rice seeds generates a net margin of 846,289 CFA francs/ha for seed companies of limited technical efficiency and 1,017,606 CFA francs/ha. for those who are highly technically efficient.

More so, Konan et al. (2014), in part of their analysis of the reactions of upland rice producers to Striga hermonthica infestations, used the stochastic frontier analysis method with the Cobb-Douglas production function. The efficiency indices were subsequently introduced into a Tobit model to identify the parameters that affect the efficiency of rice producers in Côte d'Ivoire. It emerged from the analysis of the data that the efficiency indices vary between 28.6% and 89.7%, with an average of 70.9%, and that Striga hermonthica exerts a negative influence on the distribution of efficacy indices.

In the same vein, Coulibaly et al. (2017) evaluated the parameters determining the technical efficiency of rice farmers in the Office du Niger region. At the end of their study, they concluded that parameters such as experience as a producer, agricultural equipment, membership of a armers' organization, and land rental statistically determine the technical efficiency of rice farmers in the Office du Niger region. According to their research results, the average technical efficiency score for a farm is 0.66. The Cobb-Douglas type stochastic frontier production function was used by Kpenavoun Chogou et al. (2017) to estimate the level of technical efficiency of pineapple producers in Benin. Subsequently, from the maximum likelihood method, the parameters of the production frontiers were obtained. The results attained by these authors stipulate

that the popularization of technical information is parameter determining the efficiency of producers.

III. Methodological approach

III.I. Study area

This study was carried out in Benin, which, with a population of approximately 12 million inhabitants, covers an area of 112,620 km^2 (Figure 1). It is bounded to the northeast by Niger, to the south by the Atlantic Ocean, to the east by Nigeria, and to the west by Togo (INSAE, 2019). This research took place in the communes of Gogounou and Malanville. These communes were specifically selected because of their significant contribution to national rice production (Kinhou, 2019; MAEP, 2010; Yabi et al., 2012; Yabi, 2009). Moreover, in Benin, these provinces are production areas par excellence. The monograph studies conducted by Bani (2006) and INSAE (2009) also made it possible to present the characteristics of these communes.

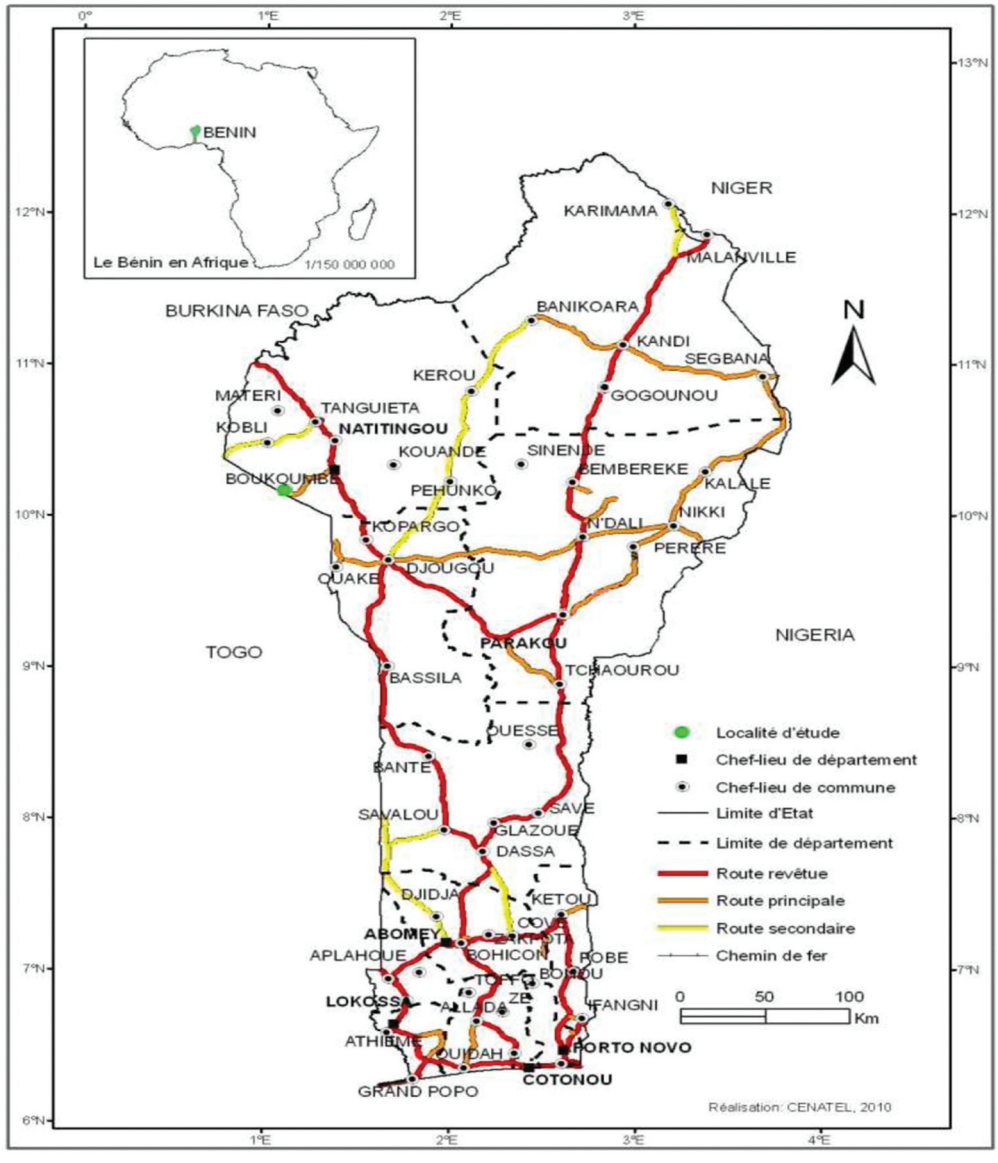


Figure 1. Geographical location of the selected communities in Benin republic.

The Municipality of Gogounou is located at the southern entrance to the Department of Alibori and lies between 10°33“and 10°57” North latitude and 2°15“and 3°15” East longitude. It covers an area of 4,910 km^2; which represents 18.66% of the area of the entire Department of Alibori (26,303 km^2). The climate, of the Sudano-Guinean type, is marked by a rainy season from May to October and a dry season with the harmattan blowing from November to April. The average annual precipitation is 1,100 mm. The months with the highest rainfall are August and September, with a maximum in August. The temperature fluctuates between 18°C and 38°C, the latter being the case especially in the dry season. The relief is essentially made up of plains and plateaus, surmounted in places by hills reaching maximum heights of around 300 m.

The soils are those of the granito-gneissic basement type, mostly ferruginous and generally suitable for agriculture. In the alluvial plains, the alluvial, clayey-sandy soils are quite rich owing to the contribution of organic matter deposited by the annual flooding of the rivers. The cultivable area is estimated at 1,705 km^2, or about 35% of the total area (4,910 km^2). The town is fed by two major rivers and their tributaries belong to the Niger River basin. These are the Sota and the Alibori, located to the east and west, respectively. Agriculture is the most important economic activity in the commune of Gogounou. Cotton, rice and peanuts are the main cash crops. Besides agriculture, the inhabitants undertake other activities such as trading, crafts, tourism and transportation.

The commune of Malanville is in the far north of the Republic of Benin. It extends between 11.5° and 12° latitudes from north to south over 50 km and from east to west over 60 km. The municipality of Malanville is bordered to the north by the Republic of Niger; to the south, by the municipalities of Kandi and Ségbana; to the west, by the municipality of Karimama; And to the east, by the Federal Republic of Nigeria. It covers an area of 3,016 km^2, including 8,000 ha. of arable land. The climate of the commune of Malanville, of the Sudano-Sahelian type, is marked by a dry season from November to April. The average rainfall recorded over the last five (05) years is 750 mm. The relief of the commune of Malanville is made up of plains and valleys set between the Niger River, and a few plateaus and hills of ferruginous sandstone.

The city is built on a sandy site that is inundated in places during floods. The soils on the territory of the commune of Malanville are mostly of the gneissic type, but in the Niger valley and its tributaries, the sandy clayey soils are ferruginous. Some gritty skeletal soils and raw minerals on cuirass are found in pockets on the territory of the commune. The commune of Malanville is crossed in its breadth (east—west), by the Niger River with its tributaries, the Alibori, the Mékrou, and the Sota, which are in flood during the months of August and September. The Niger River encompasses exploitable lowlands, 300 ha. of which have already been developed. The town experiences cyclical flooding owing to torrential rains. Agriculture is the main source of income for the town. Agricultural activity in the city is limited to the rice-growing area that surrounds the city, particularly to the north, on the right bank of the Niger. The rice-growing area covers more than 500 ha. As in the commune of Gogounou, some inhabitants undertake other activities, including trading, crafts, tourism and transportation.

III.II. Sampling and data collected

Data recorded by the Ministry of Agriculture, Livestock, and Fisheries (MAEP) of Benin in 2018 indicate that the communes of Malanville and Gogounou have nearly 8,500 producers. A simple random sampling technique was used to give farmers an equal chance of being selected. An updated list of producers was obtained from the groups of rice producers in the study area. Each producer was assigned a number and then the selection was made randomly in Excel. This method makes it possible to obtain the most appropriate sample size for this type of study (Karagölge & Peker, 2002). The following formula was used to calculate the sample size (Yamane, 1967):

$$n = \frac{N.\Sigma\left(Nh.Sh^2\right)}{N^2.D^2 + \Sigma\left(Nh.Sh^2\right)} \quad (1)$$

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Where:

n: sample size,

N: number of units in the population,

Nh: the number of units in layer h,

Sh^2 : the variance of the layer h,

$D^2 = (d^2/z^2)$,

where,

d: the maximum margin of error that can be accepted or the difference between the sample mean and the population mean,

z: the corresponding value of z in the standard normal distribution table according to the margin of error.

Sampling was performed within the 95% confidence limit. Thus, to achieve the objectives of the research, the data collected were related to the inputs and outputs of production. In other words, information related to production revenue, the acquisition of agricultural inputs (the cost of fertilizers, pesticides, herbicides, labour, etc.), and all other expenses related to production were collected. Data in respect of the links with rice production also made it possible to analyze the level of efficiency of the farms. These data also made it possible at the same time to identify and then evaluate the parameters determining the technical efficiency of the rice producers. To these data were added the socio-economic and demographic characteristics of the producers, as well as the constraints they face in the production process. Primary data were obtained from a survey of 200 rice farmers in the provinces of Benin.

III.III. Analysis methods and tools

To identify the level of efficiency of farms, the DEA model called *Data Envelopment Analysis* was used. This approach was used by Bessan et al. (2018) to analyze the productive efficiency of rice production in central Benin.

Data Envelopment Analysis (DEA) is an analytical tool that helps to identify the best approaches to combining production factors in order to optimize yield. Identifying these factor-combination approaches highlights possible improvements in the efficiency of rice production. This analytical approach is also useful because it considers returns to scale in the calculation of efficiency and highlights the concept of increasing or decreasing efficiency with size and production levels. However, the Cobb-Douglas (CD) function imposes an arbitrary level for the possibilities of substitution between inputs.

The technical efficiency of a farm is defined by the following formula:

$$TE_k = \frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}} \quad (2)$$

Where:

TE_k is the technical efficiency of the farm “k” using “m” inputs to produce “s” outputs;

Y_{rk} is the amount of rice “r” produced by farm “k”;

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X_{ik} is the quantity of input "'i'consumed by farm'k'";

U_r is the weight of the output "'r'";

Y_i is the weight of the input "'i'";

"s" is the number of outputs;

"m" is the number of inputs.

In the DEA model, the amount of rice harvested by the farmer was used as the output. The inputs considered were the quantities of fertilizer (in Kg), pesticide (in liter), seed (in Kg) and the labor force (in man-days) used for rice production. Based on the work of Ndiaye (2018), then Audibert et al. (2003), once the levels of technical efficiency for each of the farms had been determined and regressed in a Tobit model to obtain the determinants for the technical efficiency of rice production in northern Benin. In other words, the levels of technical efficiency determined from the DEA model for each of the producers were considered as the dependent variable in the Tobit regression model which made it possible then to identify the determinants of technical efficiency. The choice of this model was based on the studies of Choukou et al. (2017), who applied it to analyse the variables to explain the efficiencies, this according to the character of the dependent variables (efficiencies) which are presented as relative frequencies and can also be censored. Another factor influencing the Tobit model as a satisfactory choice was the truncated nature of the efficiency indices which are between 0 and 1 (Greene, 1980), and which provide a better approximation of the model (Choukou et al., 2017). According to Konan et al. (2014), the general double censoring model reads as follows:

$$y_i = \begin{cases} C_{1i} \text{if} y_{i*} \leq C_{1i} \\ y_i * \; if \; C_{1i} > y_{i*} \leq C_{2i} \\ C_{2i} \text{if} > C_{2i} \end{cases} \tag{3}$$

where

- C_{1i} and C_{2i} are the lower and upper limits of the technical efficiencies; and

- y_i* is the efficiency index of the i^{th} rice farmer.

This model makes it possible to assess the determining factors of farm efficiency.

The Tobit model can be written as follows:

$$\begin{aligned} Y &= X\beta + \mu_i \text{ if } X\,\beta > \mu_i, 0 \; if \; X\,\beta = \mu_i \\ Y &= Y_{*,} \text{ if } Y* > 0 \\ &= 0 \text{ if } Y* \leq 0 \end{aligned} \tag{4}$$

In the equation,

Y represents the value that the continuous latent variable can take for the efficiency of farmer *i*,

X denotes the vector of the explanatory variable,

β represents the vector of maximum likelihood estimates in the Tobit model, and

μ denotes the random error term (independently distributed with a mean of 0).

By introducing the explanatory variables of the efficiencies, the model can be written as follows:

$$Y = \beta_0 + \beta_1 AGE + \beta_2 EXP + \beta_3 HOUSEHOLDSZ + \beta_4 AGRIASS + \beta_5 GROUP + \beta_6 CREDT + \beta_7 ULABOR + \beta_8 CLABOR + \beta_9 CONSUM + \beta_{10} SEED + \beta_{11} FERTILIZER + \beta_{12} INSECTICIDE + \beta_{13} HERBICIDE + \beta_{14} Urea + \mu_i \quad (5)$$

where

Y= technical efficiency of farmers,

β_0= constant, and

μ= the random error term. The variables used in the Tobit model are described in Table 1.

There are several tools for analyzing production constraints in agriculture. In order of importance, the tools most used are Kendall's W concordance test, comparative description, and actor discourse analysis (Dossa, 2017). In this study, given that Kendall's W concordance test is the most relevant of the approaches according to Dossa (2017), these researchers decided to use it to prioritize the constraints related to rice production in North Benin.

Table 1. Description of the variables used in the Tobit model

Variables	Description	Abbreviation	Unit	Expected sign
Age	Age of the farmer	Age	Years	±
Years of Experience	Number of years of experience	Exp	Years	±
Household size	Number of family members	Household Sz	Number	±
Agricultural assets	Number of agricultural assets	Agri Ass	Number	+
Membership of a group	Whether the farmers belong to any group or not	Group	1= Yes 0= No	±
Credit amount	Amount of agricultural credit obtained	Credit	FCFA*	+
Use of labour	Whether or not farmers have access to an external labour force	U Labour	1= Yes 0= No	+
Cost of labour	Cost of labour used	C Labour	FCFA*	±
Intermediate consumption	Value of intermediate consumption	Consume	FCFA*	±
Quantity of seed	Quantity of seed used	Seed	Kg	+
Quantity of fertilizer	Quantity of fertilizer used	Fertilizer	Kg	+
Quantity of insecticide	Quantity of insecticide used	Insecticide	Liter	±
Amount of herbicide	Amount allocated for the acquisition of herbicide	Herbicide	Liter	±
Amount of urea	Amount allocated for the acquisition of urea	Urea	Kg	±

Note: * Franc of the Financial Community in Africa

Word software was used as the word processing software; Access software as the data processing software; and finally, SPSS V20 software and the DEAP (Data Envelopment Analysis Programming) programme were used as the analysis software.

IV. Results

IV.I. Socio-economic and demographic characteristics of producers

The socio-economic and demographic characteristics of the producers were presented according to the size of the areas sown by them (Table 2).

The following findings were made:

The average area sown by rice farmers is 2.7 hectares. Most producers (57.0%) seed areas of less than 0.75 hectares. In fact, very few producers manage to seed large areas. Only one percent (1%) of the producers manage to cover areas of 5.38 hectares. The average age of the rice farmers

Table 2. Socio-economic and demographic characteristics of producers

Variables	Groups	Total
Age	<= 28,00	43
	29,00–43,00	89
	44,00–58,00	57
	59,00+	11
Total		200
Sex	Women	46
	Men	154
Total		200
Number of years of schooling	<= 10,00	164
	11,00–17,50	21
	17,51+	15
Total		200
Number of years of experience	<= 10,00	67
	11,00–23,50	91
	23,51+	42
Total		200
Household size	<= 5,00	67
	6,00–16,00	104
	17,00+	29
Total		200
Agricultural workers	<= 5,00	98
	6,00–13,00	83
	14,00+	19
Total		200
Membership of a group	None	82
	Self-help group	26
	Production group	92
Total		200
Access to agricultural credit	No	164
	Yes	36
Total		200

surveyed is 38.7 years. Most producers, 45.3%, are aged between 29 and 43 years. The oldest producers are those farming the largest area (50.3 years on average). The youngest producers, on the other hand, are those farming the smallest areas (27.2 years on average). We could therefore deduce that as producers grow older, they increase their rice production area. Their experience, as well as the income accumulated over the years, are parameters that allow them to increase the areas that they sow.

There are many rice producers in North Benin. However, there are far more male producers than female producers. The research sample was made up of 86.1% men *versus* 13.9% women. Because it is practised mainly by men and requires a large physical workforce, rice production in North Benin is, therefore, predominantly a male activity. On average, 80% of men compared to 20% of women own areas of less than 5,389 hectares. At the same time, land with an area of more than 5,389 square meters is mainly occupied by men. The average number of years of schooling for producers is 4.6 years. Most producers (71.9%) are not educated or are at a level equivalent to the primary level; 23.5% have a secondary education level; and 4.6% have a university education. Producers who have received a university education are mostly young graduates who, at the end of their university studies, have decided to settle in rural areas to embark on rice production.

The average number of years of experience of rice farmers is 15.5 years. The most experienced producers are those sowing areas greater than 5,389 hectares. Rice farmers whose sown area is less than 0.750 hectares have an average of 2.8 years of experience; while those who sow on areas greater than 5,389 hectares have an average of 22.2 years of experience. The average household size of rice producers is nine people. Producers with the largest households are those who cultivate the largest areas. Rice-growing households with the area sown amounting to less than 0.750 hectares accommodate an average of seven people, while those sowing areas greater than 5,389 hectares accommodate an average of 12 people.

The average number of agricultural workers in the households of rice producers is seven people. The producers with the most agricultural assets in their household are those who sow the largest areas. Rice-farming households with a sown area smaller than 0.750 hectares have an average of six agricultural workers, while those sowing an area larger than 5,389 hectares accommodate an average of nine people. Some rice producers belong to groups or associations that allow them to better organize their agricultural activities and to better manage their sales. For this purpose, a distinction was made self-help groups and production groups. Those producers belonging to self-help groups represent 25.9% of the producers surveyed. These self-help groups allow producers to receive physical support from other producers in the group. This could be aid for the purposes of weeding, ploughing, harvesting, etc. In fact, it is a rotation system where all producers receive and provide support to other producers.

Producers belonging to production groups represented 30.7% of the sample. Production groups allow producers to better organize the sale of their harvested products. The rice harvested by the producers is collected and a wholesale transaction is organized by the group leaders, who have previously established partnership relations with processing companies, wholesalers, and semi-wholesalers. Producers belonging to production groups often benefit from the support of certain agricultural development programmes and projects through which the producers are trained in the use of new agricultural technologies. However, some producers (43.4%) do not belong to any of these groups.

Based on the statistical analysis carried out, it was found that 70.9% of producers do not use agricultural credit. This allowed the researchers to deduce that rice farmers may not have easy access to agricultural credit. Such credit-granting procedures are often complex, and the interest rates are generally fixed (2% per month or 24% per year) by the credit services, and are, as such, often considered by the producers to be high. These sources of funding are formal or informal. The main sources of formal financing used by rice farmers in Benin are CLCAM (Mutual Fund of Credit Agricole Local), PAPME (Agency for the Promotion and Support of Small and Medium-sized Enterprises), and PADME (Support Project for the Development of Micro

Enterprises). Informal funding sources include all loans made to third parties. Lacking access to agricultural financing, producers are therefore forced to cultivate small areas. 87.8% of producers have not been able to take out agricultural credit for cultivated areas of less than 0.750 hectares. However, 95% of the producers who sow on areas of 5,389 hectares have obtained agricultural credit.

IV.II. Farm efficiency level

The technical efficiency levels were obtained from the non-parametric data envelopment approach, commonly referred to as the Data Envelopment Analysis (DEA) method. In this model, the amount of rice (in kg) harvested by producers was the output. Factors and production inputs (land, labour, and production contributions) were the inputs. The analysis of the results obtained shows that the average level of efficiency of rice farms in North Benin is 0.51. In other words, rice farmers are only achieving 51% efficiency (Table 3).

The technical efficiency of about 60% of the farms is between 0 and 0.25 on the one hand and between 0.76 and 1 on the other. The remaining 40% are divided between farms whose technical efficiency is between 0.26 and 0.50 or between 0.51 and 0.75 (Table 4).

IV.III. Production constraints

Based on studies previously carried out on the constraints related to rice production in the world, a list of the difficulties encountered by the producers has been drawn up. The production constraints not belonging to this list were completed by the producers themselves during the surveys. For each of the production constraints, they were asked to assign a score ranging from 0 to 10, depending on the relevance of the problem. In other words, the producer would give the problem a rating of 0 if he did not find the problem relevant and 10 if he considered it to be very relevant. Firstly, using descriptive statistics, the average scores were calculated to identify the constraints for which the highest scores were recorded.

Secondly, a Kendall W test was performed to support the results of the descriptive statistical analysis. The analysis of the obtained descriptive statistics showed that the most relevant constraints faced by rice producers relate to access to agricultural equipment, adequate agricultural equipment, and the problems associated with climate change. Respectively, for each of these constraints, the scores 4.7, 4.6, and 4.4 were obtained (Table 5). These results were confirmed by Kendall's W test ($P = 0.000$). The difficulties of access to agricultural credit, the effects of climate

Table 3. Average farm efficiency (a)

	Effective	Minimum	Maximum	Average	Standard deviation
Technical Efficiency	200	0,06	1,00	0,5185	0,32306
Total	200				

Table 4. Average farm efficiency

		Frequency	Percentage
Technical Efficiency	0–0,25	61	30,5
	0,26–0,50	48	24,0
	0,51–0,75	35	17,5
	0,76–1	56	28,0
	Total	200	100,0

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Table 5. Scores obtained from descriptive statistics

	Minimum	Maximum	Average	Standard deviation
Inefficiency of agricultural equipment	0.00	10.00	***4.7550***	2.64954
Difficulties in accessing inputs	0.00	10.00	***4.6150***	3.23405
Impacts of climate change	0.00	9.00	***4.4600***	2.84055
Destruction of fields	0.00	9.00	3.8000	2.25509
Soil fertility decline	1.00	9.00	3.8700	2.06748
Lack of access to agricultural credit	0.00	10.00	2.7550	1.76775
Inferior seed quality	0.00	7.00	2.6200	1.72058
Limited availability of labour	0.00	9.00	1.3850	1.98405
Sale price fluctuations	0.00	8.00	0.1400	0.98756
Difficulty accessing the market	0.00	8.00	0.1100	0.87276

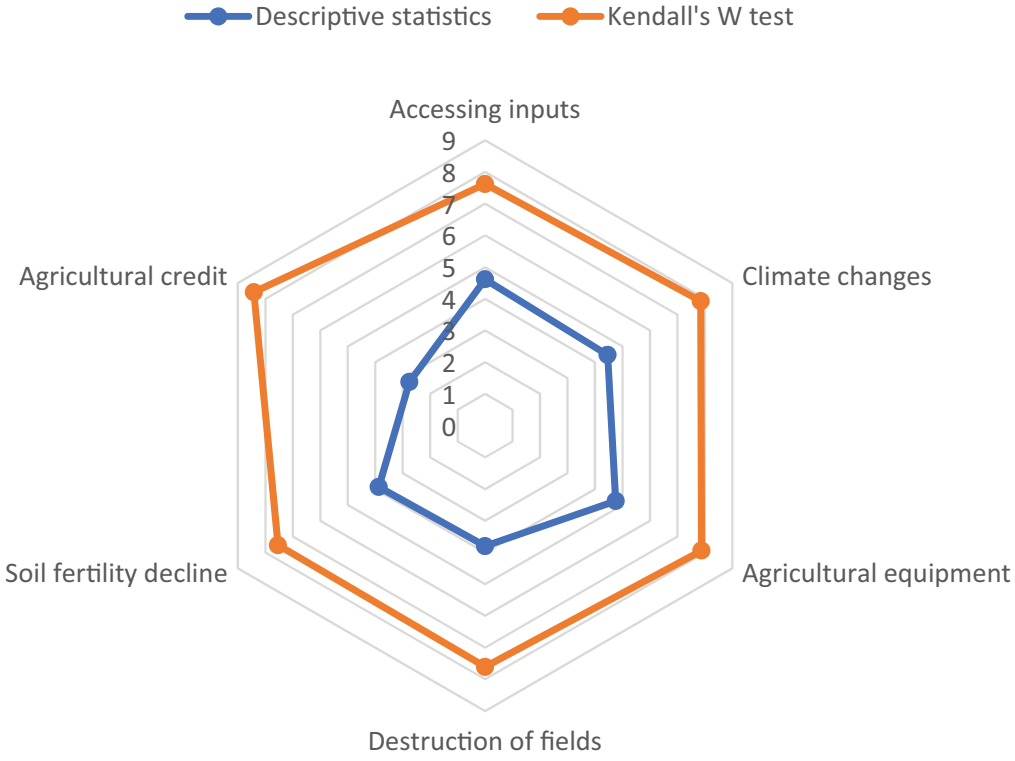


Figure 2. Descriptive statistics and scores obtained after Kendall's W test.

change, as well as the difficulties of access to agricultural equipment remain the major constraints faced by producers in this regard. The scores 8.4, 7.9 and 7.8 were respectively obtained (Figure 2).

IV.IV. Determinants of the technical efficiency of rice production

The Tobit regression model carried out to identify and analyze the determinants of the technical efficiency of rice production in North Benin is statistically significant at the one percent (1%) level

Table 6. Determinants of the technical efficiency of rice production

Technical Efficiency	Coefficient	Standard Error	T	P>t	Marginal effects
Age	−0.0060476	0.0028593	−2.12	0.036**	−0.0090384
Years of Experience	0.0077995	0.0035756	2.18	0.030**	0.0051793
Household size	0.0182873	0.0086583	2.11	0.036**	0.0240477
Agricultural assets	−0.0078766	0.0112811	−0.70	0.486	−0.0041049
Membership of a group	−0.0124042	0.023489	−0.53	0.598	−0.0490173
Credit amount	5.70e-07	1.89e-07	3.01	0.003***	0.0040564
Use of labour	−0.1465041	0.0471184	−3.11	0.002***	−0.1085018
Cost of labour	8.64e-07	5.10e-07	1.70	0.092*	0.0040974
Intermediate consumption	−1.15e-06	4.35e-07	−2.65	0.009***	−0.0035531
Quantity of seed	0.0016379	0.0007324	2.24	0.027**	0.0493253
Quantity of fertilizer	0.0185344	0.0084025	2.21	0.029**	0.0020194
Quantity of insecticide	0.0132365	0.0251663	0.53	0.600	0.0041774
Amount of herbicide	−0.0088543	0.014698	−0.60	0.548	−0.0050349
Amount of urea	−0.1435286	0.0348378	−4.12	0.000***	−0.0491849
Constant	0.6468603	0.0863753	7.49	0.000***	0.3582745
Tobit Regression	**Number of observations**			**200**	
	LR chi2(14)			**86.90**	
	Prob > chi2			**0.0000*** **	
Log likelihood = −15.441742	**Pseudo R2**			**0.7378**	

***: significant at the one percent (1%) level (P _ 0.01); **: significant at the five percent (5%) level (0.01 <P _ 0.05); *: Significant at the 10% level (0.05 <p _ 0.10).

($P = 0.000$). Moreover, the R^2 obtained is equal to 0.7378. This result, therefore, indicates that the variables introduced in the regression model determined the technical efficiency level of rice production in North Benin at 73.78%. The likelihood ratio obtained is relatively high. This shows that considering the variables introduced in the model rice production has 86.98% chance of being technically efficient in the study area. It emerges from the analysis of the results obtained that the technical efficiency of rice production in North Benin is influenced by parameters such as the age and number of years of experience as rice producers, household size, the use of hired labour, the financial resources allocated to the acquisition of hired labour, the intermediate consumption, the quantity of rice seed used for production, and the quantity of fertilizer and the amount of urea used for rice production (Table 6).

V. Discussion

The average efficiency level of rice farms in North Benin is 0.51. The average value of technical efficiency was estimated 51% which showed that there is still scoped to increase 49% more through proper allocation of available resources and technology. This degree of efficiency is lower than that determined by Houngue et al. (2020), Bessan et al. (2018) and Yabi (2009). Houngue et al. (2020) claim that factors including labor, seeds, fertilizer, and herbicide considerably boost the efficiency of rice production in Benin. In comparison to other agricultural inputs,

seeds have a greater impact on yield. Producers who employed more enhanced seed per hectare had better results. According to the same author, herbicide and labor are the inputs that contribute the least to the production of rice. These results corroborate with those of Yabi (2009). Thus, producers in North Benin have more difficulty reaching their maximum productive capacity level. Rice production requires significant capital from the producers, most of whom consider it to be an expensive enterprise. In that it allows producers to cover production costs, agricultural credit is therefore of paramount importance in promoting rice production. Agricultural credit could increase the level of rice production and allow the producer to strictly follow the technical production itineraries and carry out effective field operations.

The second limitation for rice farmers is climatic variability. Climate change impacts can be seen in two different ways. They emerge as increasingly frequent dry spells or severe downpours. (Konan et al., 2014). In the first case, the rice fields are flooded following the flooding of the rivers. In the second instance, there is a yellowing of the plants due to a lack of water, which eventually results in their death. Unlike the production of other cereal crops, such as corn and soya, the production of rice requires more physical strength and effort from the paddy workers because it is grown in the lowlands (Yabi et al., 2017). The hardship associated with fieldwork in the lowlands is the main reason why producers feel the need to acquire and use adequate agricultural equipment specifically adapted to rice growing to make the fieldwork much less arduous. What they need ranges from equipment for ploughing to harvesters for harvesting. In fact, the efficiency of rice producers is mainly impacted by their socio-economic and demographic characteristics, as well as the allocation of production factors.

Age has a negative and significant effect at the five percent (5%) level on the technical efficiency of rice production in North Benin ($p = 0.036$). Thus, the older the farmer, the less efficient his methods of rice production. This result is in line with that obtained by Choukou et al. (2017). Two parameters explain the results obtained. On the one hand, the oldest producers, given their advanced age, devote less time to their agricultural operations. The management of rice production is therefore left to the young people in the household, most of whom have very little experience. This partly explains the negative effect of the age of the producer on the technical efficiency of rice production.

On the other hand, this result can also be explained by the fact that older producers are conservative. In other words, they remain attached to the old ways and techniques of rice production. Older farmers are risk-averse and not open to new farming techniques and innovations. However, the use of new innovative technologies (improved seed varieties, improved production inputs specifically for rice production, etc.) developed for rice production would enable them to improve the technical efficiency of their production methods (Ngom, 2016). Unlike them, the younger producers have opened to the new agricultural technologies made available to them.

Unlike the "'age'" variable, the number of years of experience as a rice producer has a positive and significant effect at the five percent (5%) level on the technical efficiency of rice production in North Benin ($p = 0.030$). This result, therefore, makes it possible to deduce that the more experienced the rice producer, the more technically efficient his production. According to Nuama (2006), the number of years of experience of a producer has a significant impact on the performance of his farm. Indeed, over time, the producer acquires experience that allows him to adjust and/or modify the technical rice production itinerary according to parameters such as rainfall, availability of raw materials, etc. (Coulibaly et al., 2017). The experience acquired by the producer also enables him to better cope with production constraints such as declining soil fertility and soil erosion.

The size of the producer's household positively and significantly influences at the five percent (5%) threshold level the technical efficiency of rice production in North Benin ($p = 0.036$). Therefore, the larger the size of the producer's household, the more efficient his production. Indeed, the constituent members of the household represent to the head of the farm a potentially exploitable

labour force for production (Daud et al. 2018; Miassi et al., 2020; Nkonki-Mandleni et al. 2019; Omotayo, 2017; Omotoso et al. 2018; Omotayo and Oladejo 2016). Thus, the larger the size of the household, the more likely it is to have a labour force to support it in monitoring the technical itinerary of rice production. Thus, when the size of the household is large, the producer, being the head of the household, is in control of a key element, thus allowing him to better associate with the members of the household as a workforce and to combine the potential of the household's agricultural assets. In other words, according to the aptitudes and skills of the members of the household, he would then stand a better chance of succeeding in the distribution of the tasks to be entrusted.

The acquisition of salaried labour, as well as the amount invested in production, has a positive and significant impact at a threshold level of one percent (1%) ($p = 0.002$) and 10% ($p = 0.092$) respectively on the technical efficiency of rice production in North Benin. These results thus stipulate on the one hand that the rice farmers who resort to the acquisition of hired labour for the execution of fieldwork are those who attain the highest levels of production efficiency. These same results also indicate that the greater the amount invested in the acquisition of labour power, the more efficient the rice production. According to Yabi et al. (2012), the use of hired labour has a positive impact on the performance of cereal crops, particularly rice. Indeed, rice farmers acquire labour according to the demand or need for it that they feel. Unlike other cereal crops, such as corn and soybeans, the execution of the technical itinerary of rice production is much more arduous and requires much more labour, with significant transaction costs emanating from these conditions.

The difficulty of executing the technical route of rice production lies above all in the fact that it takes place in the lowlands, which makes the job more arduous. Producers with sufficient financial means manage to cover all the costs to improve the technical efficiency of their rice production. On the other hand, producers with very little are not able to carry out the technical route of production effectively. This has a negative impact on production efficiency. In this case, agricultural credit is the first formal source of financing in agriculture to which producers have recourse to finance their activity.

This consideration led, therefore, to an assessment of the effect of agricultural credit on the technical efficiency of rice production. The analysis of the results obtained showed that the amount of credit obtained by the producer does indeed have a positive and significant effect at a threshold level of one percent (1%) on the technical efficiency of rice production in North Benin. Thus, the greater the amount of credit obtained by the producer, the more efficient his production. The importance of agricultural credit in the emergence and sustainability of farms has been demonstrated in the studies of Akdemir et al. (2021). The agricultural credit received by the rice growers at the end of the season enables them to prepare for the next season (soil preparation, acquisition of product inputs, etc.).

Intermediate consumption has a significant but negative effect at the one percent (1%) level on the technical efficiency of rice production in North Benin ($p = 0.009$). Intermediate consumption includes expenses related to the acquisition of production inputs. Thus, the negative effect of Intermediate Consumption on production efficiency makes it possible to deduce that there is a poor combination of production inputs. To assess the impact of each of the production inputs, the effect of the amount of money allocated for the purchase of seeds, fertilizers, insecticides, herbicides, and urea, on the technical efficiency of rice production has been evaluated. The analysis of the information obtained shows that the production inputs that impact the technical efficiency of rice production in North Benin are notably the quantities of seeds, fertilizers, and the amount of urea.

The quantities of seeds ($p = 0.027$) and fertilizers ($p = 0.029$) have a positive and significant effect at the five percent (5%) threshold level on the technical efficiency of rice production in North Benin. Thus, the larger the quantities of seeds and fertilizers, the more efficient the rice producer. The most efficient rice farmers are those who stock up on enough seed and then apply second sowings

after the rice plants have emerged. This technique allows the producer to avoid having a sparse rice field when the seed germination rate is no longer high.

Given the fact that the quantities of production inputs to be applied depend on the area sown by the producer, this approach allows them to optimize the efficiency of the inputs used. Very few producers use this approach, however. At the same time, since rice production is demanding in terms of the fertilizers applied, producers who meet the production requirements in terms of the quantities of fertilizer used (50 to 100 kg/hectare) manage to improve the technical performance of their production. The amount of urea used has a significant but negative effect at the five percent (5%) threshold level on the technical efficiency of rice production in North Benin. This result is explained by the fact that the seed varieties used for rice production are sensitive to urea. Consequently, an excess of urea induces a negative impact on the technical performance of rice production.

VI. Conclusion and recommendations

This study was conducted to assess the factors affecting the technical efficiency of rice production, as well as production constraints, in Benin. To this end, information on the social, technical, and economic characteristics of producers and the technical efficiency of rice farms was collected. Based on the results obtained from the applied econometric models, factors such as the age of the producer, the number of years of experience, the size of the household, the use of hired labour, intermediate consumption, the amount of money allocated for the purchase of seeds, and the quantity of fertilizer and the amount of urea used affect the technical efficiency of rice production. However, it was noted that the most relevant constraints faced by rice farmers relate to access to agricultural credit, the effects of climate change, and access to adequate agricultural equipment. Considering these results, agricultural development policies related to the determinants in respect of the technical efficiency of rice production in Benin should be formulated to improve the efficiency of the producers. The authorities in charge of rice development should set up activities to facilitate experience sharing among the producers. In addition, strategies must be developed to facilitate producers' access to production inputs and adequate agricultural equipment. It should also be considered necessary to reduce administrative formalities to facilitate producers' access to agricultural credit.

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