Effect of the Ecology of Rice-growing system on Rice Farmers Technical Efficiency: a case study in Western Burkina Faso

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Abstract
The Government of Burkina Faso has, since several decades, made efforts to developpe plains and lowlands in order to increase rice production. However, the ecology of rice-growing system on which rice production is technically more efficient is not yet well-known. Optimal use of resources by farmers is an essential element for rice production increase. The objective of this study was to assess the technical efficiency of two groups of rice farmers in western Burkina Faso, one farming on irrigated plain and the other farming on developed lowland. Cobb-Douglas stochastic frontier production function is used for the empirical estimations. Cross-sectional data were collected from 60 rice farmers, 30 on each ecology of rice-growing, using a structured questionnaire survey method. Data were related to the 2017/2018 rainy season agricultural year. The results showed that rice farmers on irrigated plain are technically more efficient than those who are farming on developed lowland. In addition, the mean frontier output of rice production on plain is significantly greater than that on developed lowland. These results suggest that the Government should prioritize developed lowland, where there is a great potential to increase rice production, in agricultural development policy for food sovereignty and poverty reduction in rural areas.
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1. Introduction

In Burkina Faso, rice is the fourth cereal after sorghum, millet and maize concerning cereals production and consumption. Besides, rice is the most consumed cereal, especially in urban areas. Moreover, its average annual consumption per capita has grown rapidly. This growth is relative not only to that of the population but also to usual food changes or variation. Moreover, from 1960 to 2008, rice consumption has evolved from 4.2 to 21 kg/per capita/per year in rural areas and to 50 kg/per capita/per year in urban areas (Kaboré, 2016). Nevertheless, national rice production is still insufficient and covers less than 50% of the needs of population.

Consecutive to the food crisis during the year 2008, several measures were taken by the Government in order to increase national rice production. The objective was to cover the nutrition needs of the population whilst reducing the quantities of imported rice. Indeed, during the 2012/2021 period, developed area for rice production showed an upward trend from 41,526 ha to 72,055 ha. That correspond to a global increase of 74% (MAAHM, 2021). Rice production increase can be a reality if a number of parameters are met. Among these parameters, we have areas expansion, technological innovation and an optimal use of resources. Optimal use of resources seems the most appropriate in the short run, because it does not require huge investments. The optimization is measured by the technical efficiency of rice farmers which is defined in this study as their capacity to obtain the maximum quantity of rice given the level of inputs used.

Many empirical studies assessed the technical efficiency of rice farmers in sub-Saharan Africa (Miassi *et al.*, 2023; Ngom *et al.*, 2016). In Burkina Faso particularly, Kaboré (2016) ; Ouédraogo (2015) and Ouédraogo (2015b) estimated the technical and economic efficiency of rice production at Kou valley, Bagré and Sourou irrigation systems. They identified factors contributing to the inefficiency of rice production including among others household type, household head age, farm size, years of experience in rice farming and education. Globally, all of these studies showed that rice farmers could improve their production levels with the same quantity of inputs. However, most of these studies addressed only the socio-economic factors accounting for the inefficiency of rice production without the ecology of rice-growing systems. Thus, its effect on rice production technical inefficiency is not still well known despite the important role it could play in the optimal use of inputs.

Moreover, the study conducted by Obianefo *et al*. (2021) is a good example of studies that examined the effect of the ecology of rice-growing (upland *vs* lowland) on rice production technical inefficiency.

In the case of Burkina Faso, we distinguish two main ecologies of rice-growing systems which are irrigated plains and lowlands. Then, given the current state of knwoledge, we do not know the ecology on which rice production is technically more efficient. That constitutes a limit of the empirical literature. Thus, the main research question of the present study is as follow: what is the difference in technical efficiency between rice production on irrigated plains and that on developed lowlands? Besides, it is rooted on the theory of limited rationality (Thaler, 1980 ; Leibenstein, 1966 ; Simon, 1957). According to this theory, production unit can be structurally located below its production frontier, contrary to the postulate of neoclassical microeconomics.

The objective of this study is to estimate the technical efficiency of rice production on developed lowland and on irrigated plain in Western Burkina Faso. More specifically, it is about determining the factors which explain the technical efficiency of rice production on the plain of Karfiguela and on the developed lowland of Kiribina. It contributes to the literature by providing a better understanding of the ecology of rice-growing which enables an optimal use of inputs. Furthermore, it is necessary to know as clear as possible how maner rice farmers under irrigated plains and developed lowlands are using their scarce resources. The expected results would have significant implications for the agricultural extension services development and orientation at the Ministry of Agriculture in Burkina Faso.

The rest of the article is organized in five sections. The first one is about the literature review. The second section concerns methodological frameworks of the study. The empirical findings are presented in the third section and discussed in the fourth one. Finally, a conclusion with policy implications are showed in the last section.

2. Literature review

According to traditional microeconomic theory, technical efficiency studies are not relevant, since farmers are assumed to be rational (Nuama, 2006). Consequently, each production unit would always locate on its output or cost frontier. This theory was strongly criticized and its limitations immediately appeared. Indeed, modern microeconomic theories, notably limited rationality (Thaler, 1980, Simon, 1957) and X-inefficiency (Leibenstein, 1966) justified the possibility for sub-optimal use of inputs within production unit which is intended to be rational.

The theoretical framework for technical efficiency analysis of production units emerged with the seminal work of Koopmans (1951). Debreu (1951) which made the first empirical measure of technical efficiency consecutive to the work of Koopmans (1951). In addition, Farrell (1957) proposed for the first time a decomposition of economic efficiency into two components : technical efficiency and allocative efficiency. According to Farrell (1957), technical efficiency reflects the ability of a firm to obtain maximal feasible output from a given set of inputs (output-oriented) or produce a given level of output using the minimum feasible amounts of inputs (input-oriented).

Four methods are presented in the literature for technical efficiency measurement (Birhanu *et al*., 2022). There are Least squares econometric production model, Total factor productivity (TFP), Data envelopment analysis (DEA) and Stochastic Frontiers Analysis (SFA). DEA and SFA are widely used in empirical studies. DEA is a non-parametric or determinist approach proposed by Banker *et al*. (1984) and Charnes *et al*. (1978). This approach uses a linear programming technique to estimate technical efficiency. SFA is a parametric or non-determinist method developed by Aigner *et al*. (1977) and Meeusen and van den Broeck (1977). It is based on econometric method and production function to estimate efficient production frontiers using cross-sectional data.

Empirically, several studies have estimated the technical efficiency of major cereals, including rice, and identified factors influencing the technical efficiency of farm households in developing countries. For example, Miassi *et al*. (2023) evaluated the determinants of technical efficiency, the factors influencing this efficiency, as well as the constraints related to rice production in Benin using the *Data Envelopment Analysis* (DEA) method. The technical efficiency rate was estimated to be 51%. Additionally, inferential analysis showed that the age of the rice producers, household size, the amount of agricultural credit and the use of inputs influence the technical efficiency of rice production.

Using the stochastic meta-frontier model, Obianefo *et al.* (2021) determined the technical efficiency and technological gap ratios of rice production from the upland and lowland regions in Nigeria. Their data used were from a cross-section sample of randomly selected rice farmers. Results revealed that lowland regional rice producers are on average, significantly more technically efficient (91.7%) than their upland counterparts (84.2%). Additionally, mean technology gap ratios associated with lowland rice farmers are higher (92.1%) than their corresponding upland producers (84.7%).

In Burkina Faso, Kaboré (2016) examined the technical efficiency of irrigated rice production for the three irrigation systems: along the river at Kou, downstream the dam at Bagré and pumping system at Sourou. The results showed that the overall technical efficiency is estimated to be 87%. In addition, chemical fertilizers and equipment expenses had a positive relationship with rice production, in contrast of the cropped area which comes as a complementary factor to equipment. The socio-economic factors that significantly reduce technical inefficiency are the household type and the age of the head of the household. The findings also revealed that increasing cropped area alone is not enough to increase rice production without a better access to fertilizers and to equipment implement.

The study conducted by Ngom *et al*. (2016) in the Senegal River valley evaluated whether rice producers have reached their maximal production regarding their available inputs and what are the determinants of their inefficiency. The results showed that, the mean producer would increase his actual output by 30% without further inputs if he was efficient. Besides, the less performant producer would record a potential margin of progress of 86%. The efficiency determinants are mainly the place of residence, the gender, the household size, the level of education, the ethnicity, the walking distance between the house and the rice plot and the number of plots farmed.

Ouédraogo (2015) studied the level of technical efficiency, allocative efficiency and economic efficiency of rice farmers on the irrigated plain of Bagré in Burkina Faso, in order to assess the potential for increasing rice production. The data used for the study were obtained by a questionnaire survey from 170 rice producers selected randomly. Moreover, the author used Frontier version 4.1 to estimate the stochastic frontier production and cost functions. The results indicated that technical, allocative and economic efficiency of producers are respectively 80%, 93% and 74% on average. Moreover, these results show clearly that economic efficiency could be improved if some inputs such as mineral fertilizer, improved seed and capital were properly used by farmers.

In this article we break new ground by examining the effect of the ecology of rice-growing system on the technical efficiency of rice farmers in Western Burkina Faso. It is expected that rice farmers who are operating on irrigated plain are more technically efficients than those who are farming on developed lowland.

3. Methodology

3.1 Study area and data

This study was conducted in the Cascades region in Western Burkina Faso, which is one of main rice-producing regions with 11% of total rice production in the country (Koutou *et al*., 2021). Indeed, Cascades region is among the regions which accounted for a large area of irrigated plains and lowlands dedicated to rice production. This region is composed by Comoe and Leraba provinces. Karfiguela and Kiribina villages located in the Comoe province are where the data used were collected. These villages are particularly known as rice-based farming in the region. In this part of Burkina Faso, annual average rainfall received is ranging from 800 mm to 1300 mm. That is suitable for rice production. These reasons justify the choice of the study area presented by the figure 1 below.

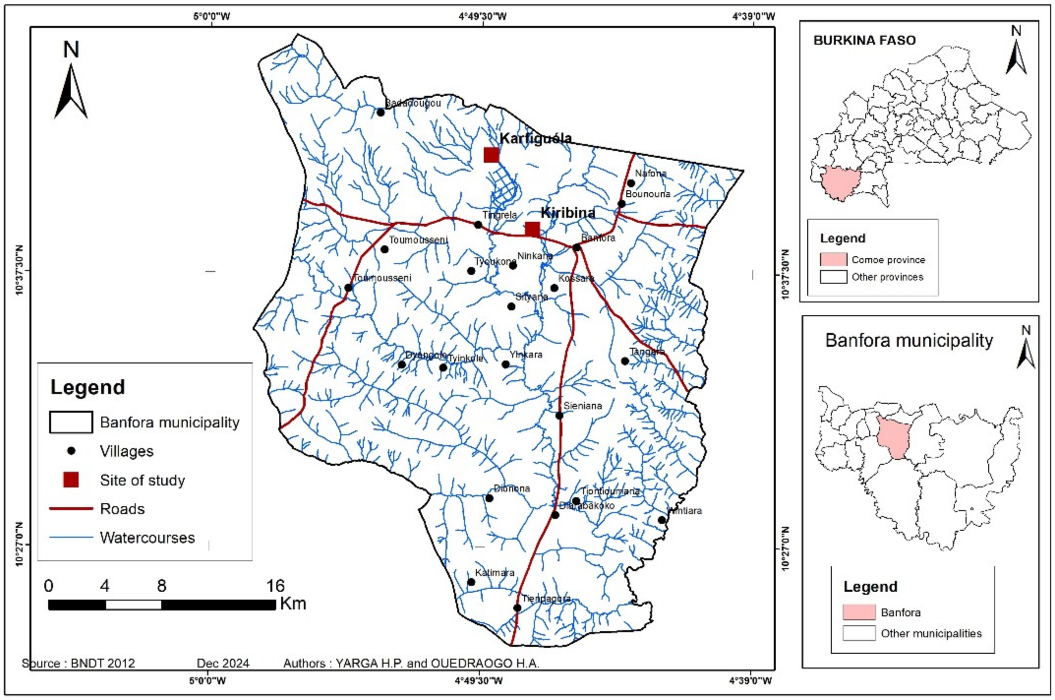

Figure 1: Localization of study area

The technical efficiency of rice farmers according to rice farming system analysis was performed on a sample of 60 farmers. Then, primary data for the study purpose were collected using a structured questionnaire administered by a cross-sectional survey conducted in June 2018. Information asked were related to rice yield, production factors and farmers socioeconomic characteristics. Firstly, a representative sample of 30 rice farmers was selected randomly in the developed lowland of Kiribina. In order to make a valuable and rigorous comparison of the technical efficiency of farmers under irrigated plain and lowland, a sample of 30 rice farmers were also selected randomly from those who were farming on the irrigated plain of Karfiguela.

3.2 Theoretical farmework

Rice farmers combine production factors such as labour, fertilizers, seeds, and so forth to obtain a given quantity of rice according to their production technology. The functional relationship between output and inputs can be specified by Cobb-Douglas or Translog production function. The choice of the more appropriate function to the data is based on the likelihood ratio test. See Mariko *et al*. (2019) for more details on likelihood ratio test implementation.

Given a vector x_i of production factors that a producer i disposes, he realizes a quantity y_i of rice production. By approximating the relation between output and inputs using Cobb-Douglas production function, the production frontier of the i^{th} farmer can be specified by the following equation (Kumbhakar and Lovell, 2000).

$$y_i = f(\gamma, x_i)e^{(v_i - u_i)}, \text{ avec } i = 1,2,3, \dots n \qquad (1)$$

In equation 1, y_i is the quantity of rice produced by the farmer i with the inputs x_i, γ is a vector of parameters to be estimated, v_i is a positive random variable, normally distributed with parameters (0, σ_v^2) : [$v_i \sim N(0, \sigma_v^2)$]. It measures the random variation of rice production due to factors which are not controlled by the farmer, u_i is a positive random variable with a semi-normal or exponential distribution and representing the technical inefficiency due to factors controlled by the farmer. Whatever i, v_i et u_i are independents.

The technical efficiency (ET_i) of the i^{th}farmer is measured by the ratio between the effective production obtained (y_i) on the optimal one (y_i^*) given the inputs used. This relation is expressed by equation (2).

$$ET_i = \frac{y_i}{y_i^*} = \frac{f(\gamma, x_i)e^{(v_i - u_i)}}{f(\gamma, x_i)e^{v_i}} = e^{-u_i} \qquad (2)$$

The farmer i is supposed to be technically efficient when his technical efficiency index is equal to 1, showing that $u_i = 0$. Conversely ($u_i \neq 0$), he is considered inefficient. Battese and Coelli (1995) proposed a model for the technical inefficiency specified by equation (3).

$$u_i = \varphi_0 + \sum_{k-1}^{K} \varphi_k \omega_i + \varepsilon_i \qquad (3)$$

Where ω_i is a vector of explanatory variables of the technical inefficiency of the farmer i, φ_k is a vector of the model parameters to be estimated, ε_i is the model specification error term normally distributed

From equation (2), the stochastic frontier output for the i^{th} farmer can be deduced as follow:

$$y_i^* = \frac{y_i}{ET_i} \qquad (4)$$

3.3 Empirical modelling

The theorical models exposed above call three categories of variables. There is the production output, the production inputs and finally the determinants of the technical inefficiency of farmers. These variables explained in table 1 with their expected sign. These variables are commonly used by several authors among which Birhanu *et al*. (2022) and Miassi *et al*. (2023).

Table 1: Definition of explanatory variables and their expected sign

Variables		Definition	Expected Sign
Rice production inputs			
yield	=	Quantity of rice production in kg/ha	
Rice production inputs			
area	=	Farm area for rice production (in ha)	±
labour	=	Number of active persons involved in rice production	+
chemical	=	Quantity of chemicla fertilizers used (in kg)	+
organic	=	Quantity of organic fertilizers used (in kg)	+
Determinants of the technical inefficiency of rice farmers			
exten	=	1 if the farmer accessed to extension agent, 0 if no	+
dist	=	Distance from home to the rice farm (in km)	
gender	=	1 if the household head is a man, 0 if woman	
exp	=	Rice farming experience (in years)	
hhsize	=	Household size (number of persons)	+

The stochastic frontier model for rice production according to the Cobb-Douglass production function is specified by equation (5).

$$lnY_i = \gamma_0 + \gamma_1 \ln(area) + \gamma_2 \ln(labour) + \gamma_3 \ln(chemical) + \gamma_4 \ln(organic) + (v_i - u_i) \qquad (5)$$

Where i indicates the i^{th} farmer, ln represents the natural logarithm, Y represents the output of rice (in kg/ha), labour represents the number of active persons involved in the rice production operations, γ_k are unknown parameters to be estimated, v_i is assumed to be independent and identically distributed random errors having $N(0, \sigma_v^2)$ and u_i is the technical inefficiency effect, which is assumed to be independently distributed with mean μ_i and variance σ^2. Battese and Coelli (1995) defined μ_i as a function of exogenous explanatory variables as follow.

$$\mu_i = \delta_0 + \delta_1 gender + \delta_2 age + \delta_3 exp + \delta_4 dist + \delta_5 exten \qquad (6)$$

Equation (6) means that the technical inefficiency effect is a function of the gender, age and experience (exp) of rice farmers, together with the access to the extension (exten) assistance they received from the development agents, dist is the distance from the home of the farmer to the rice field.

3.4 Data analysis

For the data analysis, we used descriptive statistics and econometric methods. Numerical and graphical statistics are used to summarize and visualize data. Econometric estimation is performed by the maximum-likelihood method. Then, all the parameters of the stochastic frontier and inefficiency model, defined by equations (5) and (6) are simultaneously obtained by using Stata software Version 17.

4. Results

4.1 Summary statistic of rice farmers characteristics

Farm households' socio-economic characteristics are presented in table 1. It shows that rice farmers are relatively younger population with average age around 50. In the whole sample, males represent 60%. This frequence of males reaches 86% one irrigated plain. Conversely, females are largely represented on developed lowland given that males have only a frequence of 33%. This means that females have a limited access to irrigated plain dedicated to rice production in the study area. Years of experience in rice farming is between 2 and 60 years with an average of 30 years as well as in the whole sample and in each ecology of rice-growing. The average household size is 10 persons which provides the labour for the activities of rice production. Rice farming size is ranging from 0.25 ha to 3.2 ha, with an average of 1.13 ha. Almost the total rice farmers (93%) operating on the irrigated plain access to agricultural extension services.

Table 2: Summary statistics of rice farmers characteristics

Variable	Sample		Ecologies of rice-growing system			
			Plain		Lowland	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Household head gender	0.6	0.49	0.87	0.35	0.33	0.48
Household size	9.28	4.72	11.63	4.78	6.93	3.31
Rice farming experience	30.30	12.78	30.43	9.37	30.17	15.64
Distance from home to farm	1.59	1.52	2.34	1.84	0.85	0.42
Access to extension services	0.47	0.50	0.93	0.25	0	0
Rice farm area	1.13	0.87	0.69	0.46	1.57	0.97
Number of observations	60		30		30	

Source: Authors analysis

4.2 Technical efficiency of rice farmers by the ecology rice growing system

The likelihood ratio test indicated that the Cobb-Douglas production function is more suitable to the data used. Then, for the estimated parameters of the stochastic frontier production functions for the farmers according to the ecology of rice-growing are given in table 3.
The elasticities of area for both categories of rice farmers as well as all the sample are estimated to be negative and less than 1. That value indicates that an additional one hectare leads to decrease in rice production by 0,7%. Conversely, chemical and organic fertilizers used increases rice production quantity by 0.33% and 0.28%, respectively for 1% additional use of these inputs. However, these inputs are not significant in lowland rice-growing.

Few variables have significant effect on technical inefficiency of rice farmers. Indeed, results show that the technical inefficiency of farmers who are farming under irrigated plains is influenced by the gender of farmers and their access to agriculture extension services. The estimated coefficient of gender in the irrigated plain rice-growing on the inefficiency of farmers is negative. Thus, males are more technically efficient in rice production than females in this ecology of rice-growing. The coefficient of access to agriculture extension services is also negative for farmers in the irrigated plain. This result indicates that the involvement of extension agents tends to decrease the technical inefficiency of rice production. As shown in table 1, rice farmers operating on developed lowland do not benefit from the support of extension agents. So, this variable has no effect on their technical inefficiency.

λ-parameter associated with the variance of the technical inefficiency effects in the stochastic frontiers are estimated to be 4.24 and 1.78 for rice farmers farming under irrigated plain and developed lowland, respectively. These results indicate that the technical inefficiency effects are a significant component of the total variability of rice outputs for the both ecologies of rice-growing system.

Table 3: Parameters of the Cobb-Douglas stochastic frontier production functions

Variables	Whole sample		Plain		Lowland	
	Coefficient[a]	P>|z|	Coefficient[a]	P>|z|	Coefficient[a]	P>|z|
Depedent variable: log of rice yield per hectare [ln(yield)]						
Production factor variables						
Ln(area)	-0.69 (0.09)	0.00	-0.59 (0.19)	0.00	-0.78 (0.13)	0.00
Ln(labour)	0.09 (0.09)	0.33	.08 (0.14)	0.55	.05 (0.18)	0.79
Ln(chemical)	0.33 (0.15)	0.03	.15 (0.22)	0.47	.94 (0.59)	0.11
Ln(organic)	0.28 (0.05)	0.00	.28 (0.05)	0.00	.08 (0.13)	0.55
Intercept	4.65 (0.81)	0.00	5.57 (1.31)	0.00	2.26 (2.59)	0.38
Inefficiency model						
Hhsize	0.01 (0.07)	0.88	0.00 (0.12)	0.99	.03 (2.98)	0.99
Gender	-0.75 (0.50)	0.13	-2.26 (1.07)	0.04	-5.35 (277.27)	0.98
Experience	-0.02 (0.01)	0.15	0.04 (.0)5	0.45	-1.80 (39.75)	0.96
Extension	-1.80 (0.59)	0.00	-3.73 (1.88)	0.05	-8.98 (315.13)	0.97
Intercept	0.95 (0.66)	0.15	2.15 (1.45)	0.14	12.17 (393.85)	0.97
Observation	60		30		30	
Wald Chi2(4)	131.30		56.32		54.63	
Log likelihood	-32.74		-3.65		-18.82	
Prob>Chi2	0.00		0.00		0.00	
Sigma_v	0.22		0.13		0.38	
Sigma_u	0.79		0.54		0.68	
$Sigma^2$	0.67		0.31		0.61	
Lambda (λ)	3.62		4.24		1.78	
Technical efficiency	66.3%		75%		58%	

Source: Authors
[a]The estimated standard deviation of the coefficient estimators are given in parentheses

The technical efficiencies of the rice farmers under both plain and lowland are less than 1. Indeed, the predicted technical efficiencies for the plain rice farmers go from 0.19 to 0.9, with the mean technical efficiency estimated to be 0.75. For the farmers operating under lowland, the technical efficiencies ranged from 0.12 to 0.9, with the mean estimated to be 0.58. It is clear that, on average, rice farmers under irrigated plain have higher technical efficiency than those who operating under developed lowland, relative to their respective frontiers associated with the different technologies. Above all, rice farmers on the irrigated plain as well as on the developed lowland could increase their outputs by 0.25 and 0.42, respectively using the same level of inputs. The figure 2 presents a distribution of the predicted technical efficiencies for the two ecologies of rice-growing.

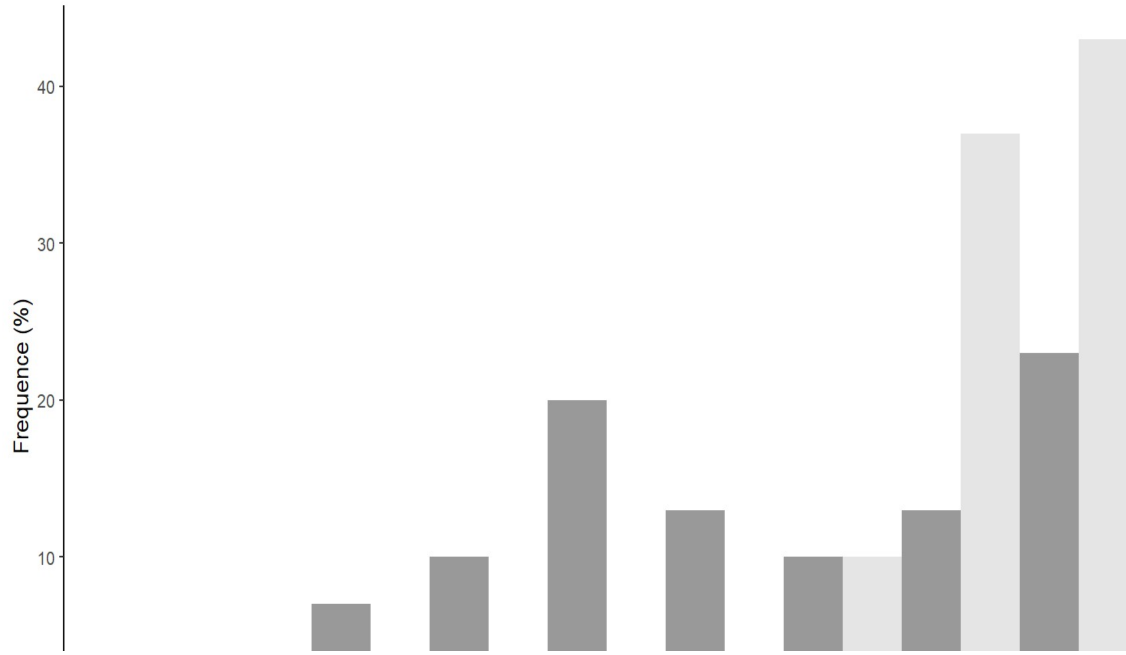

Figure 2: Distribution of rice production efficiency by the ecology of rice-growing system

From equation (4), the mean frontier outputs are estimated for rice farmers farming on irrigated plain as well as for those on developed lowland. The mean frontier output for plain farmers is estimated to be 4,264.58 kg/ha. For farmers on lowland, the mean frontier output is estimated to be 966.6 kg/ha. As presented in the figure 3, it appears that rice production on irrigated plain has higher mean frontier output than rice production on developed lowland.

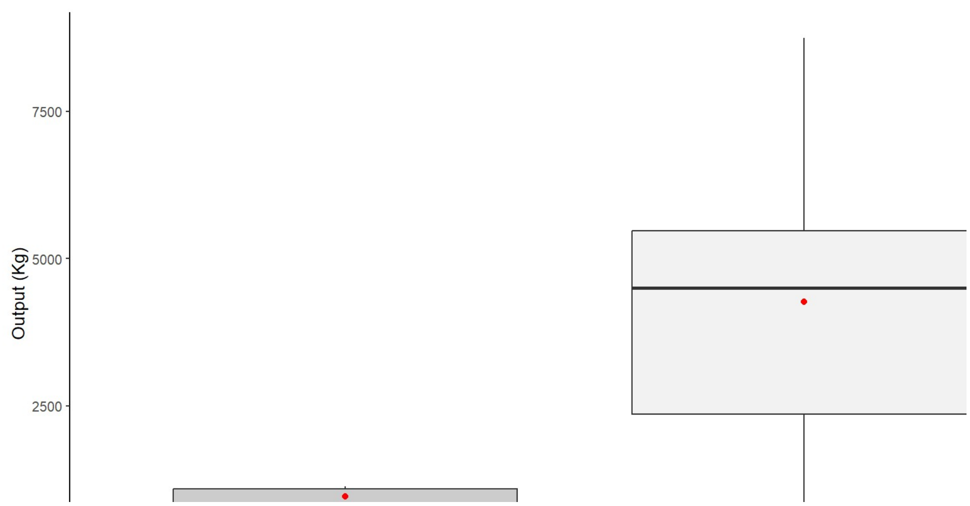

Figure 2: Boxplots for frontier outputs by the ecology of rice-growing system

5. Discussion

The significant effect of gender on the technical inefficiency of rice farmers means that males use more optimally their production factors in comparison to females. This result can be explained by several parameters. First of all, males have more physical strength to be involved in farming operations than females. Also, they have easy access to technology and equipments. In contrast, females are more diversified by carrying out several activities at the same time, homework specially. As such, are less available for rice farming operations whilst not possessing innovative technologies and equipments in comparison to males. In addition, females are often constrained to operate on a degraded soils. Above all, the inefficiency of rice production is less on male plots than their female counterparts. This result is consistent with previous findings of Yiadom-Boakye *et al*. (2013) and Addison *et al*. (2016). These authors explained the higher technical efficiency scores of males by their labour participation in rice production, larger plots and higher application of fertilizer as compared to that of females. Conversely, Boubacar and Huiqiu (2016) ; Oladeebo and Fajuyigbe (2007) reported that female rice farmers are more technically efficient compared to male farmers in their respective studies areas.

The result related to agricultural extension services shows that this variable reduces the technical inefficiency of rice farmers. In fact, extension services improve the capacity of rice farmers to better manage their farms and to optimize their scarce resources using. The result is consistent with findings by Jolex (2022) on rice farmers in Malawi.

6. Conclusion

In Burkina Faso, rice is mainly produced on two ecologies of rice-growing especially, irrigated plains and developed lowlands. A lot of efforts are made by the Government to developpe plains and lowland in order to increase rice production. To reach this objective, optimal use of resources by rice farmers is an essential element. This study estimates a Cobb-Douglas stochastic frontier production functions for rice farmers. They are farming either on irrigated plain at Karfiguela or on developed lowland at Kiribina in Western Burkina Faso. To do so, primary data were collected from 30 rice farmers on each ecology of rice-growing.

The main results showed that rice production on irrigated plain had significantly higher outputs frontier. In addition, the technical efficiency effects in rice production on irrigated plain are positively related to the gender of farmers and their access to extension services. With adequately trained extension agents, who are committed to support farmers implement best agricultural practices, there is hope that rice production may significantly increase in the future nationwide given the effort to extend irrigated plain for rice production. These results suggest that the Government should prioritize developed lowland on which there is a great potential to increase rice production.

Future research could identify ecology of rice-growing system where farmers use the best production technology through the stochastic meta-frontier approach.

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