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TECHNICAL EFFICIENCY OF IRRIGATED RICE PRODUCTION IN BURKINA FASO WATER CONTROL INFRASTRUCTURES: A STOCHASTIC FRONTIER APPROACH

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Abstract

The present study examines the technical efficiency of irrigated rice production in Burkina Faso for the three irrigation systems: along the river at Kou, downstream the dam at Bagré and pumping system at Sourou. The results show that the overall technical efficiency is high: 87%. The estimates of the stochastic production frontier model indicate that chemical fertilizers and equipment expenses have 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 (plows, harrows, and oxen). The pumping irrigation system operated at Sourou proved to be more technically inefficient than the system along the river at Kou valley. Therefore, in the current conditions, the option of the pumping irrigation system should be excluded from future irrigation scheme.

1. INTRODUCTION

Agriculture is an important sector for the economy of Burkina Faso; it is the main source of livelihood for 80% of the population; it contributes for 35-40% to the GDP and 60% of export earnings. Despite its importance, this sector has not benefited from effective policies since the political independence so that poverty is still high in rural areas (47%). This lack of performance is partially attributable to various constraints such as (i) a poor spatio-temporal distribution of rainfall, (ii) an extensive production system leading to natural resources degradation and (iii) a low level of technical equipment and innovation. These constraints are more and more acute in the presence of the harsh effects of climate change. Increasing agricultural productivity is widely

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recognized as an important engine of socioeconomic transformation in Sub-Saharan Africa and irrigation is an important vehicle for promoting increased productivity (You, 2008).

Therefore, in order to address the above constraints and increase food availability, the government of Burkina Faso initiated water control policies consisting of building water management infrastructures to crop rice. Due to a drastic increase in rice demand, rice cropping was the first option on such improved lands where water is optimally managed. Despite an absolute increase in rice production, yields remain under their potential levels so that the actual supply is lower than the potential quantity of this strategic staple food. In Burkina Faso, the national rice production which amounts to 300,000 T only meets 30% of the total needs (Kaboré *et al.*, 2011) and imports accrue to 40 billion FCFA per year.

The challenge is still there as well as the Government's propensity to pursue the same policy, namely the development of infrastructures to better manage water in order to increase and sustain national rice production. However the long-term viability of this option is questionable. In particular, it would be relevant to know if the rice producers on the sites have reached their maximum level of production, or in other words if their technical efficiency can be improved in order to increase the profitability of the whole irrigation infrastructures. Ouédraogo (2015) studied rice production efficiency in Burkina Faso but for the single site of Kou dam while Kaboré (2011) used the National Agriculture Census data, collected not only on governmental water scheme sites but also on any wetland where rice is produced, to analyze rice production efficiency in Burkina Faso. On the other hand, Kaboré (2014) did some research on production efficiency but for horticulture in the Nakanbé River basin.

The present study examines the technical efficiency of the irrigated rice production on the three irrigation infrastructures existing in Burkina Faso, namely "the along the river" system (Kou), the "downstream of the dam system" (Bagré) and "the pumping" system (Sourou). It aims to make policy recommendations in order to (i) increase the technical efficiency of the rice producers on those costly production sites leading to rice yield increase and therefore (i) improve the overall performance of water control infrastructures in Burkina Faso. Specifically, it analyzes the determinants of the irrigated rice production, computes the technical efficiency of the irrigated rice growing and analyses the factors of the associated inefficiency.

2. METHODOLOGY

2.1. Study area and data collection
The survey was conducted in November 2005 to mid-January 2006 in dry season 2005 on three sites (see Map 1 of localization): the Kou valley in the West of Burkina Faso where the operated irrigation system is along the Kou river; the Sourou valley in the North-West where irrigation is made by pumping from the Sourou River; Bagré in the Center-East with an irrigation system downstream of the Bagré hydro-electric dam.

The choice of these sites is motivated by the importance of rice cropping and the operated irrigation system. Fifteen (15) villages were selected: eight (8) in the Kou Valley, four (4) in the Sourou and three (3) in Bagré. A total sample of 150 households (10 per village) was randomly drawn to conduct the survey.
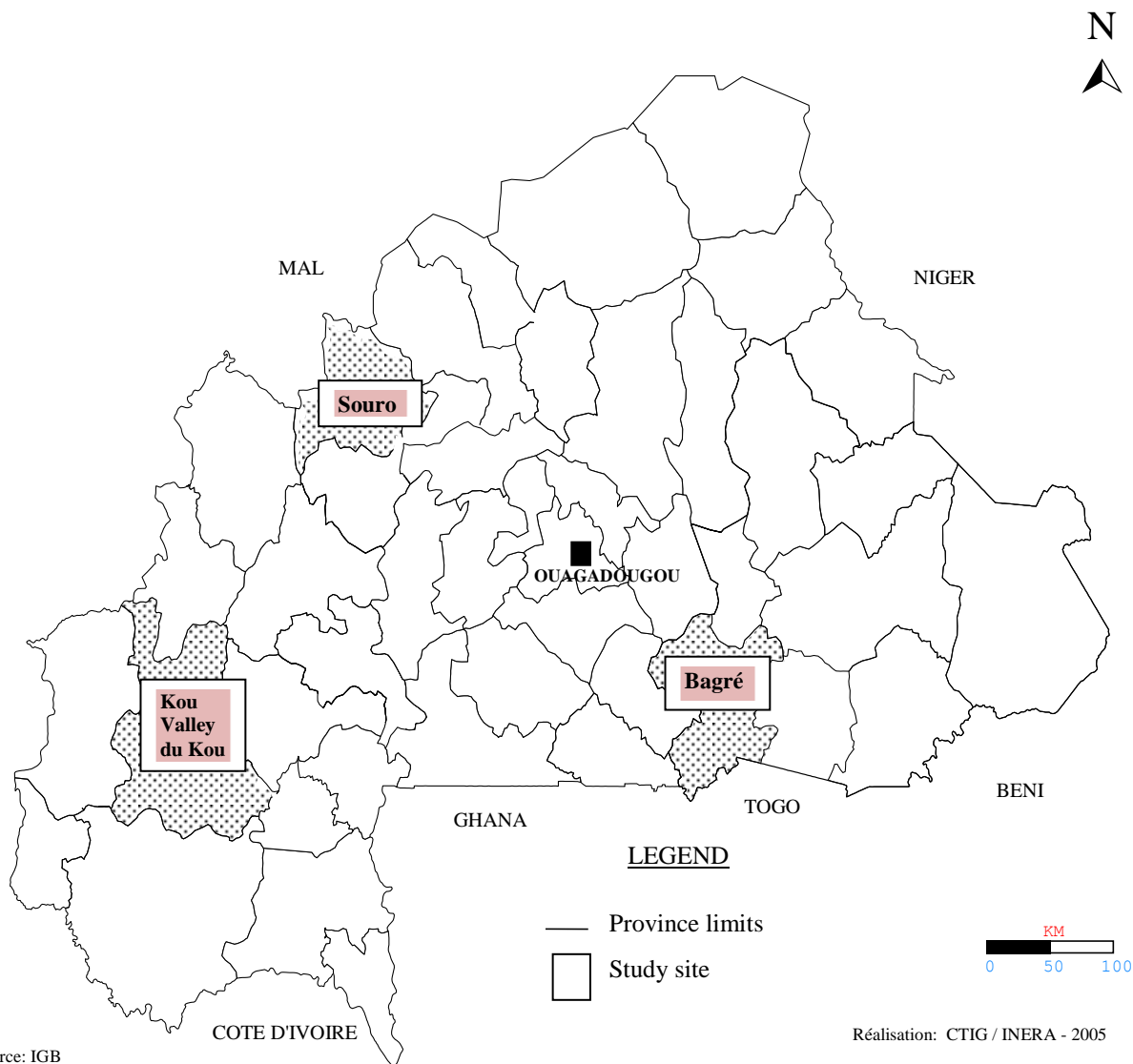
Map 1: Geographical situation of the study sites

2.2. Method of analysis: stochastic production frontier and inefficiency models

The function of stochastic production has been used to estimate the technical efficiency (TE) of the individual producers of rice and the factors of inefficiency. The use of stochastic production function has some advantages. For Battese & Coelli (1995), it is more appropriate than the DEA (*Data Envelopment Analysis*) method for agricultural productions, especially in developing countries where data are more likely to be strongly influenced by measurement errors and by other effects outside of producers' control such as weather conditions, diseases and parasites. Therefore, the stochastic production function, developed by Aigner *et al.* (1997) and Meusen & van Broeck (1997) was used in this study.

In general the production function is written as follows:

$$Y_i = f(Xi, \beta) \exp(Vi - Ui)$$
…………….... (1)

where Y_i represents the production of rice in the ith household; X_i is a vector (1xk) of inputs of production associated with the ith household; β is a (kx1) vector of unknown parameters to estimate; the V_i are random errors of distribution which are assumed to be iid N (0, σ^2_V) and the U_i, independently distributed among themselves and between the random errors. U_i which represent the inefficiency in production, are non-negative random variables assumed to be iid N (0, σ^2_U) and follow a half normal distribution (truncated distribution at zero); this distribution has more realistic properties and is often preferred to others (Chaffai, 1997).

In order to determine the effect of the inputs and the socio-economic factors of productivity and technical efficiency, a stochastic translog function was estimated, following Wilson *et al.* (2001), Alvarez & Arias (2004) and Rahman & Hasan (2008) who already used it; it is of the form:

$$\ln Y_i = \beta_0 + \sum_{j=1}^{6} \beta_i \ln X_i + 1/2 \sum \sum \beta_{ij} \ln X_i \ln X_j + V_i - U_i$$
…………….... (2)

where
Y_i = the production of rice in quantity (kg) for the household I (I=1…150)
X_i= factors of production (X_1= cropped area in ha, X_2= used inputs (fertilizers) in quantity (kg), X_3= expenditures on equipment (FCFA).
The U_i are specified by the following function: $U_i = z_i \delta W_i$ (3), where the z_i a (1xm) vector of explanatory variables associated with the technical inefficiency of production units, δ is a (1xm) vector of unknown parameters and W_i the residual term.

The z_i are the socio-economic characteristics of producers in the inefficiency model, namely:
- Z1: the household type (small=0, large=1 i.e larger than six (6) members);
- Z2: the age of the head of the household (in years);
- Z3: the education level of the household's head (in years);
- Z4: the number of years of head of the household's experience in the rice production on the site;
- Z5: pumping irrigation system (no=0, yes=1);
- Z6: downstream the dam irrigation system (no=0, yes=1); (the reference is the 'along the river' system at Kou)
- Z7: the use of organic manure (no=0, yes=1);
- Z8: the practice of soil and water conservation (SWC) techniques (No=0, yes=1).

The error terms being assumed mutually independent and of inputs, the function is estimated by the method of maximum likelihood and the associated parameters with V_i and Ui are $\sigma^2 = \sigma^2_u + \sigma^2_v$ and $\gamma = \sigma^2_u / (\sigma^2_u + \sigma^2_v)$, γ reflecting the importance of the inefficiency in the output gap. The simultaneous estimate proposed by Battese & Coelli (1997) and implemented by the software FRONTIER 4.1 (Coelli, 1996) enables to limit the criticism of the two-step estimation method. This software was used in the present study.

3. RESULTS AND DISCUSSION

3.1. Socio-economic characteristics of the sample households
Table 1 summarizes the socio-economic characteristics of rice growers on the study sites. It shows that the minimum age is 20 years (at Sourou) while the maximum is 80 at Kou valley as well as the highest mean age (54.4 years). This means that rice growing is practiced by middle age farmers. Farmers's experience ranged from 3 years at Kou to a maximum of 41 years at Sourou. The mean family size was 19 members at Kou against 12 at Sourou and Bagré. Farmers at Kou Valley have more family active members on average: 7.3 against 5.73 and 5.03 for Sourou and Bagré, respectively. The mean number of years of education is about 5 years at Kou against 3 at Bagré and Sourou. Total cropped area averaged at 0.94-1.00 ha per household while the mean yield reached 3631, 42 kg /ha at Sourou, 3245,2 kg/ha at Kou and 3164,44 kg/ha at Bagré. The mean quantity of chemical fertilizers used on rice was larger at Sourou (317, 9167 kg) than on the other two sites: 285, 7 kg at Kou and 298,6421 kg at Bagré. The results show that rice growers in Burkina Faso are small-scale farmers and this small size makes mechanization difficult.

3.2. The determinants of the stochastic function of production
The maximum likelihood estimates of the stochastic production function are presented in Table 2. The LR value of 31.76, significant at 1% for a theoretical chi-square value of 11.64, means that the model is adequate. The parameter $\gamma = \sigma^2_u / (\sigma^2_u + \sigma^2_v) = 0.83$ is significant at 1%; this implies that the effects of the technical inefficiency are significant in the irrigated rice production of Burkina Faso. In other words, almost all the variation in the irrigated rice production is attributable to producers' technical inefficiency. Idiong (2007) found a γ value of 0.77 for small rice producers in non-irrigated lowlands in the Cross River State in Nigeria; Battese & Coelli (1997 op. cit.) obtained a γ value of 0.95 for rice producers in a Indian village with panel data over 10 years, collected by ICRISAT. Myint & Kyi (2005) and Donkoh et al. (2013) have shown that γ was 0.99 for the Myanmar rice producers in South-East Asia and in the north of Ghana, respectively.

Table 2 provides information on the determinants of both the function of stochastic production of irrigated rice and the associated technical inefficiency.

The relative importance of the production factors is indicated by the sign and the magnitude of the associated coefficients. The quantity of chemical fertilizers applied and the equipment expenses have the predictable sign which is positive and significant at 1%. This indicates a direct relationship between these factors and the quantity of irrigated rice production: an increase in the quantity of chemical fertilizers of 1% results in an increase of 9% in rice production. This important role of chemical fertilizers in rice production is thus confirmed both by by Ouédraogo (2015, op. cit.) and the drastic increase in rice production by 20% during the 2008-2009 campaign, when the Government of Burkina Faso subsidized fertilizers (Kaboré et al., 2011 op. cit.). Similarly, an increase in equipment expenses (mostly for animal traction) of 1% induces an increase of 5% in the quantity of produced rice.

Table 1: Socio-economic characteristics of the sample households on three water scheme sites

Site		Age of House holhead	Family size (members)	Experience (years)	Level of education (years)	Crop area (ha)	Yield (kg/ha)	Chemical Fertilizers used (kg)	Number of active members
Kou valley	Minimum	24	7.00	3.00	0	0.50	1500	100.00	0
	Mean	54.3	18.8	25.7	4.57	1.0	3245.2	285.7	7.3
	Maximum	80	35.00	50.00	5	1.50	5250	400.00	18
	Standard deviation	14.34	7.05	11.97	7.713	0.16	668.38	76.89	3.71
Sourou	Minimum	20	3.00	3.00	0	0.50	320	160.00	2
	Mean	40.18	11.6000	14.8250	3.33	1.0938	3631.42	317.9167	5.73
	Maximum	55	37.00	41.00	20	2.00	5440	400.00	20
	Standard deviation	8.305	6.82304	8.0284	3.724	0.4732	1706.506	72.6521	3.501
Bagré	Minimum	31	5.00	7.00	0	0.75	963	100.00	2
	Mean	43.37	11.9310	22.1724	2.97	0.9417	3164.44	298.6421	5.03
	Maximum	61	23.00	36.00	10	1.00	5056	500.00	12
	Standard deviation	7.654	4.6746	8.2335	2.988	0.0849	1185.175	88.6645	2.428

Table 2: Maximum likelihood estimates of the stochastic production function for rice production in Burkina Faso

Variables	Coefficients	t-ratios
Stochastic frontier production model		
Constant (β_0)	-43.5326***	-10.3147
Area (β_1)	-5.1301**	-1.7963
Chemical fertilizer (β_2)	9.1239***	10.1588
Expenditures on Equipment (β_3)	4.6348***	5.7131
$(\text{Area})^2$ (β_4)	0.0007	0.0011
Chemical fertilizer^2 (β_5)	-0.0377	-0.2218
Expenditures on Equipment^2 (β_6)	0.0096	0.26
Area x Chemical fertilizer (β_7)	0.2446	0.3866
Area x Equipment (β_8)	0.4770*	1.5484
Chemical fertilizer x equipment (β_9)	-0.8141***	-5.2374
Inefficiency model		
Constant δ_0	0.0241	0.0292
Household type (δ_1) (small=0 ; large=1)	-0.9051***	-3.0333
Age of the head of household (δ_2)	-0.0263**	-1.5032
Level of education (δ_3)	-0.1457	-0.7255
Experience on the site (δ_4)	-0.0275	-0.9059
Pumping irrigation system (0/1)(δ_5)	2.3409***	3.4327
Downstream the dam irrigation system (0/1)(δ_6)	0.0144	0.026
Use of organic fertilizer (0/1)(δ_7)	0.5338	1.0333
Practice of Soil and Water Conservation technique (0/1)(δ_8)	-0.2631	-0.6427
Diagnostic statistics		
σ^2	0.2889***	4.673
γ	0.8264***	14.892
Likelihood Ratio	31.76***	
Mean Technical Efficiency	0.87	

*, ** and ***: significant at 10, 5 and 1 percent respectively

The cropped area showed an inverse relationship with the produced quantity: an increase in cropped area of 1% leads to a decline in rice production of 5%. Such a finding is due to the factor-intensive nature of rice production which requires a lot of labor and fertilizers (organic and inorganic) to keep productivity at the same level when the cropped area increases. Therefore, cropped area appeared to be a limiting factor to irrigated rice production in Burkina Faso, in the absence of favorable conditions in terms of fertilization and equipment to implement timely and appropriate operations.

Despite the crucial role of the fertilizers in irrigated rice production, this input is neither financially affordable nor available on a timely basis to the producers. Our research results are confirmed by similar findings by Donkoh *et al.* (2013) *op. cit.* on the irrigated perimeter of Tono in northern Ghana, where an increase in cropped area also induces a negative effect on rice production while an increase in fertilizer and labor has a positive effect on produced rice quantity.
Regarding interactions, the positive sign of a coefficient indicates that the variables are complementary while the negative one implies that they are substitute. The results show that cropped area and equipment are complementary while fertilizers and equipment expenditures are somehow substitutable.

3.3. Distribution of technical efficiency score

The estimation of the stochastic production allowed to get an average technical efficiency score of 87%, meaning that there exits an improvement margin of 13% in rice production in Burkina Faso. This result is comparable to the 81% score found on the water scheme of Tono in northern Ghana by Donkoh *et al. (2013) op. cit.* and 86.6% on Ijesha rice production site in Osun State in Nigeria (Tijani. (2006). Ouédraogo (2015, *op. cit.*) found a technical efficiency score of 80% at Kou Valley in Burkina Faso.

Figure 1 presents the distribution of producers by the level of the technical efficiency score: 83% of producers have a score between 80% and 95%; only 5% of the rice producers displayed a score between 96% and 100%; the other 13% are the least efficient producers with a score between 50% and 80%.
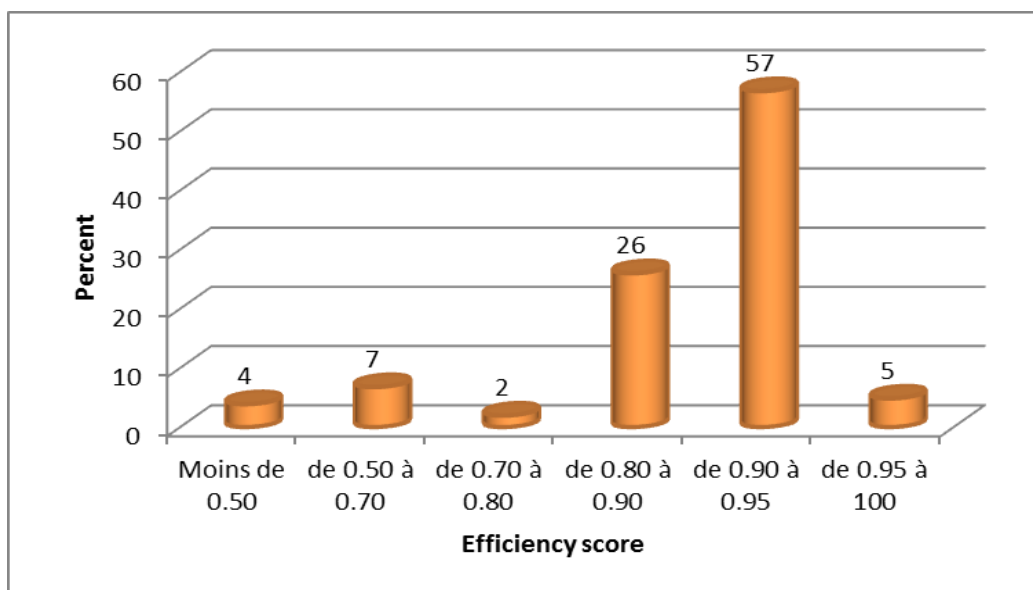
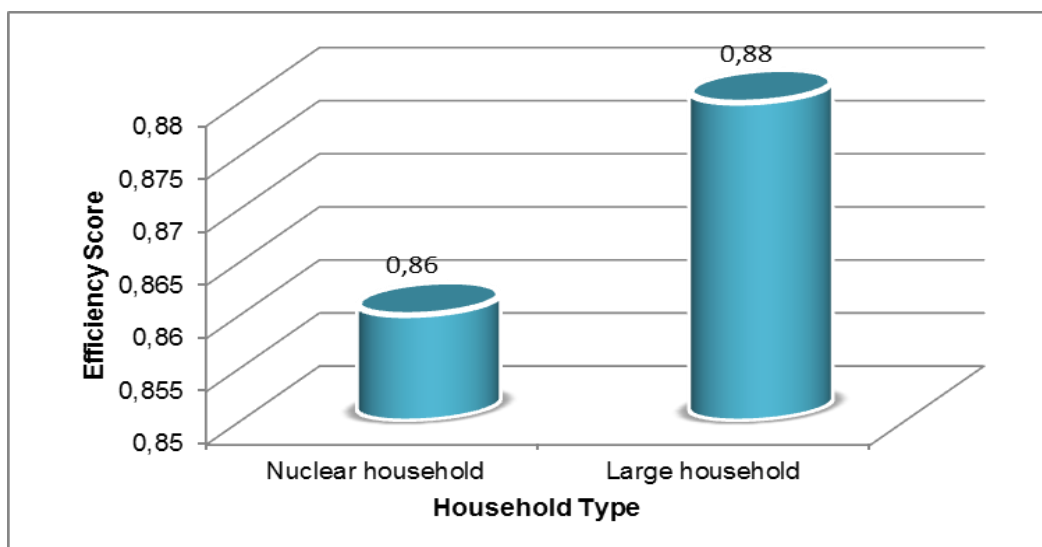**Figure 1: Distribution of rice producers by level of technical efficiency score, Burkina Faso, dry season 2005**

3.4. The sources of inefficiency

Results on the technical inefficiency model are presented in Table 2; the δ coefficients account for the effect of different variables on the technical inefficiency: the variables with a negative sign coefficient have a negative relationship with the inefficiency, in contrast of those having a positive sign (Battese & Coelli, 1995). In the model, significant variables are the type of household, the age of the head of the household and the type of irrigation.

Figures 2-6 give an illustration of the source of the producers' technical inefficiency. The negative sign of the coefficient associated with the household type means that the large size of the household (more than 6 members) tends to reduce technical inefficiency. A similar result was highlighted by Otitoju *et al. (2014)* for the soybean producers in Nigeria.

It can be seen in Figure 2 that the score of large households of 0.88 is higher than that of small households (0.86). The greater availability of family labor in large households enables them to timely implement cropping operations, which tends to reduce inefficiencies in irrigated rice production.
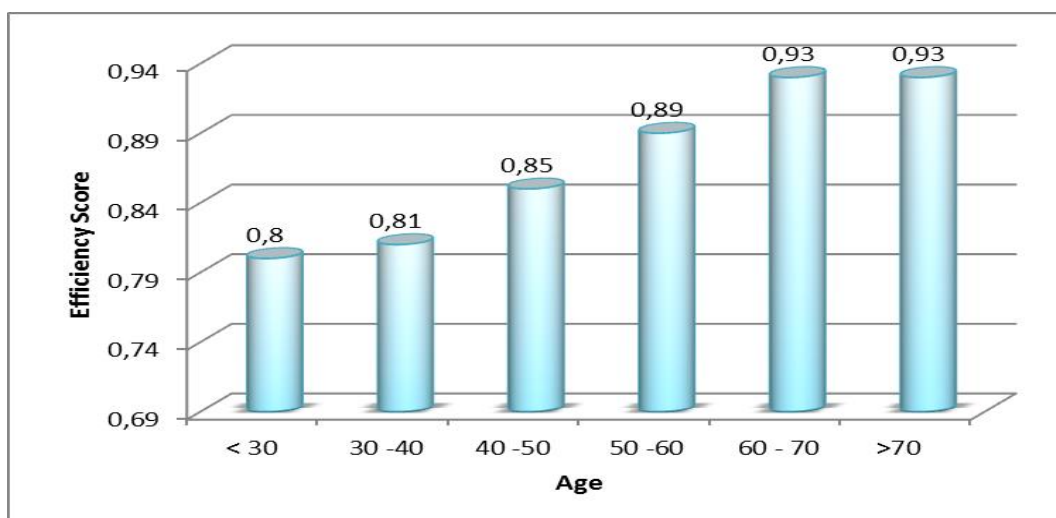
Figure 2: Distribution of rice producers by level of technical efficiency and type of household, Burkina Faso, dry season 2005

The finding about the age of the head of the household indicates that older household heads are less technically inefficient. In other words, the age is a reducer of the technical inefficiency in the practice of the irrigated rice production in Burkina Faso. Otitoju *et al. op. cit* have also found a similar result in the production of soybeans in Nigeria.

This finding is illustrated in Figure 3 where it is clear that the score of efficiency increases with age: the household heads of over 60 years have an efficiency score of 0.93 against 0.80 for the younger heads of household (less than 30 years).

Figure 3: Distribution of rice producers by level of technical efficiency and age of the head of the household, Burkina Faso, dry season 2005

Only the pumping irrigation system (present in the Sourou) has a positive and significant sign; this indicates that compared to the reference system (the along the river system in Kou valley), this irrigation system records a technical inefficiency. This result is not surprising given the high energy costs incurred in operating the water pumping engines. The downstream of the dam of

Bagré has a positive although non-significant sign. Therefore, the two irrigation systems are technically inefficient compared to the 'along the river system'. Figure 4 illustrates the case: the technical efficiency score of 'the along the river system' is 0.92 against 0.88 and 0.64 for 'the downstream of the dam' and the pumping system, respectively.
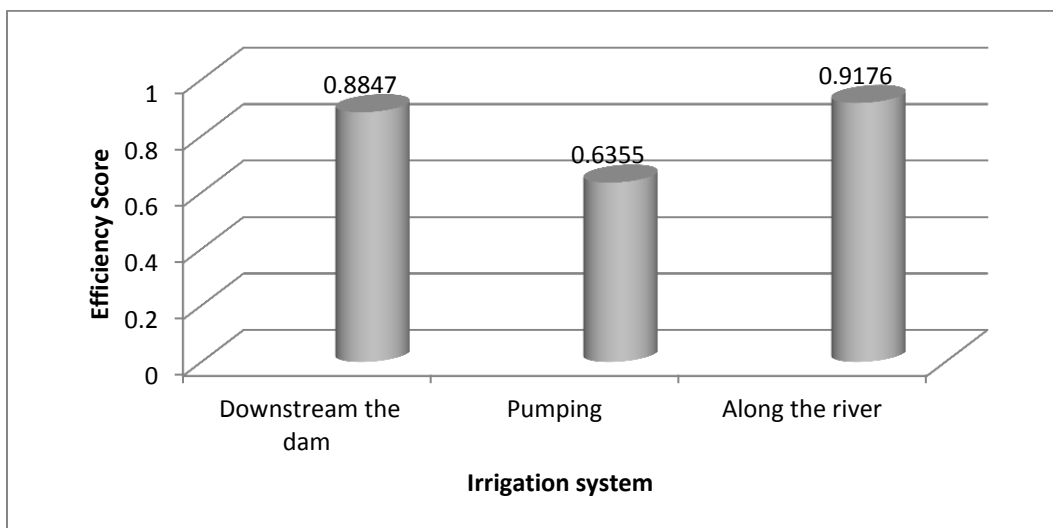
Figure 4: Distribution of rice producers by irrigation system, Burkina Faso. dry season 2005

Coefficients associated with the experience of the head of the household, his level of education have a negative but non-significant sign.

The coefficient associated with the grower's experience is positive although not significant. Figure 5 shows that the effect of this variable on the technical efficiency is not clear-cut. It seems that the experience alone does not reduce technical inefficiency by itself.
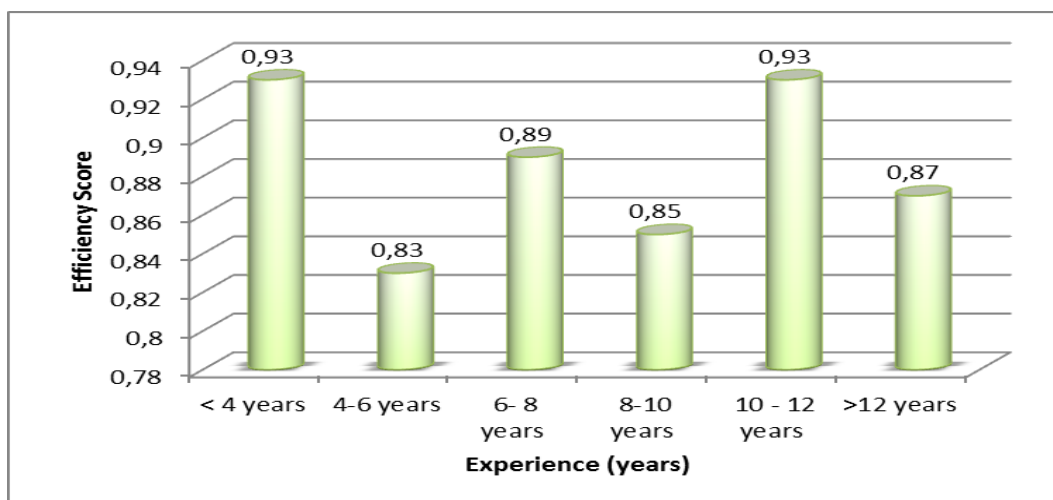
Figure 5: Distribution of rice producers according to the level of technical efficiency and the experience of the household, Burkina Faso, dry season 2005

The same trend is observed for the level of education; as it can be seen on Figure 6, it is not clear that the level of education is a reducer of technical inefficiency since the households with less than

two years of education have proved to be more efficient than those with 2-6 years of education. Those of 8-10 years of education are more efficient than those of over 10 years of education.
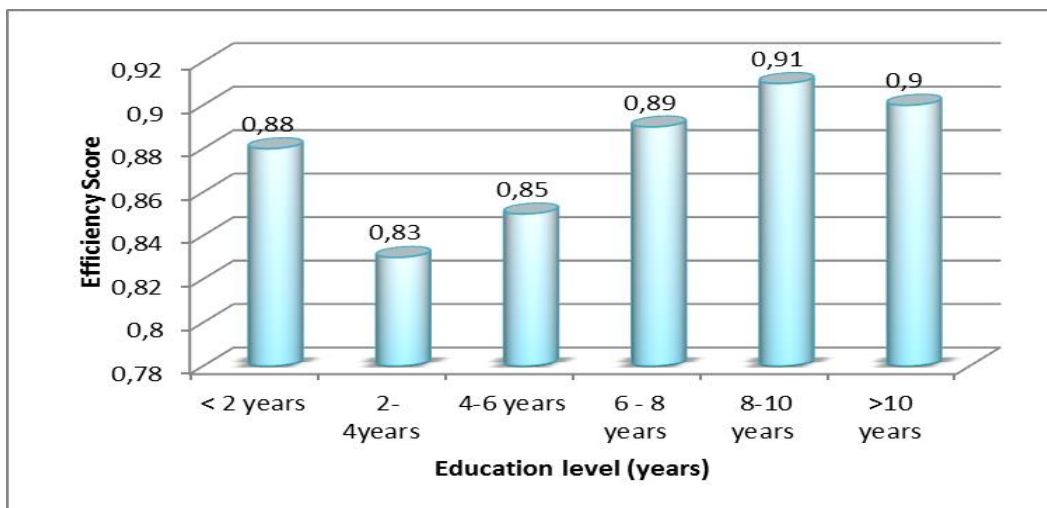

Figure 6: Distribution of rice producers by technical efficiency score and the level of education, Burkina Faso, dry season 2005

4. CONCLUSIONS AND POLICY RECOMMANDATIONS

This study aimed to analyze the determinants of the irrigated rice production and calculate the growers' technical efficiency on the so costly water control infrastructures of Burkina Faso. Maximum likelihood method was used to estimate a stochastic frontier translog production function.

The findings of the study revealed that factors which significantly determine irrigated rice production are the cropped area, the quantity of used chemical fertilizers and equipment expenses. Chemical fertilizers and equipment expenses have a positive coefficient as expected but the one associated with the cropped area is negative, which indicates that an increase in cropped area is a source of irrigated rice production decline. Cropped area and equipment were found to be complementary factors, which indicates that the only increase in cropped land cannot lead to a rice production increase without an improvement of operation implement.

The results also showed that the age of the head of the household and household size tend to reduce technical inefficiency. The pumping irrigation system at Sourou was found to be technically inefficient compared to the system operated at Kou valley.

Recommendations to improve the irrigated rice production in Burkina Faso focus on the main factors of technical efficiency including cropped area, chemical fertilizers use and equipment expenses. Any increase in the cropped area should be accompanied by an improvement of rice producers' equipment. Due to the intensive nature of irrigated rice growing, any extension of the cropped area which is not complemented with equipment for field operations such as plowing and planing) would be unnecessary because it would have a depressing effect on the production.

Water control for rice growing is indeed important but it is not enough to increase rice production. A policy which provides rice producers with adequate equipment (motorized plows. oxen-plows. harrows and others) as well as traction animals should be conducted on behalf of producers on existing sites, before increasing investments on water control infrastructures.

Although the chemical fertilizer revealed to be a key factor to irrigated rice production, this input is very costly and not available on a timely basis. Therefore, the Government needs not only to subsidize it, but should financially support the private sector responsible for the production and distribution of this critical input.

Another important result is that the pumping irrigation system operated at Sourou is technically inefficient compared to the 'along the river system' operated at the Kou valley. It should therefore be abandoned if it is not possible to substantially reduce operating costs, namely by using the solar energy for pumping irrigation water.

The average technical efficiency score of 87% is relatively high because the production conditions (such as the water availability) were well-controlled. However, for this technical efficiency score to stay at this high level, it is crucial to ensure that favorable conditions continue to prevail on the production sites. It is recommended that research (over several years) be conducted in order to better understand the evolution of the technical efficiency determinants and those of the associated technical inefficiency.

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