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RESEARCH ARTICLE

ECONOMIC EFFICIENCY OF MAIZE PRODUCTION IN THE CONTEXT OF CLIMATE CHANGE ADAPTATION IN THE OKPARA SUB-BASIN

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ABSTRACT

This study estimates the technical, allocative and economic efficiency of maize-producing farms in Benin and identifies the determining factors of these efficiencies in a context of adaptation to climate change. To achieve this, data was collected from a sample of 402 corn farmers randomly selected from the municipalities most vulnerable to the effects of climate change and located within the Okpara watershed perimeters. The parametric stochastic frontier approach was adopted to estimate a seedling-log stochastic frontier and a dual cost function of corn farms using the Frontier program of Stata 13 software. The Tobit regression model was used in order to identify the factors determining the efficiency of producers. The results show that the operators are all technically efficient and have significant random effects. However, the results from the cost frontier show the presence of allocative inefficiency within production units. The estimated technical, allocative and economic efficiencies are respectively on average 0,94, 0,60 and 0,57. Finally, estimation of the determinants of efficiency has shown that, the supply of mineral manure, experience in maize production, crop rotation as well as the level of education are the main determinants of efficiency.

INTRODUCTION

Climate change is one of the environmental phenomena that poses a significant threat to increasing or even stabilizing agricultural production of smallholder farming communities in Sub-Saharan Africa (SSA) (Bedeke and *al.,* 2019). This phenomenon affects crop productivity and resource use in SSA countries in the short, medium and long term. Despite much research on the impact of climate change on crop yields and food security, little is known about the effects of climate change on the efficiency of the use of the main factors of production of maize known as a staple food in Benin's agro-ecological zones. In Benin, despite the many agricultural policies implemented to make the agricultural sector competitive and sustainable, it must be noted that the impoverishment of the peasant masses has hardly regressed, and is accentuated by climatic risks, in this case long dry spells, recurrent floods and disruptions of seasonal climatic patterns (Akponikpe *et al*., 2019). As a result, these climatic disturbances, which are becoming increasingly noticeable to rural populations, have adverse effects on the productivity of factors of production, income and the well-being of farmers. Indeed, most smallholder farmers dependent on maize in Benin produce on fragile and degraded land with low fertility (Dedehouanou *et al*., 2011; Gbaguidi *et al*., 2015; Sodjinou and Hounkponou, 2019). Thus, these climatic disturbances plunge producers into a dead end that exacerbates the stress that these producers were experiencing due to their limited access to factors of production such as: land, financial capital and market information. Impact studies conducted by Tidjani and Akponikpe (2012) show that the scenarios presenting real risks of poor yields for maize varieties in northern Benin are those of rising temperatures and decreasing rainfall. Similarly, a recent study on the impact of climate change on agricultural incomes conducted by Sodjinou and Hounkponou, (2019) in six (6) departments of Benin indicate that the effects of climate change on cropping systems are expressed in terms of a decrease in agricultural production due to rainfall variability; the emergence of diseases, pests and pathogen vectors; new spatial distributions of pests and insect pests; and erratic and unpredictable rainfall. Further, the authors found that a reduction in rainfall of one millimetre would, all other things being equal, lead to a decrease in net farm income of 614 CFA francs/ha. To all this must be added the fragility of cereal crops, particularly maize, which is the most produced food in Benin, after yams and cassava, as noted (Tidjani and Akponikpe, 2012). Faced with this situation, international organizations, private agencies and public agricultural extension institutions are now actively promoting efforts to help smallholder farmers dependent on maize to adapt to climate change in SSA in general and in Benin in particular with the support of agricultural research services that have developed specific technologies adapted to different climatic

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conditions, next to practices or endogenous measures developed by producers to adapt to various climatic constraints (Dedehouanou *et al.,* 2011; Adétona *et al*., 2019). The adoption of these new practices in agricultural production systems would undoubtedly lead to the use of additional resources in terms of production factors and consequently, predispositions would be necessary in order to guarantee the effectiveness of the choices made by producers for the sustainability of the system. Climate change would also have implications for the processing, storage, transport, retail sale and consumption of agricultural products in general and maize in particular in Benin. However, in the study area, the technologies offered to producers for adaptation are limited to the production level, although the need for climate-resilient technology is growing across all parts of the maize value chain (Adanguidi and Quenum, 2005; Adebiyi *et al*., 2019; Agbodan *et al*., 2019; Adéyandjou*et al.,* 2020; Afouda*et al.,* 2020). It is therefore important to investigate the behaviour of producers adopting and not adopting these technologies in terms of optimising the resources available in this context of climate change. Indeed, increasing the volume of production through an increase in productive resources (sown areas in this case) is not a sustainable option for the agricultural production system. The increase in production does not necessarily require an overall increase in productive resources but can also result from other unobservable factors such as: the proper application of cultural practices (local knowledge and/or innovations), the right combination of factors and a good allocation of resources (Aminou, 2018). The aim of this research is to evaluate the economic performance of climate change adaptation strategies implemented in maize production in agroecological zones declared as the most vulnerable to climate risks in Benin, by estimating the technical, allocative and economic efficiencies of farmers and identifying the determinants of these efficiencies. Thus, the study aims to test the following hypotheses: (i) maize producers can improve their level of efficiency by keeping the level of consumption of the factors of production unchanged; (ii) climate change adaptation strategies such as the application of mineral and organic fertilizers, the adoption of new and improved varieties, the combination of crops and the practice of crop rotations determine effective producers. This study is structured in four (04) main sections. After this introductory section, the second section presents the materials and methods, then the results are presented in the third section and finally the last section discusses the results.

MATERIALS AND METHODS

Theoretical framework of the study: According to the traditional economic theory of the producer, the objective of all producers as economic agents is the maximization of profit (Chebil *et al*., 2013). Therefore, the production process involves not only technical capacities but also financial capacities of the producer for the achievement of its objectives. Indeed, the economic theory of the rational individual requires that in the production process, the producer must be rational in the combination of factors of production in order to minimize his cost of production and maximize his output (Muth, 1961). In order to account for this rationality in the use of resources, the notion of efficiency is widely used to measure and analyze the performance of production units. This concept of efficiency has gradually become relevant at the level of the agricultural sector and has had multiple applications and even adaptations in several sectors of activity according to the specificities of each sector. In the agricultural sector, efficiency can be defined as "the level at which producers achieve the best result with available resources and technologies" (Mamam *et al*., 2018). It therefore expresses the relationship between the potential results and the results obtained. The term inefficiency is used to mean that achieving the optimal capacity that efficiency aims at is an ideal and cannot be achieved in reality. The measurement of efficiency appeared in the work of (Koopmans, 1951) on the analysis of production and (Debreu, 1951) who introduced the resource utilization coefficient. In 1957, Farrell established that firm efficiency can be empirically calculated and proposed, for the first time, an innovative method of estimating efficiency frontiers from the observation of real production situations (Farrell, 1957). The concept of efficiency has three components: technical, allocative, and economic efficiency (Aminou, 2018; Chebil *et al*., 2013; Choukou *et al*., 2017). The simultaneous achievement of technical and allocative efficiencies is a necessary and sufficient condition for talking about economic efficiency. Indeed, it is possible for a firm to be technically or allocatively efficient without being economically so. Economic efficiency therefore appears to be the resultant between technical efficiency and allocative efficiency, exclusive and exhaustive components of economic efficiency according to (Aminou, 2018). This notion implies, on the one hand, that the firm makes an optimal combination of its factors of production and, on the other hand, minimizes its total production costs, chooses the level of the latter which must be socially optimal (in particular through an appropriate purchase and selling price or pricing policy) (Farrell, 1957). These first two efficiencies are necessary and, once achieved simultaneously, are sufficient conditions for achieving economic efficiency. This overview of the concept corresponds to that of Mamam *et al*., (2018) who note that achieving one of the two types of efficiency may be a necessary but not sufficient condition for achieving economic efficiency. It appears that a company is only economically efficient if it is technically efficient (or if it has the best technical and material organization) and allocates its productive resources efficiently; both conditions must be met simultaneously. In the literature, several methods and approaches are proposed for estimating efficacy depending on the context and nature of the study data. In the following sections, we will try to present the approaches and methods as well as the limitations and reasons for our choices.

Study Area: This study is being conducted in N'Dali, Pèrèrè and Tchaourou Districts, at Borgou Department and the District of Ouèssè,atCollines Department. The choice of these areas to conduct this study is justified by several reasons: the District of N'Dali and Pèrèrè are the most exposed to climate change according to the report of the Scientific Support Project for the National Adaptation Plan processes in 2019 (PAS-NAP) (Akponikpe *et al*., 2019).According to the same source, the District of Ouèssè and Tchaourou will see an increase in their maize production with climate change in the coming years. These Districts are renowned for the production of maize and represent areas where the risks associated with drought are very high. These are the reasons that conduct the populations of these localities along the Okpara River to cultivate the lowlands located in the perimeters of the river for their agricultural production activity. The results obtained in our previous chapters have shown that the majority of these producers perceive climate change and adopt practices (strategies) to adapt. Analysis of hydrological conditions in the Okpara basin shows that the high variability in rainfall depths during the period 1971-2010 has had an impact on the average flow of the

Okpara watershed. By 2050, this situation will have to be more difficult under the triple threat of a decrease in precipitation levels, an increase in temperatures and increased pressure from populations on natural resources in general and water resources in particular (Ogouwale *et al*., 2015).

Sampling and Data Collected: The research unit is made up of the heads of maize producing holdings selected at random. In each of the Districts selected for the study as described above, three (o3) villages were selected based on criteria such as the village's reputation in terms of maize production statistics, its position in relation to the Okpara watershed, its vulnerability to climate change. The choice of these villages to be surveyed was made in consultation with the agents of the Territorial Agency for Agricultural Development (ATDA) pole 4 and the Departmental Directorate of Agriculture, Livestock and Fisheries (DDAEP) of Borgou. For each village selected, a sample of 38 maize farmers is randomly selected from the results of a sampling frame using the random number table. A total of 410 producers were selected and surveyed, with 102 maize farmers per commune. A structured questionnaire is administered to them in order to collect primary data at the level of each individual in the sample. After the database was cleaned, a total of 402 producers were eventually used for the study. These are maize producers who are particularly vulnerable to climate change and who face problems of declining productivity. The data collected are: the socio-economic characteristics of the respondent, maize production systems, production factors, information on the perception of climate change, strategies for adapting to climate variability, costs of inputs used for production (seeds, pesticides, fertilizers, organic matter), quantities of labour used for maize production for the entire area, production costs, the costs of other factors of production, the selling prices of maize.

Table 1. Distribution of the sample by District after purification

Survey Districts	Sample size	Frequency (%)
N'DALI	99	24,63
PERERE	102	25,37
TCHAOUROU	101	25.12
OUESSE	100	24,88
Total	402	100

Data Analysis: In the literature, there are several approaches for estimating farm efficiency indices (Aparicio *et al*., 2017; Adeguelou *et al*., 2018; Mansour and El Moussawi, 2020). In this section, we present the approaches chosen, the reasons for the choice of approaches, and the specification of the models.

Empirical Model for Estimating Technical Efficiency: The literature distinguishes between parametric and non-parametric approaches. As mentioned above, the parametric approach is the most suitable for estimating agricultural production frontiers (Mansour and El Moussawi, 2020). As for the specification of the production frontier, the nature of the deviations between the observed output and the maximum output differentiates stochastic boundaries from deterministic boundaries. In the case of this study, the maize production frontier is modelled by the stochastic frontier based on the parametric approach for the determination of technical efficiency indices. In the case of this study, the maize production frontier is modelled by the stochastic frontier based on the parametric approach for the determination of technical efficiency indices. In addition, an exponential stochastic production frontier has been estimated. The explanatory variables used in our model are not favorable to a logarithmic transformation to adopt a Cobb-Douglass type specification, nevertheless a semi-logarithmic type specification (log-lin) has been adopted for the estimation of the production frontier. In this model, the dependent variable is taken in logarithm while the explanatory variables are simply linear. The parameters of the stochastic production frontier were estimated using the maximum likelihood method. The functional form (log-lin) was tested based on statistical tests of $\chi 2$ of the likelihood ratio to choose those that give the best estimates. Consider a maize farmer who combines factors of production (acreage, seeds, labour, herbicide and fertilizer (chemical and organic)) to produce a good (Prod), (quantity of maize harvested). The specified form of the stochastic production frontier as an equation to be estimated is as follows:

$$Ln(Prod_i) = \beta_o + \beta_1(Sem_i) + \beta_2(Engr_i) + \beta_3(Herbi_i) + \beta_4(Trav_i) + \beta_5(Sup_i) + \mathcal{V}_i - \mathcal{U}_i$$

Where, i represents corn producers i = 1 …………..n

n: the sample size; β_i Is the vector of the parameters to be estimated; it represents semi-elasticities because the production function is of the log-linear or semi-logarithmic type; $Prod_i$: Maize production in (Kg/ha) ; Sem_i: Amount of seed used in (Kg/ha); $Engr_i$: Total quantity of NPK and Urea fertilizer used (Kg/ha); $Herbi_i$: : Amount of herbicide used in litres (L/ha); $Trav_i$: Quantity of labour used (family and/or salaried) in man-days/ha;Sup_i: The area sown to maize in (ha); $\mathcal{V}_i$:: is the random error term; $\mathcal{U}_i$: : is an error term that reflects the technical inefficiency of the farmer$_i$. It should be noted that the calculation of the work times was carried out by choosing man/day as the basic unit. For this purpose, the weights applied by FAO were used. These coefficients are expressed as man-to-day equivalents. Then, the working time in man/day is determined by dividing the total number of hours worked by 8 (one man/day is equivalent to 8 hours of work per day). There are two hypotheses to consider regarding error terms: we assume that $\mathcal{U}_i$follows a normal distribution of parameters and $\mathbb{N}(0, \sigma_{\mathcal{U}}^2)$ follows a truncated normal distribution, i.e.$\mathcal{V}_i \rightarrow \mathbb{N}(0, \sigma_{\mathcal{V}}^2)$. On the basis of his assumptions, we obtain from the FRONTIER program of Coelli, (1998), the coefficients and$\sigma^2 = \sigma_{\mathcal{U}}^2 + \sigma_{\mathcal{V}}^2$; $\lambda = {}^{\sigma_u}/_{(\sigma_u + \sigma_v)}$ and λ measure the share of technical inefficiency in the total variation observed between points on the production frontier and the data. The technical efficiency indices are calculated by the following formula and obtained using the Stata 13 software.

$TE_i = \exp(-U_i)$

Empirical Model for Estimating Economic and Allocative Efficiency: The literature reveals that, like technical efficiency, economic efficiency is obtained after estimating a production cost model. This cost frontier can be obtained by means of the duality derivation of the semi-logarithmic production frontier function. This function will take the functional form defined for its primal equivalent, which is the production frontier function. The log-linear cost frontier function was used to estimate economic efficiency indicators in this study, drawing on the work of (Choukou *et al*., 2017). The specified equation of this model to be estimated is in the following form:

$$Ln(CT_i) = \beta_o + \beta_1(P.Sem_i) + \beta_2(P.Engr_{NPKi}) + \beta_3(Taux_i) + \beta_4(P.Trav_i) + \beta_5(P.Engr_{Uréi}) + \mathcal{V}_i - \mathcal{U}_i$$

With:

$Ln(CT_i)$, the logarithmic value of producer i's cost of production of maize expressed in CFA francs/kg; $P.Sem_i$, the average price of seed from producer i expressed in CFA francs/kg;$P.Engr_{NPKi}$, the average price of producer i's NPK fertilizer expressed in CFA francs/kg; $Taux_i$, the average interest rate of the credit obtained by producer i expressed in CFA francs/kg; $P.Trav_i$, the average price of labour expressed in FCFA/HJ; $P.Engr_{Uréi}$, the average price of urea fertilizer expressed in FCFA/kg; $\mathcal{V}_i$: is the random error term; $\mathcal{U}_i$: is an error term that reflects the economic inefficiency of the farmer i.

The economic efficiency indices are calculated by the following formula and obtained using the Stata 13 software.

$EE_i = \exp(-U_i)$

After achieving economic efficiency (EE)), it can be broken down into technical and allocative efficiency. The allocative efficiency (EA_i) is therefore estimated by the following equation:

$$EA_i = \frac{EE_i)}{ET_i)}$$

With:EE_i , economic efficiency and ET_itechnical efficiency.

Estimation of Factors Determining of Technical, Economic and Allocative Efficiency: After estimating efficiency levels, it was found that a significant proportion of producers still had inefficiencies in corn production. In other words, possibilities still exist to save on production costs with their current production. The method frequently used to explain efficacy levels is a two-step process, according to the literature presented above. It consists first of all of estimating the efficiency levels of the different farmers, then of regressing its efficiency levels according to certain specific factors such as: the size of the farm, the age and level of education of the farmer, access to credit, the training received by the farmer and his membership of a group, the area sown, the sex. Thus, the regression carried out during this second step can follow the linear regression model or the Tobit model to take into account the truncated nature (between 0 and 1) of the dependent variables, which in our case, are the technical (SD), economic (EE) and allocative (EA) efficiency indices. The equations for these three models are as follows:

$$ET_i = \alpha_0 + \sum a_i X_i + e_i$$

$$EA_i = \alpha_0 + \sum a_i X_i + e_i$$

$$EE_i = \alpha_0 + \sum a_i X_i + e_i$$

With X_i the explanatory variables (Table 2), $\alpha_0$the constant terms, $a_i$the regression coefficients and e the error terms. The full empirical form of the models is as follows:

$$(ET_i) = \alpha_o + \alpha_1 age_i + \alpha_2 sexe_i + \alpha_3 ethnie_i + \alpha_4 expm_i + \alpha_5 ufm_i + \alpha_6 ufo_i + \alpha_7 uvsa_i + \alpha_8 ac_i + \alpha_9 rc_i + \alpha_{10} ni + \alpha_{11} actip_i + \alpha_{12} cvulg_i + e_i$$

$$(EA_i) = \alpha_o + \alpha_1 age_i + \alpha_2 sexe_i + \alpha_3 ethnie_i + \alpha_4 expm_i + \alpha_5 ufm_i + \alpha_6 ufo_i + \alpha_7 uvsa_i + \alpha_8 ac_i + \alpha_9 rc_i + \alpha_{10} ni + \alpha_{11} actip_i + \alpha_{12} cvulg_i + e_i$$

$$(EE_i) = \alpha_o + \alpha_1 age_i + \alpha_2 sexe_i + \alpha_3 ethnie_i + \alpha_4 expm_i + \alpha_5 ufm_i + \alpha_6 ufo_i + \alpha_7 uvsa_i + \alpha_8 ac_i + \alpha_9 rc_i + \alpha_{10} ni + \alpha_{11} actip_i + \alpha_{12} cvulg_i + e_i$$

The main potential determinants of corn production efficiency levels are presented in

RESULTS

Descriptive statistics of database variables: Table 3 presents elements of the descriptive statistics of the variables in the Stochastic Production Frontier model. Overall, the average maize production per hectare is 1129.448kg with an estimated gap of 535.2543kg between producers.

Table 2. Variables Introduced into the Tobit Model and Expected Signs

Variables	Codes	Measurements	Expected signs
Age	age	Continuous variable (in year)	±
Sex	Sex	Binary variable (1 = male, 0 = female)	±
Experience in production	expm	Continuous variable	+
Educational attainment	ni	0=none, 1=primary, 2-secondary1, 3=secondary2, 4=high school	±
Ethnic group	Ethnie	1-Bariba, 2-Dendi, 3-peulh, 4-, 5-Nago, 6-Autres	±
Mineral Fertilization	ufm	Binary variable (1 = Yes, 0 = No)	+
Organic Fertilization	ufo	Binary variable (1 = Yes, 0 = No)	+
Use of Improved Seed Varieties	uvsa	Binary variable (1 = Yes, 0 = No)	+
Access to credit	ac	Binary variable (1 = Yes, 0 = No)	+
Crop rotation	rc	Binary variable (1 = Yes, 0 = No))	+
Main activity according to the size of income	actip	1= Agriculture ; 2= trade ; 3= breeding ; 4 = handicraft ; 5= fishing ; 6 = worker ; 7 = Services ; 8=processing, 9=other crops	+
Contact with extension services	cvulg	Binary variable (1 = Yes, 0 = No)	+

The average total amount of seed used is 34.04726 kg (±30.29967 kg) and also varies greatly from one grower to another. The quantities of NPK fertilizer and urea fertilizer are respectively 109.5896 (± 201.7122) kg/ha and 44.7139 (± 87.3643) kg/ha. The total labour force expressed here includes the family and salaried labour used by the producer for his farm. On average, it is 17.22637 (± 107.5264) man-days per hectare per producer in the study area with a strong variation around the average. The average area sown by producers in the area to produce corn is 2.0827 (±1.5542) ha. The gap in acreage between producers is significant and raises questions of land disparity.

Table 3. Descriptive Statistics for Quantitative Variables

Variables	Average	Std. deviation	Min	Max
Yield	1129.448	535.2543	44.4	5200
Area	2.082711	1.554246	0.25	10
Number of Labor	17.22637	107.5264	0	1000
Seed Quantity	34.04726	30.29967	3	250
Fertilizer (NPK)	109.5896	201.7122	0	1500
Urea Fertilizer	44.71393	87.36432	0	750
Herbicide quantity	5.830846	8.001324	0	72

Other socio-economic characteristics of the sample: Table 5 presents some characteristics of the sample studied. The analysis of this table shows that in the study area, women and men are engaged in maize cultivation, but women are less represented than men, with proportions of 7.21% compared to 92.79% respectively. This low proportion of women in maize production in the study area reveals that there are still gender disparities in access to land for sociological reasons. In addition, the majority of producers are engaged in agriculture as their main activity with a proportion of 89.6%. Other activities are also carried out as main activities, such as: animal husbandry, trade and others. This diversification of sources of income is also a strategy to reduce the vulnerability of populations to climate change. There is also a low school enrolment rate for producers. 70.9% of our sample is not in school. Financial inclusion still remains a challenge as 94.78% of producers do not have access to credit. It should also be noted that the majority of producers have not received any technical training in agricultural production (91.98%). Nevertheless, 25.9% of the producers in our sample are affiliated to a producer group or association. As an endogenous measure of adaptation to climate change, the majority of producers (87.1%) adopt while 39.8% use the addition of chemical fertilizers to support soil fertility in a context of adaptation to climate change. As far as the use of organic fertilizers is concerned, few producers (08.7%) adopt this measure.

Table 4. Other socio-economic characteristics of the sample

haracteristics	Absolute frequencies	Relative frequencies (%)	characteristics	Absolute frequencies	Relative frequencies (%)
Sex			Main activities		
Male	373	92,79	Agriculture	360	89,6
Female	29	7,21	breeding	12	3,0
Total	402	100	trade	18	4,5
			others	12	3,0
			Total	402	100,0
Instruction			Secondary activities		
None	285	70,9	Agriculture	31	7,7
Primary Secondary	74	18,4	Breeding	93	23,1
Total	43	10,7	Trade	121	30,1
	402	100	Handcraft	93	23,1
			others	64	15,92
			Total	402	100,0
Access to Credit			Use of organic Fertilize		
Yes	21	5,22	Yes		
No	381	94,78	No	35	08,7
Total	402	100	Total	367	91,3
				402	100
Capacity Building			Member of a group		
Yes	28	8.02	Yes	104	25,9
No	321	91.98	No	298	74,1
Total	66	100	Total	402	100
Use of Mineral Ferilizer			Crop rotation		
Non			No		
Yes	242	60,2	Yes	52	12,9
Total	160	39,8	Total	350	87,1
	402	100,0		402	100,0

Estimation of model parameters using the stochastic frontier: Estimation of the parameters of the corn production frontier was performed using the Frontier program of the Stata 13 software using the maximum likelihood method and the results obtained are presented in Table 5. The analysis of the results shows that the model is globally significant at the 1% level. This means that the estimated coefficients taken as a whole are significantly different from zero. On the other hand, the significance test for the effects of technical inefficiency in corn production in the study area indicates acceptance of the null hypothesis of no technical inefficiency effect. The null hypothesis tested is that all maize producers surveyed are technically efficient. The coefficient of this parameter ($\sigma^2 U$,) in the equation of the production function, is not significantly different from zero at the 1% threshold (P>z=1,000). As a result, the variation in production observed at the level of the production units studied is exclusively due to random effects. The parameter obtained by the following formula $\lambda = {}^{\sigma_u}/_{(\sigma_u + \sigma_v)}$ measures the share of technical inefficiency in the total variation observed between the points on the production frontier and the data. According to our results, this parameter is roughly equal to zero (λ= 0.00014) and not significantly different from zero at the 1% threshold. These results confirm the absence of technical inefficiencies at the level of production units. The stochastic formulation of the frontier is confirmed by the significance of the parameter which represents the deviation due to random effects that influence production and are not directly under the control of the farmer. These results reveal the importance of the vulnerability of producers in the area to climate change. In terms of the variables introduced into the model, the variables quantity of chemical fertilizer (P>z=0.000) and the area sown reveal coefficients significantly different from zero to the 1% threshold. As for the other variables, they do not show a significant effect. These results lead us to conclude that when the amount of fertilizer varies by 1%, there is an increase in maize yield. On the other hand, the 1% increase in the area sown has negative effects on maize yield in the study area. Given that climatic risks are significant, the extension of production, which results in an increase in the area, exposes the producer more to risks and therefore reduces his technical efficiency. In general, we can conclude from the results of this model that, overall, maize producers in the study area are technically efficient with an average efficiency index of 94.37%. In other words, corn producers in the study area make a good mix of production factors and get the best possible result in a changing climate. The results of the maximum likelihood ratio test reveal a lack of technical inefficiency effect among producers. This means that it is no longer possible to increase maize production at the level of these producers with the same levels of consumption of the factors available. Despite of these satisfactory results as far as technical efficiency is concerned, we shall present in the following lines the results relating to the economic and allocative efficiency of producers before moving on to the discussion of these results.

Tableau 5.

Ln(rendement)	Coef,	Std, Err,	z	P>z	[95% Conf,	Interval]
Fertilizer qtity	1,281009	0,193417	6,62	0,000	,9019185	1,660099
Seed quantity	-0,38851	1,421582	-0,27	0,785	-3,174762	2,397736
Labor quantity	-0,01400	0,036761	-0,38	0,703	-,0860552	,0580454
Herbicide quantity	4,971784	4,693335	1,06	0,289	-4,226983	14,17055
Area	-144,804	27,02207	-5,36	0,000	-197,7665	-91,84192
_cons	1289,367	814,3644	1,58	0,113	-306,7582	2885,492
Number of obs = 402 Wald chi2(5) = 63,40 Prob > chi2 = 0,0000 Log likelihood = -3066,1395 Likelihood-ratio test of sigma_u=0: chibar2(01) = 0.00 Prob>=chibar2 = 1.000						
/lnsig2v ($\square_{\square}^{\square}$)	12,41655	,0705349	176,03	0,000		
/lnsig2u ($\square_{\square}^{\square}$)	-5,215064	27631,18	-0,00	1,000		
sigma_v ($\square_{\square}$)	496,843	17,52239				
sigma_u ($\square_{\square}$)	0,0737163	1018,433				
sigma2 ($\square^{\square}$)	246853	17411,93				
Lambda (λ)	0,0001484	1018,639				

Estimation of the Parameters of the Model of Production Cost: The stochastic cost frontier established in this research as presented above is of the log-linear type. Estimates were made using the maximum likelihood (MV) method in the Frontier program of Stata 13 software. The estimation results are presented in Table 6 for the cost frontier function. These results show that the model is well specified and globally significant at the 1% level (Wald chi2(5) = 63.40 and Prob > chi2 = 0.0000). The results reveal a λ greater than unity (λ=2.040) and significant at 1%, indicating that there is allocative inefficiency at the producer level. Also, this λ value indicates that producers could achieve current yields at a relatively lower cost. The presence of allocative inefficiency was tested using the maximum likelihood ratio test (chibar2(01) = 16.93, Prob>=chibar2 = 0.000).The null hypothesis tested is that all maize producers surveyed are allocatively efficient. The results of this test reject the null hypothesis of no allocative inefficiency at the 1% level. In addition, the coefficient of the parameter, in the cost function equation, is significantly different from zero at the 10% level. Therefore, the variation in cost observed at the level of the production units studied is partly due to the effects of producer inefficiency. These results confirm the presence of allocative inefficiency at the level of production units. With regard to the individual significance of the variables in the cost of production model, it is noted that among the six (06) variables introduced into the model, four (04) are significantly different from zero. These are the variables: average herbicide price, average seed price, average NPK fertilizer price (at the 1% threshold) and the average urea fertilizer price (at the 5% threshold). The negative and significant sign of the average seed price is an unexpected sign and deserves to be discussed in the discussion section. However, the negative and non-significant effect of the interest rate is in line with expectations insofar as only 5% of producers have access to credit and with still very high interest rates. As for the price of labor, the non-significant effect can be explained by the abundance of family labor in relation to salaried labor.

The values of the estimated parameters represent the semi-elasticities (unit change in input prices relative to the change in cost). As expected, production inputs significantly affect the cost of production. Specifically, the price of fertilizers (NPK and Urea), herbicide and seed.

Table 6. Estimating Stochastic Cost Frontier Parameters

Ln_CT	Coef.	Std. Err.	z	P>z
Herbicide Price	0,00046	0,000028	16,21	0,000
Seed Price	-0,00004	8,33e-06	-4,910	0,000
NPK Fertilize Price	8,25e-06	1,66e-06	4,960	0,000
Interest Rate	-0,00511	0,007344	-0,700	0,486
Labor Price	0,00821	0,006011	1,370	0,172
Urea Fertilizer Price	7,48e-06	3,65e-06	2,050	0,040
_cons	9,278594	0,110614	83,88	0,000
N = 402 Wald chi2(6) = 625,29 Prob > chi2 = 0,0000 Likelihood-ratio test of sigma_u=0: chibar2(01) = 16,93 Prob>=chibar2 = 0,000				
/lnsig2v (σ_v^2)	-1,73026	0,2117811	-8,17	0,000
/lnsig2u (σ_u^2)	-0,30410	0,1830433	-1,66	0,097
sigma_v (σ_v)	0,420994	0,0445794		
sigma_u (σ_u)	0,858943	0,0786119		
sigma2 (σ^2)	0,915021	0,1106606		
Lambda (λ)	2,040271	0,1152546		

Distribution of technical, allocative and economic efficiency indices: After estimating the stochastic production and cost frontiers, the technical, allocative and economic efficiency indices were calculated and presented in Figure 1 below.From the analysis of this graph, it can be seen that the producers in the study area have, on average, a technical efficiency of 94.37%, an allocative efficiency of 60.32% and an economic efficiency of 56.93%.Overall, these more or less satisfactory results show that producers do combine the factors of production with optimal choices but with production costs relatively higher than the optimal cost and therefore do not achieve economic efficiency in the production of maize in the study area.These results indicate that these producers can maintain this same level of production by achieving economies of scale in corn production in a context of adaptation to climate change.

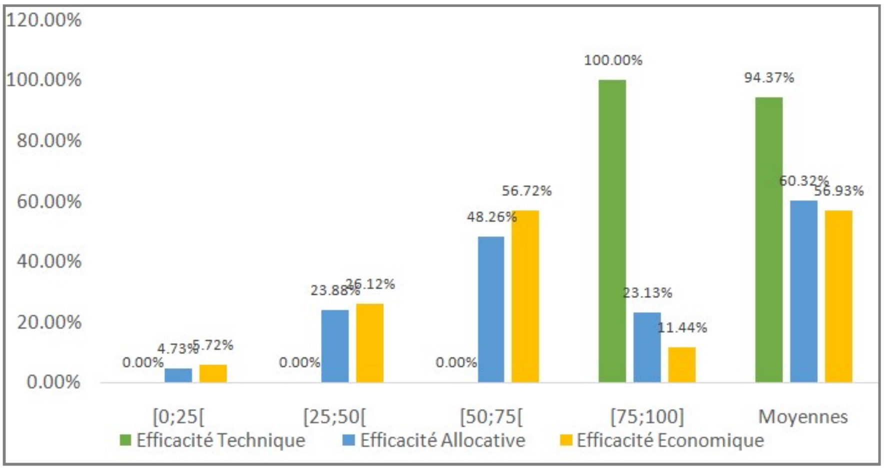

Figure 1. Producer frequencies by type of technical, allocative and economic efficiency

These results show that there is untapped potential in terms of input cost savings and maize production. It should be noted that, although 100% of the producers achieved a technical efficiency of more than 75%, only a small proportion of 23.13% were able to achieve an allocative efficiency score greater than or equal to 75% and 11.14% for economic efficiency.In view of these different results obtained on efficiency, it emerges that the adaptation strategies adopted by producers such as: the application of chemical and organic fertilizers to improve the fertility of the soil, the adoption of new varieties and crop rotation have positive effects on their technical performance but do not y*et al*low economic and sustainable performance to be achieved at this stage.

Distribution of efficiency indices by farm group: The results of the typology of farms using the Mixed Data Factor Analysis (MDF) and the Hierarchical Ascending Classification (AHC) presented in the previous chapters showed that there are three (03) groups of agricultural holdings: the group of traditional farms, the group of modern farms using chemical fertilizers for the sustainable management of soil fertility and finally the group of agroecological farms who produce corn organically. A distribution of technical, allocative and economic efficiency indices according to these different groups for comparison. The analysis of the results (Figure 2) showed that the three groups of farms are technically efficient with an average score of 94.38% technical efficiency. However, organic production has better allocative and economic efficiency scores compared to traditional and conventional production. Indeed, for organic farms, the average allocative and economic efficiency scores are respectively 62.83% and 59.30%, while they are respectively 59.82% and 56.46% for modern or conventional farms and 60.52% and 57.12%

respectively for traditional farms. Overall, it can be noted that underperformance is noted at the level of conventional farms compared to other groups of farms.

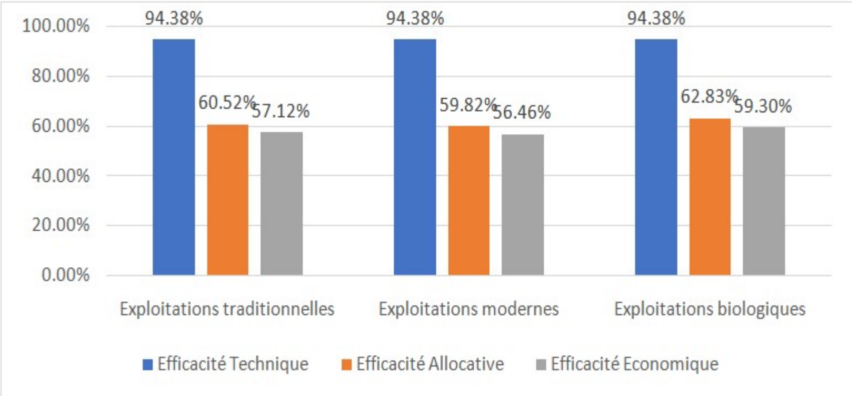

Figure 2. Distribution of efficiency scores by farm groups

Factors Determining Different Types of Efficiencies: The results of the analysis of the factors affecting the technical, allocative and economic efficiency indices are obtained from a Tobit regression carried out using the Stata 13 software and the results are presented in Table 8. These results reveal that only the variable mineral fertilizer application has a positive and significant effect at the 5% threshold on the technical efficiency of producers. These results therefore indicate that the adaptation strategy to support soil fertility is a significant source of technical efficiency for maize producers in the study area. As far as allocative efficiency is concerned, it is influenced by the variables experienced in maize production and mineral fertilizer application at the 1% threshold and crop rotation as well as the level of education at the 5% threshold. In addition, only the effect of mineral fertilizer application is positive on allocative efficiency, the others are negative. As for economic efficiency, it is negatively and significantly influenced by the number of years of experience, crop rotation and the low level of education of producers, while the strategy of applying chemical fertilizer is always significant with a positive effect on economic efficiency at the 1% level.

Table 7. Factors Determining Different Types of Efficiencies

Variable	Technical Efficiency	Allocative Efficiency	Economic Efficiency
age	1,433e-08	0,00140724	0,00132816
Sexe	1,886e-07	-0,04524128	-0,0426984
Ethnie	-2,479e-09	-0,00125337	-0,00118295
expm	-3,208e-08	-0,00406704***	-0,00383848***
ufm	1,088e-06*	0,09088193***	0,08577482***
ufo	6,074e-07	0,01378139	0,01300717
uvsa	4,116e-08	0,00290583	0,00274255
ac	1,547e-07	-0,00320134	-0,00302118
rc	-3,128e-07	-0,06512748*	-0,06146727*
ni	3,833e-07	-0,02722718*	-0,02569672*
actip	4,748e-07	0,01944488	0,01835234
cvulg	-5,411e-07	0,02333614	0,02202425
_cons	,94379581***	0,66491148***	0,6275407***
sigma			
_cons	3,608e-06***	0,16669425***	0,15732569***
Statistics			
Chi2	19,427108	68,714424	68,714954
AIC	-8748,7881	-263,11998	-308,81608

RESULTS AND DISCUSSION

The results of the estimation of the stochastic frontier parameters reveal the absence of technical inefficiency of the producers and therefore attribute the small differences observed between the estimated potential production and the actual output obtained to purely random effects. This interesting result can be explained by several factors. Producers have accumulated experience (on average 17 years) in maize production, which allows them to make better choices of production factors for a maximum level of yield. In addition, the majority of them are members of farmers' organizations and therefore benefit from the technical support of research and agricultural advisory structures through innovation packages proposed and made available to them. Indeed, these results are at odds with previous work on the technical efficiency of corn production, which has always noted the presence of technical inefficiency among producers. This is the case with the work of (T. S. Mamam *et al.,* 2016; Choukou*et al*., 2017; Aminou, 2018). At the level of the variables introduced into the model, the results reveal that the variables: quantity of chemical fertilizer (P>z=0.000) and the area sown reveal coefficients significantly different from zero to the 1% threshold. The positive and significant effect of chemical fertilizer application is unanimously agreed upon by several authors (Albouchi*et al.,* 2005;

Choukou*et al.,* 2017; Aminou, 2018).As far as the negative significance of the area is concerned, it means that the increase in the area sown by the producer makes him further away from the frontier of production. These results, although surprising, are only a confirmation of the fact that small producers are more technically efficient than large producers demonstrated by several studies. It is explained by the fact that producers operate in a random environment and whose increase in area increases the risk of technical inefficiency (Chogou*et al.,* 2013; T. Mamam *et al.,* 2016; Aminou, 2018; Mamam *et al.,* 2018). The results confirm the presence of allocative inefficiency at the level of maize production units, in contrast to the results relating to technical efficiency. These results are similar to those of (Choukou*et al.,* 2017) who analyzed the economic efficiency of resource allocation in maize production in Kanem-Chad and argued that not all maize producers surveyed are allocatively efficient. Regarding the individual significance of the variables of the production cost model, we note that the variables: average herbicide price, average seed price, average NPK fertilizer price at the 1% threshold and the average urea fertilizer price at the 5% threshold. The negative and significant sign of the average seed price is an unexpected sign and can be explained by the fact that the majority of producers do not adopt the new varieties.The majority of these producers use maize harvested for the previous season as seed for the next season, and therefore the increase in this quantity could have negative effects on the cost of production, especially since it is taken for free. These results call into question those of (Ahouangninou *et al.,* 2020) who established that a variation in the unit prices of seeds and chemical fertilizers leads to a significant variation in the cost of production. The distribution of efficacy indices reveals an average score of 94.37% for technical effectiveness, 60.32% for allocative efficacy and 56.93% for the combined effect of the first two types of efficacy in the study area. These results, compared to those of (Mamam *et al*., 2018) who assessed the level of technical efficiency of maize-based production systems in Benin, appear to be better.Indeed, these authors estimated that the technical efficiency index of the maize-based production system in Benin varies from 37.37 to 96.22% for all systems, and that of the average technical efficiency is 80.35%. In addition, the results obtained by (Choukou *et al.,* 2017) who analyzed the economic efficiency of resource allocation in maize production in Kanem-Chad seem to be better than our results in terms of allocative and economic efficiency. The authors found that the average allocative efficiency is 80.5% and the economic efficiency of maize production is between 13.6% and 83.4% and the average is 55.8%. On the other hand, the average technical efficiency estimated in our study at 94.37% is higher than that estimated for smallholder producers in Benin by (Aminou, 2018).This author in his study estimated the average technical efficiency score of the producers in his sample at 65.40% with a minimum of 20.47% and a maximum of 93.46%.As for the determinants of the different types of efficiency, our results indicate that technical efficiency is positively influenced by the use of chemical fertilizers for the sustainable management of soil fertility adopted by producers as a climate change adaptation strategy. These results differ from those of (Aminou, 2018) which identify factors such as: the gender of the farmer, the use of improved seeds, the selling price of maize, the share of off-farm income, contact with an NGO, access to credit and production area as the main determinants of the technical efficiency of smallholder maize producers in Benin.Our results also reveal that low educational attainment, low crop rotation, and proven experience of producers in maize production have significant negative effects on their allocative efficiency. Indeed, the instruction allows the producer to assimilate the training provided to him and to master the technical itinerary. It is true that most of the training and awareness-raising campaigns carried out by research and development organizations are carried out in the local language, but education awakens the consciousness of the individual to assimilate the new knowledge acquired in a rapid manner. It allows the individual to have a spirit of openness and discernment. This works in favour of the adoption of new technologies. The instruction allows maize producers to choose the appropriate amounts of inputs and to make a good choice given the cultivation techniques available and the prices offered on the market (Ahouangninou *et al.,* 2020).These results of the study are in agreement with those found by (Ahouangninou *et al.,* 2020) according to which the age of the producer, the area sown, the contribution of nightshade to income, the level of education and technical training are the main determinants of the technical, allocative and economic efficiency of nightshade producers in southern Benin.The results of this study are also consistent with those of (Choukou *et al.,* 2017) regarding the positive effect of fertilization on the technical, allocative and economic performance of maize producers.

CONCLUSION

The objective of this study is to assess the technical, economic and allocative efficiency levels of maize production on riverside farms in the Okpara watershed in order to identify the determinants of different types of efficiency. The results obtained from the analysis of the data revealed that the producers have an average technical efficiency score of 94.37% and accept the null hypothesis of no technical inefficiency among the producers. The least technically efficient producer has an index of 0.9436 and the most efficient has an index of 0.9438, indicating little variation between producers. On the other hand, the results of estimating the parameters of the cost frontier confirm the presence of allocative inefficiency at the level of production units. These results indicate that the variables: average herbicide price, average seed price, average NPK fertilizer price (at the 1% level) and the average urea fertilizer price (at the 5% level) are the main determinants of the maize production cost frontier.Finally, the estimation of the determinants of technical efficiency showed that only the variable mineral fertilizer application has a positive and significant effect at the 5% level on the technical efficiency of producers. These results therefore indicate that the adaptation strategy to support soil fertility is a significant source of technical efficiency for maize producers in the study area.As far as allocative efficiency is concerned, it is influenced by the variables experienced in maize production and mineral fertilizer application at the 1% threshold and crop rotation as well as the level of education at the 5% threshold. In addition, only the effect of mineral fertilizer application is positive on allocative efficiency, the others are negative.As for economic efficiency, it is negatively and significantly influenced by the number of years of experience, crop rotation and the low level of education of producers, while the strategy of applying chemical fertilizer is always significant with a positive effect on economic efficiency at the 1% level. In view of the results obtained and presented above, this study concludes that the climate change adaptation strategies adopted by producers following their perception of climate change significantly improve their technical performance but do not promote allocative and economic efficiency. These indices draw attention to the need to strengthen the support system for maize producers in the management of resources on their farms.

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