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Comparative Technical Efficiency of Maize Growers in the Northern Region of Cote D'ivoire: Stochastic Meta Frontier Analysis

Loa Bi Loa Rodolphe[1*], N'guessan Sylvain[2], Karamoko Bintou[3]

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ABSTRACT

This study investigates maize production efficiency in northern Côte d'Ivoire, a savannah region where maize farming is closely integrated with cotton-based production systems. The analysis is motivated by the national policy objective of achieving cereal self-sufficiency in a context of increasing agronomic and technological constraints. A key gap in the literature is that few studies account for technological heterogeneity between farmers using traditional maize varieties and those adopting improved hybrid seeds, while also clearly distinguishing technical inefficiency from technology-driven productivity differences. The empirical analysis is based on a cross-sectional sample of 313 maize-producing farms drawn from cooperative-based cotton and maize farmers. Data were collected through a survey conducted under the COMPACI (Competitive African Cotton Initiative) project in collaboration with Cotton Made in Africa (CmiA), which promotes the dissemination of improved agricultural technologies, particularly hybrid maize seeds. Methodologically, the study applies a Stochastic Meta-Frontier Analysis (SMFA) production function framework, which enables the estimation of group-specific production frontiers and a common meta-frontier, while decomposing productivity differentials into technical efficiency and technology gap components. The results reveal a substantial technology gap of approximately 63% in favor of improved maize systems, with hybrid seed adopters achieving significantly higher productivity levels. Market orientation and greater land allocation to cash and alternative food crops are found to reduce technical efficiency. Overall, the findings highlight the central role of technological upgrading in enhancing maize productivity and strengthening food security in the study area.

INTRODUCTION

For several years now, agriculture has been a highly strategic sector, making a significant contribution to economic growth in Côte d'Ivoire. Given the stakes involved, developing this sector remains a major challenge for the country. With this in mind, the Ivorian government has set up the National Agricultural Investment Program (PNIA) to revitalize the sector and boost the country's agricultural production capacity. Several strategies have been developed to ensure efficient implementation of the PNIA. One of these is the national strategy for the development of food crops other than rice (SNDCV), which has identified maize as a priority crop. Maize is the main cereal used to feed people in West Africa (Adjanohoun *et al.*, 2012). It is also the most energetic and economical cereal from a production point of view (Charcosset and Gallais, 2009; Nuss & Tanumihardjo, 2011). In Côte d'Ivoire, this cereal is the fifth most important food crop in terms of tonnage produced, after cassava, plantain, yam and rice. Increasing agricultural productivity in general will only be effective if producers have access to and adopt the technological innovations developed by research. Among these innovations, improved maize varieties occupy pride of place. As a result, the country has embarked on large- scale intensive maize production with the support of agro-industrialists (long leases from the State/integration of small-scale producers on equivalent land), mainly for animal feed, where demand is high for the development of short-cycle livestock (poultry and pigs), and as a raw material for certain industries (breweries, soap factories and oil mills) (Yeo, 2011). Maize has thus become the second most important cereal crop after rice.

In the northern zone, maize has become the second most important crop in agricultural production systems often dominated by cotton and/or cashew nuts. Farmers in the north of Côte d'Ivoire rely on the marketing of maize alongside cotton and cashew nuts to boost their incomes. This cereal systematically occupies an important place, both in terms of its presence on farms and in terms of the area devoted to it. With an average annual production of around 600,000 tonnes, the productivity of maize farms in Côte d'Ivoire increased from 1.5 tonnes per hectare to 2.1 tonnes per hectare between 1995 and 2015 (FAOSTAT, 2016).

However, despite all the efforts made, the supply of maize is far from meeting the ever- increasing demand, and yields are increasingly low due to frequent climatic disturbances. Although Côte d'Ivoire's favorable agro-ecological conditions facilitate the diversification of food

[1] Abidjan University Institute (UIA), Ivory Coast
[2] Economic Policy Analysis and Modeling Laboratory (LAMPE), Alassane Ouattara University of Bouaké, Bouaké, Ivory Coast
[3] University Félix Houphouët-Boigny, Ivory Coast
[*] Corresponding author's e-mail: rodloabi@yahoo.fr

production systems, food security remains a problem. The country's score on the Global Hunger Index fell from 32.6 to 26.5 between 2000 and 2017, but it still falls into the "severe" category. An estimated 12.8 percent of the population was food insecure or severely food insecure (4.2%) in 2015 (WFP, 2019). Food insecurity is most pronounced among farming households (14.3 percent), particularly in the rural north, whose access to sustainable food sources is limited by poor farming practices, environmental degradation, climate disruption, post-harvest losses , market access problems and lack of dietary diversity (WFP, 2018). More than half of food-insecure households in the Savanes region are farming households (53%). In this region, 20% of food-insecure households resort to credit or borrowing to be able to meet their needs (WFP, 2018).

It is therefore clear that the main constraint facing the maize sector is its low productivity (CORAF, 2018). To address this constraint and increase production, the Ivorian government has opted for maize varietal innovation by initiating a maize technology transfer program in the farming environment through the cultivation of hybrid maize. To help improve maize yields, it is therefore necessary to replace the local varieties that represent the bulk of the planting material used (Missihoun *et al.*, 2012) with improved varieties with high yield potential (Deffan *et al.*, 2015). Several improved maize varieties have been developed by the Centre National de Recherche Agronomique (CNRA). However, the input supply company Callivoire has developed two high-yielding hybrid varieties of white and yellow maize adapted to Ivorian agro-climatic conditions, and the Arysta group it represents in Côte d'Ivoire has set up a research hub focused on maize that develops technical solutions adapted to the West African context (Rongead, 2014). The adoption of Callivoire yellow maize (Manoj or Kabamanoj or F1) is fundamentally part of the success of an agricultural innovation, which is largely dependent on the effectiveness of its dissemination, given that low agricultural productivity is fundamentally due to the low use of improved varieties by producers (MAEP, 2014).

However, if productivity gains can be achieved through the adoption of this maize innovation, it remains undeniable that geater efficiency in their use will enable full benefit to be derived from their agronomic potential. Improving the technical efficiency of maize growers remains of major interest. Numerous studies have shown that certain factors affect efficiency levels. Gniza and Loa (2023) used recent empirical data from Côte d'Ivoire on the socio-economic determinants of crop diversification. The authors found that factors such as access to resources, institutional support, and farmer characteristics significantly influence the production decisions and performance of smallholder farmers in Côte d'Ivoire.

These factors include farm size, level of education, age of head of household, access to credit and membership of an economic interest group (Alvarez and Arias, 2004; Coelli T., Fleming, 2004; Nyemeck *et al.*, 2004; Helfand and Levine, 2004). Researchers have been interested in efficiency research in the energy sector, banking sector (Boqiang et, 2016; Jatin *et al.* 2018) other studies have analyzed efficiency in agriculture (Nuama, 2003; Audibert *et al.*, 2003; Mamam *et al.*, 2016). However, studies of the efficiency of maize growers in Côte d'Ivoire are rare.

In view of the above, this paper poses a fundamental question, namely, what is the level of efficiency of maize growers in northern Côte d'Ivoire? From this main question flow three secondary questions:

How efficient are hybrid maize growers? What is the technological gap between farmers growing traditional and improved maize varieties? What factors are likely to influence maize growers' efficiency levels?

The central objective is to analyze the level of efficiency of maize growers in northern Côte d'Ivoire. Specifically, this involves assessing the efficiency scores of hybrid maize growers, measuring the technological gap between farmers growing traditional varieties and those growing improved maize varieties, and identifying the socio-economic factors influencing maize growers' efficiency levels. The research hypotheses are as follows: hybrid maize growers are technically efficient, farmers growing improved maize varieties have better productivity than farmers growing traditional varieties, and poverty negatively influences the efficiency level of maize growers.

This study is of major interest at several levels. This paper should enable producers to make better use of production factors. It is useful in the sense that it would identify the losses of resources that are made in the maize sector. In addition, the study concerns a key crop in the implementation of food security policies in Côte d'Ivoire. Indeed, the risks of food insecurity on a national scale as a result of the crisis indicate that attention should be paid to the maize sector, and in particular to improving its performance. For the international community aiming to eliminate hunger and reduce poverty as set out in the MDGs, this study offers a new opportunity through the production and marketing of new varieties of maize. For farmers, this study could offer new prospects for improving their standard of living and living conditions through the production, consumption and marketing of varietal maize. From a methodological point of view, stochastic meta-frontier analysis (a method for comparing the effectiveness of a product or technical innovation) in maize production seems to be virtually non-existent to our knowledge. As a result, this study proves to be quite contributory to the literature on efficiency techniques.

To meet the research objectives, the remainder of this paper is structured in two parts. The first part is devoted to the literature review, while the second is based on the econometric analysis used, on the one hand the methodological approach, and on the other the results, together with their interpretation and conclusion.

LITERATURE REVIEW

This chapter looks at both the theory of efficiency in

agriculture and the work that attempts to verify it. The first deals with the theoretical foundations of efficiency concepts, while the second reviews empirical work.

Theoretical basis

Efficiency theory is concerned firstly with the concepts of technical efficiency, allocative efficiency and economic efficiency, and secondly with measures of technical efficiency, allocative efficiency, economic efficiency and x-efficiency.

This limited and non-exhaustive definition has led the so-called modern microeconomics movement to redefine the concept of efficiency. In general, the concept of efficiency refers to the microeconomic theory of production (Koopmans 1951 & Debreu 1951). Following the work of Shephard (1953 1970), the elaboration of production possibilities is based on the concepts of production set and distance function. The production set is defined as the locus of all possible combinations of inputs for the production of at least one output. Two notions are fundamental to understanding the concept of efficiency: technical or productive efficiency, and allocative or price efficiency.

Measuring technical, allocative and economic efficiency

The measurement of efficiency first appeared in the work of Koopmans (1951) on production analysis 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, a radial method for estimating efficiency frontiers based on observation of real production situations. Farrell defines efficiency by dissociating that which is of technical origin from that which is due to a poor choice, in terms of the combination of inputs (products), in relation to the price of inputs (products). Having defined the various notions of efficiency, we now turn to the measurement proposed by Farrel (1957).

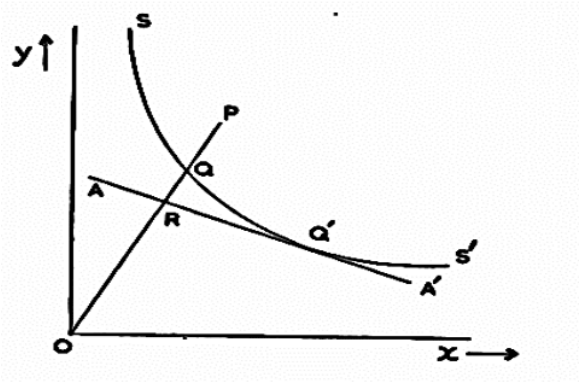


Figure 1: Measuring technical, allocative and economic efficiency
Source: Farrell (1957)

Measures of technical efficiency

Technical efficiency refers to the most technologically efficient use of productive resources. The measurement of technical efficiency was first proposed by Debreu in 1951, in the numerical evaluation of the deadweight loss in the economy. This is a non-Pareto-optimal situation, whose resolution requires the calculation of efficiency coefficients. It allows us to situate the performance of the production unit in the economy. Debreu (1951) presents the system's production activity in terms of a vector y, made up of the factors of production (input). Following on from Debreu's work (1951), Farrell (1957) developed a measure of technical efficiency and went further by determining allocative efficiency. He proposes a measure of technical efficiency that can be adapted to organizations regardless of their size (large or small) or the number of factors of production they use. In this way, we can determine the level of efficiency of companies that use a large number of production factors, as well as those that make do with a small number of production factors.

For simplicity's sake, Farrell considers a company employing 2 factors of production for a single product (output). However, he assumes perfect and correct measurement of all inputs and outputs. He also assumes that the efficiency function is known in advance and that returns are constant. This efficiency function is the isoquant SS' (see figure 1), which represents the combination of two perfectly efficient factors for the production of one unit of output.

Q represents the firm's efficiency. It is the meeting point of P and the isoquant SS'. Technical efficiency can be given by the following formula:

Q' expresses the best production method that leads to

$$ET = OQ/OP \text{ is between 0 and 1} \qquad (1)$$

optimal production when the slope of

AA' is equal to the price ratio. It is desirable to give the same efficiency to production units (use the same factors of production). But this has not been verified to any great extent.

Measuring allocative efficiency

The allocative efficiency (AE) is obtained when the marginal rate of substitution (MRS) is equal to the price

ratio. AA' is the isocost, and through its tangent, we can determine Q' that leads to optimal production. Like technical efficiency, allocative efficiency also belongs to the interval [0,1]. Thus EA can be obtained by :

$$EA = OR/OQ \qquad (2)$$

Measuring economic efficiency

Economic efficiency (EE), which is the sum of the two previous efficiencies (ET and EA), is equal to their products.

$$EE = ET * EA \qquad (3)$$

$$EE = \frac{OQ}{OP} * \frac{OR}{OQ} = \frac{OR}{OP} \qquad (4)$$

Since Farrell's pioneering work (1957) on measuring technical efficiency, the literature has developed on methods for estimating it. Two main families of methods have been developed: parametric and non-parametric methods. In 1966, Leibenstein formulated the "X efficiency" criterion ("allocative efficiency versus X efficiency X"). His starting point was the idea that companies with equivalent characteristics (in terms of size, number of employees, technology) obtained very different results. But Leibenstein's primary thoughts on X-efficiency theory did not establish a formal link between X-inefficiency and public organizations. This link was established for the very first time in an article published in 1978, in which the author identified a number of factors which would be the source of X-inefficiency in public organizations and which, consequently, could implicitly justify certain "inefficiencies".

Thus, in the literature, the efficiency of an organization can be judged under its technical, allocative or economic aspect. However, in empirical work, several authors have used different techniques to assess the level of efficiency of an agricultural production unit.

Empirical works

Few studies have used meta-frontier analysis to compare the level of technical efficiency between several groups. For example , Boris *et al.* (2020) analyze irrigation infrastructure efficiency and agricultural productivity in the Philippines using stochastic meta-frontier analysis. Analyzing technical efficiency (TE) using a stochastic meta-frontier on a dataset for 1154 rice plots, find that the irrigation project had a statistically significant impact on frontier production but not on TE . This suggests that improved irrigation technology increased beneficiaries' production potential, but did not improve ET, probably due to a lack of training and access to inputs.

Regional assessment of the water-energy nexus in China's industrial sector via an interactive meta-frontier DEA approach show that although the eastern and central regions have high industrial production efficiency, most regions have relatively low wastewater treatment efficiency (Ding *et al.* 2019). In addition, the degree of linkage of the eastern region maintains a relatively high level and shows stable improvement, while the other two regions perform relatively worse. Comparing the central and western region, the industrial production technology of the central region is better, but the wastewater treatment efficiency of the western region is higher, resulting in a higher degree of connection of the western region. The work of Jatin *et al.* (2018) endeavours to conduct an intra-sector efficiency assessment of the Indian banking sector based on cross-sectional data from 66 banks for the year 2015-16. The authors use a meta-frontier DEA approach based on the directional distance function, and the results reveal that the Indian banking sector is 73.44% efficient. It also confirms the existence of different production functions across different industry ownership structures. Among the different ownership structures, the frontier of the foreign bank group coincides with the meta- frontier. The boundary of the private-sector bank group is the second closest to the meta-border, and public-sector banks are judged to lag behind the industry as a whole.

Previous studies have not considered an important aspect of port efficiency. A regional perspective of port performance using meta-frontier analysis is examined in the case of Vietnamese ports (Nguyen *et al.*2018). This study examines the technical efficiency (TE) of ports in Vietnam and their influencing factors using meta-frontier analysis. The results show that cargo handling facilities and information technology are the most important inputs for ports, despite their varying contribution to port performance from region to region. In ideal situations, northern ports could reduce berth length by up to 57% without affecting throughput. National and regional reference networks are being developed to identify the main regional and national ports and their connections with other ports. The Technical Efficiency Analysis of Major Agricultural Producing Countries in Asia also uses the zero inefficiency meta-border approach (Jianxu *et al.* 2018). The study assessed the technical efficiency of Asia's 12 leading agricultural producing countries. The results revealed that Japan and South Korea performed well in improving technical efficiency throughout the period. The main conclusion of the study is that all these 12 major agricultural producing countries need to improve their technical efficiency performance. The following section is entirely devoted to the methodological framework of our work.

MATERIALS AND METHODS

Study area

The area selected for this study is the Poro and Bagoué region, located in northern Côte d'Ivoire in the Savanes district. The study area comprises 4 departments, including Dikodougou and Korhogo in the Poro region, and Tengrela and Kouto in the Bagoué region. 13 sub-prefectures comprising 57 localities make up the study area. The population is made up of Senoufo natives, non-natives from various regions of Côte d'Ivoire and

non-natives from ECOWAS countries, notably Burkina Faso and Mali. Agricultural analysis shows that cotton is the main cash crop, followed by cashew nuts and mangoes. Food crops are dominated by maize and rice, followed by groundnuts, yams and vegetables. In rural areas, the population is predominantly agricultural. The land is farmed by local people, especially when it comes to perennial crops (DRADER_Poro , 2016). Indeed, the northern regions are those that mainly grow cotton, which sometimes faces numerous problems (low productivity, falling prices on the world market, etc...). It was therefore to improve their standard of living that the hybrid maize production project was set up. The data collected in this study are both qualitative and quantitative. It covers the demographic and socio-economic characteristics of maize farmers, as well as the characteristics and management of maize-growing plots.

Study population and data source

Our study focuses on 313 maize farms run by various producers associated in a cooperative and who are both maize and cotton growers. The primary data used in this paper come from a survey conducted under the COMPACI (Competitive African cotton Iniative) project in association with Cotton Made in AFRICA (CmiA). The overall aim of this project is to improve the standard of living of cotton producers. To this end, priority is given specifically to the production of hybrid maize (an improved variety of corn). For a better understanding, it should be noted that the maize-growing system in northern Côte d'Ivoire is closely linked to cotton cultivation, which is the main cash crop. Increasingly large areas are devoted exclusively to maize, while other crops are also grown. As a result, the traditional cereal-growing system has been considerably improved through the cultivation of cotton. Our study focuses on the production of a new variety of maize used by farmers to improve their standard of living (ensuring food security and financial needs following the marketing of this commodity). The BFCD (Bureau de Formation et Conseil en Développement) is a non-governmental organization in charge of distributing hybrid maize seed to cotton growers. Among the new maize varieties in Côte d'Ivoire, our study places particular emphasis on the production of KABAMANOJ (a yellow-orange, horny, toothed maize variety). This variety is direct-seeded, with ploughing methods depending on the local context.

Variable description

The variables used to represent economic and social characteristics are shown in the following table:

Table 1: Total variable descriptions

Variables	Description	Variable type
Corn production	It is expressed in kilograms obtained on each farm during the campaign.	Continuous variable
Area under corn	The area of land that the farmer allocates to growing corn. Land represents physical capital for farmers.	Continuous variable
Workforce	The amount of labor used by the farmer. This is expressed in men/day and represents the sum of labor used to carry out all cultivation operations. It takes into account permanent, occasional and family salaried labor.	Continuous variable
Herbicide	It is expressed in liters in corn production.	Continuous variable
Fertilizer	It is expressed in kilograms for corn production.	Continuous variable
Commercial Orientation	Commercial orientation means that the grower decides whether or not to market at least half of his hybrid corn production	Binary coded variable
Age of farm manager	Age is expressed in years.	Continuous variable
Household size	Household size is expressed in number	Continuous variable
Feminization Rate	Percentage of working-age women in the workforce used to carry out cultivation operations	Variable continues
Area under cash Crops	The area of land that the grower allocates to cotton and shrub crops. It is expressed in hectares.	Continuous variabl
Area of other food crops	The area of land that the grower allocates to food crops other than maize. It is expressed in hectares.	Continuous variable
Crop rotation	Growing other crops on the hybrid corn plot	Binary coded variable

Source : Author

Descriptive analysis of technical variables

The following table compares the inherent characteristics of the two corn varieties.

From the above table, we compare the maize production obtained for the two varieties according to the area, labor, herbicides and fertilizers used by the farmers. The results of the test of equality of means reported in the table are significant at the 1% level, except for labor. Consequently, the hypothesis of equality of means is rejected, and we can conclude that there are differences in means between the techniques used by variety type. The surface areas are quite small, because the pressure on labour to be distributed between the different farming activities is high, with each farmer practising several farming activities at the same time (Nuama, 2006). The results obtained show that, on average, farmers using traditional maize varieties are seeking to increase their production by increasing the surface area (4 ha), rather than by seeking higher yields. As a result, the area devoted to this crop is constantly increasing, while those who have adopted the new maize variety produce more (high yield) on smaller areas (2 ha). It should also be pointed out that the adaptation of technical and scientific knowledge (extension) leads to a principle of crop innovation in favor of the improved maize variety. As a result, the improved maize variety has a comparative advantage and is highly competitive on the agricultural market.

Table 2: Comparative averages of technical variables by type of variety

Variable	Traditional Variety	Improved variety	Total	statistical t-test
Production	3,467	8,567	5,292	-10,279***
Area (ha)	4,072	2,027	3,340	7,011***
Work (h/d)	0,445	0,411	0,433	0,951
Herbicide	0	7,353	2,631	-15,257***
Fertilizer	357,5	763,839	503,365	-7,479***

Source : Author

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Explanatory variables for level of efficiency and descriptive statistics

The table below highlights the economic and socio-demographic characteristics of maize production for the two varieties studied.

Table 3: Statistical summary of economic and socio-demographic variables

Variable	Traditional variety (Average)	Modern variety (Average)	Sample Total			
			Average	Standard deviation	Min	Max
Age of farm manager	45,965	47,847	46,643	12,576	24	97
Household size	16,866	19,777	17,907	11,938	1	97
Feminization rate	0,560	0,599	0,574	0,138	0	1
Area under cash crops	17,830	21,664	19,202	10,009	4	63,25
Area of other food crops	4,302	5,382	4,688	3,283	0	25
Crop rotation	0,691	0,875	0,757	0,429	0	1
Commercial orientation rate	0,530	0,924	0,709	0,403	0	4,4

Source: Author's calculations

The estimates in the table above show that maize growers range in age from 24 to 97, with an average age of 46. The distribution of farmers by household size shows that, on average, 17 people from one family provide family labor

to improve production. It is important to note that a large proportion of farms also call on external unsalaried labor through "self-help groups" or "work groups". Thanks to these groups, producers can pool their forces at times of peak workload, such as ploughing, sowing or harvesting. These groups, which can range in size from 10 to over 100 people, carry out joint farming activities on each member's plot of land. For each intervention, the farm benefiting from the group's work pays for the workers' meals, but they receive no other remuneration. The advantage of these work groups lies mainly in the social motivation and emulation they provide, which increases work productivity on each plot. Gender analysis reveals an average participation rate of 57% for women, mainly in food crop production. With regard to the area used for maize production, an average of 19 ha was used among the areas set aside for the production of various cash crops, compared with an average of 4.7 ha for the production of other food crops.

As far as crop rotation is concerned, farmers' first reaction is to minimize monetary production costs. As a result, the practice of growing maize at the head of the rotation has been abandoned. Maize is grown after cotton in the cropping system, thus benefiting from the after-effects of the cotton crop. This technique is more common on manoj plots. As regards the commercial orientation of the different varieties, we note an average rate of 70%, with an average of 92% for the modern variety versus 53% for the traditional variety. Manoj production is more oriented towards trade, thus ensuring income for farmers, which will enable them to improve their living conditions. Following an analysis of the different characteristics of maize growers, the next chapter looks at the methodology used in our study, as well as the estimation and interpretation of the results.

Stochastic meta-frontier analysis

In the literature, studies on measuring efficiency have employed numerous methods, including Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). Within this framework, the stochastic frontier approach has become widely used in the analysis of technical efficiency. Based on the efficiency model developed by Battese and Coelli (1995), inefficiency effects can be integrated into the production function, distinguishing between random shocks and producer-specific inefficiencies. This approach is well-suited to agricultural production, where random shocks such as weather conditions can affect output. For this reason, the stochastic frontier approach is adopted in this study. In this section, we present the specification of the meta-boundary model and its theoretical foundations.

Theoretical model of meta-frontier analysis

According to Battese *et al.* (2004), the technical efficiency of farms operating under a given production technology, defined by a production frontier model, is not comparable with that of farms operating under different technologies. Moreover, the efficiency levels obtained by one frontier cannot be compared with those of another (O'Donnell *et al.*, 2008). The meta-frontier approach is a solution to this problem, enabling a comparison of the efficiency of different but related groups. Meta-frontier functions were first introduced by Hayami (1969) and Hayami and Ruttan (1970, 1971). As defined by Hayami and Ruttan (1971), "the production meta- frontier function can be seen as the envelope function of the production functions as defined by the neoclassicals". In their study of agricultural productivity between different countries, Ruttan *et al.* (1978) define the meta-production frontier as "the envelope function formed by the production points of the most efficient country". The concept of the meta frontier is theoretically appealing in that it is based on the simple assumption that all producers in the same group potentially have access to the same technology. Mundlak and Hellinghausen (1982) and Lau and Yotopôulos (1989), building on the pioneering work of Hayami and Ruttan (1970), have used this approach to compare agricultural productivity between countries. The econometric advantages of applying a meta-frontier function are discussed by Lau and Yotopôulos (1989). However, the absence of comparable data is the major limitation of this approach. The specificity of this study is that it uses the meta-frontier approach as a solution to the problem of choosing a technological reference frame. The stochastic meta-frontier function used has a composite error term comprising a symmetric disturbance term (the usual error term) and a non-negative inefficiency term, in line with the pioneering model developed by Aigner, Lovell and Schmidt (1977) and Meeusen and Van den Broeck (1977).

Stochastic meta-frontier model

To obtain a stochastic meta-frontier model, it is preferable to assume that production boundaries can be defined for different groups in the same industry (Béké ,2010). Indeed, analyzing meta-frontiers assumes that there are several clearly defined groups operating in the same sector. These might be producers in the same sector, grouped by country, region or technology.

It is assumed that the $ji\grave{e}me$ group has a size of Nj farms producing the same output from different inputs. Mathematically, if we consider a farmer who combines production factors (land, labor, fertilizer, herbicide) to produce a good Y (traditional variety or improved variety), then the stochastic production frontier is represented for this group as follows $ji\grave{e}me$ as follows:

$$Y_{ij} = f(x_{ij}, \beta) e^{V_{ij} - U_{ij}}, \quad i = 1,2 \ldots N_j \qquad (5)$$

Where Yij represents the production of farm i in group j ; xij is the vector of inputs used by farm i in group j; the terms Vij are assumed to be independent and identically distributed according to a normal distribution ($N(0,\sigma_V^2)$), with mean zero and variance σ_V^2. They are independent of the terms U_{ij} which are defined as the

inefficiency terms according to the models of Battese and Coelli (1992, 1995). For simplicity of notation, the index j is omitted from the equations. The stochastic production frontier model for group j becomes :

$$Y_i = f(x_i,\beta)e^{V_i-U_i} = e^{x_i\beta+V_i-U_i}, \quad i = 1,2....N_j \quad (6)$$

In order to obtain a linear frontier model in the parameters, two types of function are required. In general, there are two main categories of nonlinear function estimation models (Greene, 2008), namely simple functional forms, of the Cobb-Douglas (1928) type, and flexible functional forms, of the translog ("transcendental logarithm") type. The latter was introduced by Christensen *et al.* (1971). The Cobb-Douglas production function is commonly used because it is based on very restrictive assumptions, such as the principle of degree-1 homogeneity of production factors. It also relies on constant factor elasticities, whereas in a trans-log production function, these elasticities depend on the level of production factors. In contrast to the translog framework, which imposes no value, the Cobb-Douglas framework requires partial elasticities to be unitary. In our meta-frontier analysis, we apply a logarithmic transformation to expression (7). The expression of the stochastic meta-frontier model for all farms in the sector is as follows:

$$Y_i = f(x_i,\beta)e^{V_i^*-U_i^*} = e^{x_i\beta^*+V_i^*-U_i^*}, \quad i = 1,2....N \quad (7)$$

Where $N=\sum_{(j=1)}^{J} N_j$ is the total number of farms in all J groups. The assumptions on the terms $V*$and U∗ terms are analogous to those for V_i and U_i terms respectively.
The parameters of a given frontier for a group are estimated using only the farm data for that group. In contrast, the parameters of the meta-frontier model are estimated using all the farm data for all the groups (stacked data). The meta-frontier function in equation (7) is considered as an envelope function of the stochastic frontiers of the different groups. The stochastic frontiers for the different groups and that of the meta-frontier are considered to have the same functional form (e.g. Cobb-Douglas or translog).
The productivity and technical efficiency of farms in group j can be studied using the frontier production functions of group j or meta frontier.The components of the meta-border analysis are presented as follows:

Technology gap and efficiency index

The observed production of the ith farm in group j can be written as follows:
as specified by equations (7) and (8), respectively. The

$$Y_i = e^{x_i\beta+V_i-U_i} \quad \text{où } y_i = e^{x_i\beta^*+V_i^*-U_i^*} \quad (8)$$

relationship $x_i\beta+V_i-U_i=x_i\beta^*+V_i^*-U_i^*$ is therefore always satisfied, the deterministic values being those of the meta-boundary. The relationship $x_i\beta+V_i-U_i=x_i\beta^*+V_i^*-U_i^*$ can be rewritten as follows:

The three ratios on the right-hand side of equation (9) are the technology gap ratio (TGR), the error term

$$1 = \frac{e^{x_i\beta}}{e^{x_i\beta^*}}\frac{e^{V_i}}{e^{V_i^*}}\frac{e^{-U_i}}{e^{-U_i^*}} \quad (9)$$

ratio (RER) and the technical efficiency ratio (TER) respectively.
The technology gap ratio indicates, for a given group of operators, the gap between the

$$TGR_i = \frac{e^{x_i\beta}}{e^{x_i\beta^*}} \equiv e^{x_i(\beta-\beta^*)} \; ; \; TER_i = \frac{e^{-U_i}}{e^{-U_i^*}} \equiv \frac{TE_i}{TE_i^*} \; ; \; TE_i \equiv e^{-U_i} \quad (10)$$

technology used in this group and the most efficient technology available in the sector. This ratio, as well as the indices and the technical efficiency ratio, can be estimated for each farm i. The technical efficiency of farm i in relation to the frontier of its group $TE_i \equiv e^{-Ui}$ is estimated by :

$$TE_i \equiv E\left(\frac{e^{-U_i}}{\varepsilon_i} \equiv V_i - U_i\right) \quad 11$$

$$TE_i^* = E(e^{-U_i^*}/\varepsilon_i^* = V_i^* - U_i^*) \quad (12)$$

We can see that the relationship is an identity.
Consider the technical efficiency ratio $TE_i \equiv e^{-Ui}/e^{-Ui*} \equiv (TE_i)/(TE_{i^*})$, which can be greater than or equal to unity. However, since , U_i and U_{i^*} are random variables, there is a non-zero probability that the technical efficiency ratio TER is less than unity.
the resulting probability that U_{i^*} is less than U_{iis}.

$$\text{Formally } TE_i \le TE_i^* \text{ if and only if } e^{-U_i} \le e^{-U_i^*}, \text{ ou } U_i^* - U_i \equiv x_i(\beta^* - \beta) + V_i^* - V_i \le 0 \quad (13)$$

If V_{i^*} and V_i are random terms that are independently and

$$P(U_i^* - U_i \le 0) = P(V_i^* - V \le -x_i(\beta^* - \beta)) = \frac{\varphi(-x_i(\beta^* - \beta)}{\sqrt{(\sigma_V^2 + \sigma_{V^*}^2)}} \quad (14)$$

normally distributed with Φ(.) the normal distribution function, it is clear that $x_{i^*}\beta$ exceeds $x_i\beta$ and the lower the probability of U_{i^*} being less than U_i. Using the means, an identity relation is obtained as follows.

$$1 = \frac{e^{\bar{x}\beta}}{e^{\bar{x}\beta^*}}\frac{e^{\frac{1}{2}\sigma_V^2}}{e^{\frac{1}{2}\sigma_{V^*}^2}}\frac{E(e^{-U_i})}{E(e^{-U_i^*})} \quad (15)$$

$$\text{Where } TGR = \frac{e^{\bar{x}\beta}}{e^{\bar{x}\beta^*}} = e^{-\bar{x}(\beta^*-\beta)} \text{ : is the average technology gap ratio;} \quad (16)$$

$$RER \equiv \frac{e^{\frac{1}{2}\sigma_V^2}}{e^{\frac{1}{2}\sigma_{V^*}^2}} \text{ : is the average disruption ratio} \quad (17)$$

$$TER \equiv \frac{E(e^{-U_i})}{E(e^{-U_i^*})} \text{ is the average technical efficiency ratio (18)}$$

From the previous equation we can decompose the technical efficiency of a particular input-output combination as follows:

$$TE_i^* = TE_i . TGR_i \qquad 19$$

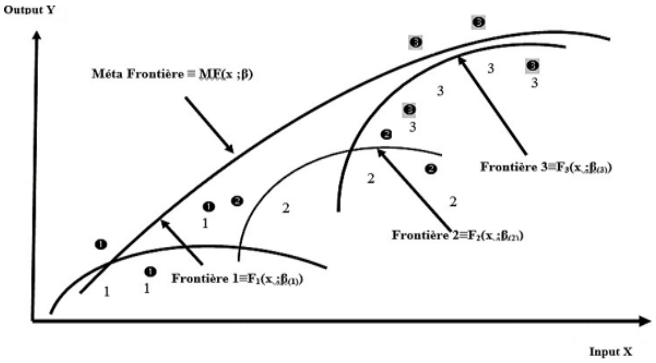


Figure 2: Meta-boundary function model
Source: Battese et al. (2004)

Specification of the stochastic frontier model

A Cobb-Douglas-type production frontier is estimated for all farmers differentiated according to the technology adopted. The technology adopted is in fact represented by a dummy variable "TECH" that takes on two states: "TECH" takes on the value 1 for the group of farmers who have adopted improved varieties and the value 0 for the group of farmers growing traditional varieties. Drawing on the work of Béké (2010) who evaluates technical efficiency in rice production, our stochastic Cobb-Douglas-type frontier model to be estimated is as follows:

$$LnY_i = \beta_0 + \beta_1 Lnsuperf_i + \beta_2 Lntrav_i + \beta_3 Lnfert_i + \delta\ TECH_i + V_i - U_i \qquad (20)$$

LnYi represents the logarithm of the production or quantity of corn harvested by the producer in kilograms. Lnsuperfi: Is the logarithm of the farm's area in hectares; Lntravi: Refers to the logarithm of the amount of labor (family and salaried) provided. Lnferti Is defined as the logarithm of the quantity of fertilizer used in kilograms; TECHi: Is a qualitative binary variable taking the value 1 if the new improved maize variety is adopted, and 0 if the traditional varieties are used.Vi : Is the usual error term assumed to be exogenous or random (uncontrolled error) and Ui is the truncated error term representing the producer's technical inefficiency. The two terms (Vi et Ui) are independent of each other and of the explanatory variables. The parameters of the production frontier with technical inefficiency effects can be estimated simultaneously using the maximum likelihood method. The results of these estimates give the following error variances:

$$\sigma^2 = \sigma_U^2 + \sigma_V^2 \text{ et } \gamma = \frac{\sigma_U^2}{\sigma_U^2 + \sigma_V^2} \qquad (21)$$

The parameters σ^2 and γ describe the contribution of technical efficiency to production. Battese and Corra (1977) define σ^2 as the sum of the variance of the inefficiency term and that of the random term, and γ as the share of the inefficiency term in the total variance. These parameters (γ, $\beta 0$, σ^2, ……. βk) are estimated by the maximum likelihood method at model level.

This method therefore amounts to maximizing the log likelihood function with respect to the unknown parameters. The parameter γ determines whether the production frontier is stochastic or deterministic. When γ indicates a null value, deviations from the frontier are entirely due to noise and error terms Vi (so a zero value of γ represents the absence of stochastic technical inefficiency). The ordinary least squares OLS method is applicable in this case. The closer the value of γ is to 1, the smaller the difference between the results of stochastic and deterministic estimation. If γ is equal to 1, then in this case deviations from the frontier are entirely due to the occurrence of inefficiency. U_i . The work of Béké (2010), which evaluates technical efficiency in rice production through the meta frontier, makes the assumption that the new variety is considered a technological innovation. Thus, drawing on this author, we mean that in our analysis, the frontier model makes the assumption that improved varieties constitute technological innovations shifting the maize production frontier upwards.

RESULTS AND DISCUSSION

Interpretation of the stochastic frontier

The frontier output includes estimates of the standard deviations of the two error components, and , which are labelled sigma_v and sigma_u, respectively. In log likelihood, they are parameterized as $\ln\sigma_V^2$ and ln ln σ_U^2 and these estimates are called $\ln\sigma_V^2$ and ln σ_U^2 in the results. The frontier output also reports two other useful parameters. The estimate of the total variance of the error, $\sigma_S^2=\sigma_U^2+\sigma_v^2$ Vis called sigma2, and the estimate of the ratio of the standard deviation of the inefficiency component to the standard deviation of the idiosyncratic component, , $\lambda=\sigma_U/\sigma_V$ is called lambda. At the bottom of the output, Frontier reports the results σV of a test according to which there is no technical inefficiency component in the model. This is a test of the null hypothesis H0: $\sigma 2 = 0$ against the alternative hypotheses H1 = $\sigma 2 > 0$. If the null hypothesis is true, the stochastic frontier model reduces to an OLS model

with normal errors. This hypothesis reflects the absence of inefficiency. However, if the test is on the frontier of the parameter space of σ2parameter space, the standard likelihood ratio test is invalid and a one-sided generalized likelihood ratio test is estimated; (Gutierrez *et al.* 2001). The validity of this hypothesis reflects the presence of inefficiency.

Analysis of production function input variables

The above table reveals that the estimated elasticities of the production factors, i.e. area, labor and fertilizers, show a positive sign and reveal the importance of these factors in relation to maize production, indicating that an increase in each of these factors would lead to an increase in production depending on the variety used. However, only the labor variable (labor) and area significantly influence the level of traditional maize production obtained. Indeed, the elasticity of the labor input was found to be significant at the 1% threshold, and shows that the partial elasticity coefficient is the highest with an elasticity of 94%, so a 1% increase in the labor force in traditional maize farming contributes to a 94% increase in this output obtained.

Table 4: Estimated production frontiers

Ln(y)	**(1) Traditional variety**	**(2)Improved variety**	**(3)Meta-border (Total sample)**
Lnsuperf	0,885***	1,590***	1,082***
Lntrav	0,945***	0,241	0,080
Lnfert	0,003	0,679*	0,022***
TECH			1,015***
_cons	0,412***	0,402	-0,182**
/lnsig2v	-2,918***	-3,237***	-2,310***
/lnsig2u	-1,589***	-1,493***	
sigma_v	0,232	0,198	0,315
sigma_u	0,452	0,474	
sigma2	0,258	0,264	
Lambda	1,944	2,391	
Log (Likelihood) LR	chibar2(01)= 11.18 P> (chibar2)= 0.000	chibar2(01) = 6.52 Prob P> (chibar2) = 0.005	

Note: (***), (**) and (*) represent significance at the 1%, 5% and 10% thresholds respectively.

In contrast to the improved maize variety production function, for which the use of labor is unimportant (seen as wasteful), this result favors the use of labor power as a source of increased production, especially in the northern region where labor is becoming scarce. As a result, traditional corn growers have to resort to a more abundant labor force to carry out specific agricultural activities in order to increase their production and standard of living. The elasticity of land area is estimated at 0.88. This means that a 1% increase in maize-growing area would increase traditional maize yields by 88%. This fully justifies the extension of maize-growing areas. The result found corroborates those of Béké (2010) and Farah (2018) and contradicts that obtained by Zhu *et al.* (2012), who argue that small farms record the best levels of performance. Contrary to area, which is considered the essential input for the three production functions, the use of labor and fertilizer varies according to the production technique (traditional or innovative).

These results highlight the importance of socio-economic and structural factors in explaining differences in productivity and efficiency among maize producers. This finding is consistent with studies published in American Journal of Multidisciplinary Research and Innovation, such as Wal *et al.* (2023), which emphasize the critical role of structural and socio-economic factors in shaping development outcomes in rural areas.

As for the fertilizer factor, its contribution remains important in explaining the increase in the level of improved maize production to the detriment of that with the traditional variety. The coefficient linked to fertilizer proved positive and significant. An elasticity of 0.67 means that a 1% increase in the quantities of fertilizer used leads, all other things being equal, to a 67% increase in improved maize production. This could be explained by the enrichment of the land, and therefore the greater surface area used compared with the traditional technique. The results found contradict those of Farah and Amara (2023), who found that the use of fertilizers, which remains irregular, is insufficient to cover the needs of olive trees, mainly because of their high cost.

Analysis of production function inefficiency

The results provide information on the standard deviations of the two error components, and , respectively parameterized in the log likelihood function, as /lnsig2v and /lnsig2u in the result table. These values are estimated at -2.91 and -1.58 (traditional variety) , -3.23 and -1.49 (improved variety) for the respective efficiency errors. These values are significant at the 1% level ($P < 0.01$), indicating the presence of technical inefficiency

in maize production for both types of variety. Sigma_U shows that deviations between total production and the frontier are explained by farmers' technical inefficiency at 46% on average, and at 21% on average by random shocks (climate change etc.). Thus, the hypothesis that model deviations are mainly due to technical inefficiency is verified. In other words, this result indicates that the component attributable to maize growers' technical inefficiency is much higher than that inherent in random effects.

Furthermore, the presence of inefficiency captured by the maximum likelihood ratio (MLR) also leads to rejection of null hypotheses at 1% thresholds, given that the probability associated with chi-square tests ($\chi 2$) is highly significant at the 1% threshold. Given the presence of technical inefficiency determined by errors linked to the operators themselves, a production function is represented by the general translog functional form in order to explain this inefficiency by several suspect variables. Thus, the search for major determinants is determined by econometric estimation, presenting the technical efficiency scores and highlighting the effects of the determinants of maize growers' inefficiency.

Technical efficiency frequency distribution and technology gap

Frequency distribution of technical efficiency

As indicated in the stochastic frontier results, there is a presence of inefficiency in maize production in general. The following table shows the efficiency scores of corn growers according to the technology used (traditional or improved).

According to our estimates, analysis of the distribution of individual technical efficiency scores shows that no grower is on the production frontier. Indeed, their technical efficiency score is below 100% or 1. In other words, maize growers produce below the frontier (Benchmarking). This result confirms exactly the hypothesis of the existence of inefficiency observed in the stochastic production function with the presence of error inherent in particular to the production technique used by maize growers. However, a comparison of efficiency scores between growers using traditional technology (traditional variety) and innovative technology (improved variety) reveals that growers using the improved variety did not have scores below 0.7, i.e. 70%, unlike those using the traditional variety. This finding justifies the importance of

Table 5: Distribution of efficiency scores by technology used

Traditional varieties				**Improved varieties**		
Efficiency score	Number of producers	Relative frequency	Cumulative frequency	Number of producers	Relative frequency	Cumulative frequency
≤ 0,4	11	5,47	5,47	-	-	-
[0,4-0,5[	1	0,50	5,97	-	-	-
[0,5-0,6[	1	0,50	6,47	-	-	-
[0,6-0,7[	1	0,50	6,97	-	-	-
[0,7-0,8[	11	5,47	12,44	2	1,79	1,79
[0,8-0,9[	11	5,47	17,91	4	3,57	5,36
[0,9-0,95[	30	14,93	32,84	15	13,39	18,75
[0,95-0,975[	26	12,94	45,77	18	16,07	34,82
[0,975-1[	109	54,23	100,00	73	65,18	100,00
Total	201	100,00		112	100,00	

Source: Author's calculations

varietal innovation in the agricultural sector for greater profitability, commercial development and improved living conditions for growers. The technology gap ratios are presented in the following section.

Calculation of the technological gap between improved and traditional varieties

From the production frontier results table, the parameter of interest in the production frontier is the coefficient of the binary variable "TECH", which allows us to examine the technological gap between producers of the traditional maize variety and producers of the improved variety (manoj). The meta frontier has a coefficient of 1.015, enabling us to determine the technological gap between the different crops. The technological gap ratio is determined using the following formula:

The technological gap ratio indicates a value equal to 0.362. This result makes it possible to obtain and estimate productivity gains associated with improved varieties of around 63%. Indeed, such a value reflects the importance of production of the improved maize variety. Production of this variety is a palliative for improving farmers' incomes and is likely to improve their living conditions. It can be recommended for marketing and consumption. Following the results obtained from the estimation of the stochastic production frontier, which tested for the presence or absence of efficiency, we determined the technical efficiency scores of maize growers. As a result, given the presence of inefficiency, it becomes relevant to

$$TGR = \frac{\exp(\bar{x}\beta)}{\exp(\bar{x}\beta^*)} = \exp(-\delta) = \exp(-1{,}015295) = 0{,}3623 \quad (22)$$

identify the main factors explaining the technical inefficiency of maize farms. Indeed, the search for the major determinants is certainly of great interest, in order to conduct appropriate agricultural policies, particularly in terms of courses of action to improve the performance management of maize growers.

Determinants of maize growers' technical inefficiency

A large number of empirical studies have examined the determinants of technical efficiency within agricultural production units (Nyemeck *et al.*, 2004 and Nuama, 2010 , Béké, 2010). According to this literature, several relevant variables likely to influence the level of efficiency of production units were selected. Based on our stochastic production function :

$$y_i = f(x_i, \beta)e^{V_i - U_i} = e^{x_i\beta + V_i - U_i}, \quad i = 1,2.... N_j$$

$$\mathrm{LnY_i} = \beta_0 + \beta_1 \mathrm{Lnsuperf_i} + \beta_2 \mathrm{Lntrav_i} + \beta_3 \mathrm{Lnfert_i} + \delta\, \mathrm{TECH_i} + \mathrm{V_i\text{-}U_i}$$

We seek to determine the inefficiency factors through the following model:

$$\mathrm{TE_i} \equiv \mathrm{e}^{-\mathrm{U_i}} \text{ Avec } \mathrm{U_i} = \alpha_0 + \sum_{i=1}^{j=n} \alpha_i X_i + w_i \qquad (23)$$

By adding the variables retained in our study, the model to be estimated takes the following form:

$$\mathrm{U_i} = \alpha_0 + \alpha_1 \mathrm{Orcom} + \alpha_2 \mathrm{Age} + \alpha_3 \mathrm{Menage} + \alpha_4 \mathrm{femmerate} + \alpha_5 \mathrm{Suptot} + \alpha_6 \mathrm{Sup_{vivr}} + \alpha_6 \mathrm{IRotcultult_1} + \mathrm{w_i} \qquad (24)$$

Results and interpretation of determinants

This production function is estimated using the maximum likelihood method, and the results obtained are presented in the following table:

Table 6: Determinants of maize growers' technical inefficiency

Explanatory variables	Coef.	Std. Err.	P>|z|
Commercial orientation	-7,725**	3,451	0,025
Age of farm manager	0,0159	0,023	0,498
Household size	0,019	0,024	0,439
Feminization rate	3,550	2,981	0,234
Area under cash crops	-0,105**	0,046	0,022
Area of other food crops	-0,410**	0,188	0,029
Crop rotation	0,470	0,891	0,598
Constant	-5,353**	2,231	0,016

Note: (***), (**) and (*) represent significance at the 1%, 5% and 10% thresholds respectively. Source: Author's calculations

Analysis and discussion of results

The sign of the parameters associated with the determinants of technical efficiency indicates their impact on productive counter-performance. Thus, a significantly negative value suggests a positive influence on technical efficiency and vice versa (Béké 2010). In our study, our results suggest that age of household head, household size, feminization rate and crop rotation practice are insignificant. This means that these variables are not potential sources of technical inefficiency among maize growers in the north. The significant and negative coefficient of commercial orientation translates into a positive effect of this variable on the productive efficiency of maize farmers.

This result could be explained by the fact that maize growers who receive agricultural assistance (technical advice), mainly on new techniques used in this field, increase their production compared with those using traditional methods. In fact, during the COMPACI project, cotton growers who received maize seed benefited from guidance on the production and marketing of new varieties of maize, in order to improve their living conditions (increase their income, combat food insecurity). This finding corroborates the work of Béké (2010), who finds that mentoring services significantly reduce the degree of inefficiency of producers by enabling them to better master cultivation techniques, thereby enhancing their ability to reduce resource wastage and be more productive.

The sign and significance of its coefficient indicate the significant and favorable impact of cash crop area on grower efficiency. A 1% increase in cash crop area increases producer efficiency by 10%. This result is neither strange nor surprising. Indeed, the main activity of farmers in the North is cotton production (cashew nuts are a close second), and this crop makes the area the leading national producer, giving Côte d'Ivoire a comparative advantage. Cotton and cashew growers in particular devote more land, techniques and time to these export crops, to the detriment of food crops. These cash crops remain their primary source of income, despite the innovation of other commodities. This priority given to cash crops (cotton and/or cashew) effectively explains the efficiency of producers in the North.

The negative sign and significance of the coefficient for this variable also indicate the positive impact of the area under other food crops on grower efficiency in the study area. In fact, a 1% increase in the area distributed to other food crops significantly improves grower efficiency by 41%. This result is justified by the equitable distribution of the area limited to one variety of food crop exploited by growers in the North. In fact, for a given plot, there is a combination of several food crops grown. This way of farming a given plot of land is what makes farmers in the North so original and special (traditionally). Indeed, several foodstuffs (cereals) such as fonio, maize and rice are produced on a given plot. This value-adding technique helps combat food insecurity and increases farmers'

financial resources.

CONCLUSION

The aim of this study was to analyze the comparative efficiency of maize growers in the northern region of Côte d'Ivoire, where the COMPACI project supplied improved maize seed (Kabamanoj) to cotton growers to improve their living conditions. A survey was carried out in the Poro and Bagoué regions, covering four departments. The econometric approach used, the stochastic meta-frontier method, was used to test the hypotheses formulated. The results show that the use of labor and fertilizers varies according to production technique (traditional or improved). Maize growers generally operate below the production frontier. However, users of the improved variety obtained efficiency scores above 0.7, unlike those using traditional varieties. The technological gap between the two groups is significant, with a 63% advantage in favor of the improved variety, underlining the importance of varietal innovation for productivity. The main factors limiting the efficiency of maize growers were commercial orientation, and the area given over to cash crops and other food crops. In conclusion, the study recommends technical support for maize growers to improve their production and living conditions, followed by the allocation of more space to improved maize production to combat food insecurity. And finally, the modernization of agriculture through varietal innovation for better productivity and food security.

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