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Analysis of the effect of production factors on the agricultural productivity of small rice producers: prospects for optimizing subsidies in Senegal.

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Abstract

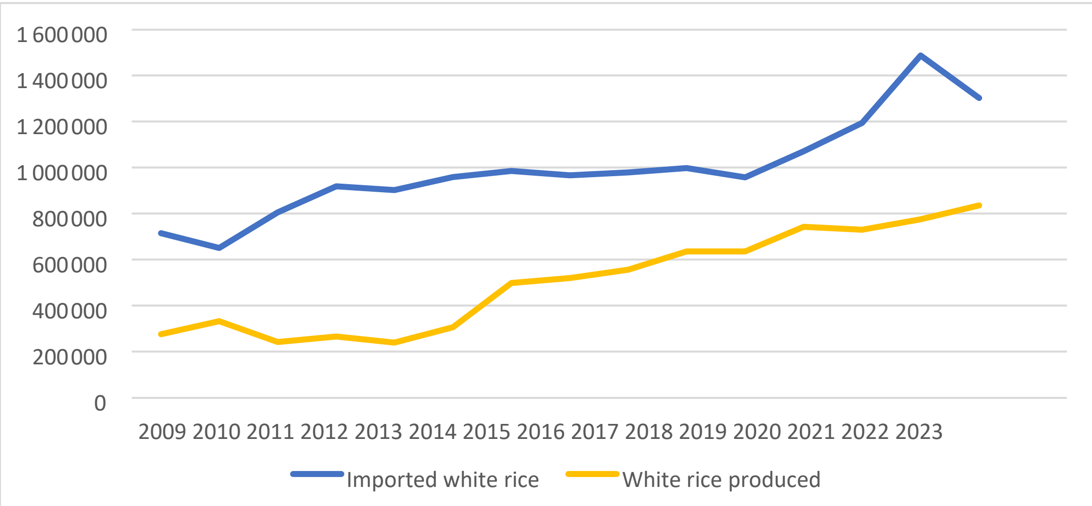
This study analyses technical efficiency of rice producers in Senegal using a database covering 396 plots, mainly located in Casamance (94.6% of the sample). The descriptive results reveal a predominance of males (86.1%), an ageing agricultural population and a low presence of young people under 35 in the sector. Average yields are 2.47 t/ha, with significant heterogeneity (725 to 5,127 kg/ha) linked to differences in access to inputs and farming practices. Statistical analysis shows that the use of certified seeds and deep ploughing are significantly associated with higher yields, while excessive use of seeds tends to reduce productivity. Furthermore, increased government subsidies contribute to improving the technical performance of rice farms. The technical efficiency model reveals an average score of 0.724, suggesting that rice farmers could increase their production by 27.6% without additional inputs, simply by optimising their practices. Finally, receiving subsidies and using certified seeds appear to be the key drivers of performance. These results confirm the importance of better targeting public policies, equitable access to quality inputs and appropriate technical support in order to reduce inefficiencies and sustainably improve rice productivity in Senegal.

Key Words : Technical efficiency ; Rice production ; Certified seeds ; Government subsidies

Introduction

In Africa, rice plays a major role in the diets of rural and urban households (Ipar, 2020). It is a fundamental source and component of the diet of households in sub-Saharan Africa (PAPA, 2018). Indeed, it accounts for 20% of cereal consumption and is the fourth most important crop in terms of production after sorghum, maize and millet worldwide (FAOSTAT, 2016). In Senegal, rice plays a strategic role in national food security. It is the main cereal consumed, accounting for around 40% of households' calorie intake (FAO, 2022). Average annual rice consumption in Senegal is estimated at 1,622,923 tonnes of white rice, of which 780,104 tonnes are imported and 842,819 tonnes are produced domestically (DAPSA, 2023). The predominance of rice consumption is reflected in an average annual per capita consumption at the national level of 108.1 kg, with averages of 86.6 kg in urban areas and 90.9 kg in rural areas (Ipar, 2020). These data indicate that Senegal is 52% dependent on the international market for its rice supply, exposing it to the vagaries of that market, such as Covid-19 or the Russian Ukrainian war. In 2021, more than 60% of the rice consumed in Senegal was imported, exposing the national economy to exogenous shocks, particularly price fluctuations on the world market (USAID, 2022).

Figure 1. Rice imports vs domestic production in Senegal



Source : Ministry of Agriculture, Food Sovereignty and Livestock, 2024

This dependence is a major obstacle to the country's food sovereignty ambitions.

The various crises that have occurred in recent years (COVID-19, the Russian-Ukrainian war) around the world have prompted Senegal to move decisively towards a policy of food sovereignty (DAPSA, 2023). This option calls for the definition of a food policy aimed at intensifying value chains to ensure the availability and accessibility of sufficient, high-quality food for the Senegalese population. The evolution of national rice production is closely linked to the different phases of public policy since independence (PNAR, 2019). Policies such as PNAR and PRACAS have increased production, but total self-sufficiency has not been achieved.

Aware of these challenges, the Senegalese authorities have been implementing proactive policies for several years to promote rice self-sufficiency, notably through the National Rice Self-Sufficiency Programme (PNAR) launched in 2009. These policies are based on targeted subsidies for small-scale producers, including the distribution of improved seeds, chemical fertilizers and mechanisation services (MAER, 2021). However, despite these considerable efforts, rice yields remain highly heterogeneous, varying according to region, production systems and the socio-economic profiles of farmers (World Bank, 2020).

In this context, the implementation of a sequential rice production policy is recommended. This includes investments in the quality of local rice to align it with consumer preferences, followed by investments in productivity and a national marketing strategy (Chohin-kuper et *al.*, 1999; Rutsaert et al., 2013; PAPA, 2018, Diouf, 2019). It is within this framework that the government proposed the PNSIA (National Agricultural Input Subsidy Programme). The annual budget allocated to the subsidy is 6 billion, which will be distributed between fertilizers and seeds. Approximately 14,000 tons are allocated for rainfed varieties of the Sahel type and similar, while an additional 2,000 tons are earmarked for Nerica plateau varieties and other related types (Diouf, 2019).

Despite the potential of inputs to increase yields, the subsidy has not delivered the expected results (Reliefweb, 2015). Recent studies have highlighted the partial effectiveness and even poor targeting of subsidies, calling into question their efficiency in sustainably improving productivity (FAO, 2022; Minviel & Latruffe, 2017). In this context, a major question arises: Why does the rice production performance of smallholders remain low, despite significant support in the form of subsidised inputs?

Answering this question requires analysing current subsidy mechanisms and their effect on production in order to identify bottlenecks, better target agricultural policies, and optimise the allocation of public resources with a view to efficiency and equity. This research will provide a better understanding of the effect of current subsidies on the adoption of agricultural innovations and farm productivity, and will enable recommendations to be made for subsidy policy reforms. For example, this could involve determining the most effective types of subsidies (seeds, fertilizers or mechanisation) and identifying the conditions necessary for these subsidies to have a lasting effect on productivity.

The objective of this study is to analyze the effect of production factors (certified seeds, the quantity of fertiliser and the type of tillage) on the productivity of small-scale rice producers in

Senegal, with a particular focus on the potential for optimizing agricultural subsidies. More specifically, it aims to identify the key determinants of productivity, assess the effectiveness of existing subsidies, and formulate recommendations to improve their impact.

This research is being conducted by a researcher at ISRA (Senegalese Agricultural Research Institute) and a Data Science and Statistics specialist at the University of Reims Champagne-Ardenne, allowing for a combination of a rigorous empirical approach with advanced analytical tools.

The remainder of the article is structured as follows : the first section presents a literature review, the second section describes the methodology, the third section presents the results and discussion, and the final section proposes policy recommendations.

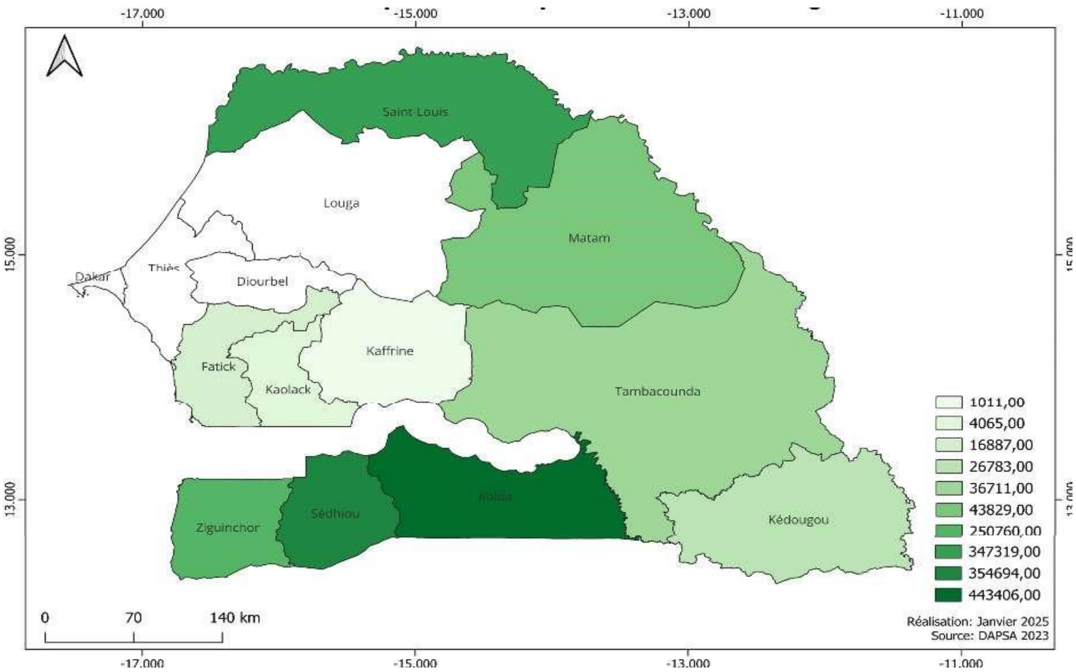
Rice cultivation in agricultural policies

Rice cultivation in Senegal is mainly divided into two systems: irrigated and rain-fed, with the latter dominating in terms of area. Irrigated rice, concentrated in the Senegal River Valley and the Anambé Basin, accounts for less than 20% of cultivated land (Fall, 2015). In contrast, rainfed rice includes several variants (Fall, 2015; CIRAD, 2019; PNAR, 2019):

- ***Strict rain-fed rice cultivation:*** practised in the central, southern and south-eastern regions (Kaolack, Fatick, Kédougou, Kolda, Casamance), with little water control, low yields (0.8-3 t/ha), traditional varieties and strong involvement of women. It contributes to self-consumption and food security.
- ***Lowland rice cultivation:*** located mainly in Casamance, it relies on the humidity of valleys and runoff areas. Yields remain low and variable depending on rainfall.
- ***Mangrove rice farming:*** practised in Casamance and the Saloum Islands, on land subject to alternating fresh and salt water. It requires infrastructure to protect against salt and capture fresh water. It is exclusively for self-consumption.
- ***Plateau rice farming:*** still little used in rice farming, except in lower and middle Casamance and to a lesser extent in the centre of the peanut basin. This extensive, fertiliser-free system is highly vulnerable to drought and yields less than 700 kg/ha.

Rainfed rice cultivation in Senegal is predominant but fragile, characterised by low yields and heavy dependence on rainfall. Developing the significant potential of irrigated rice cultivation (240,000 ha in the valley, 12,000 ha in Anambé) and improving rain-fed systems requires institutional and infrastructure investment (Fall, 2015). Irrigated rice farming (Senegal River valley) has made a significant contribution, as has rainfed rice farming (Casamance). The effectiveness of government interventions has varied; they have been crucial in initiating increased production in irrigated areas, but liberalisation has had a complex impact, creating difficulties for local producers (Fall, 2015). Despite efforts and investments, Senegal remains heavily dependent on rice imports for domestic consumption (PNAR, 2019), due to increased consumption (urbanisation, changing habits) and the competitiveness of imported rice (Brüntrup et al., 2006). Significant investment by the government has made it possible to reach this point today.

Figure 2. Distribution of rice production in Senegal



Source : DAPSA, 2023

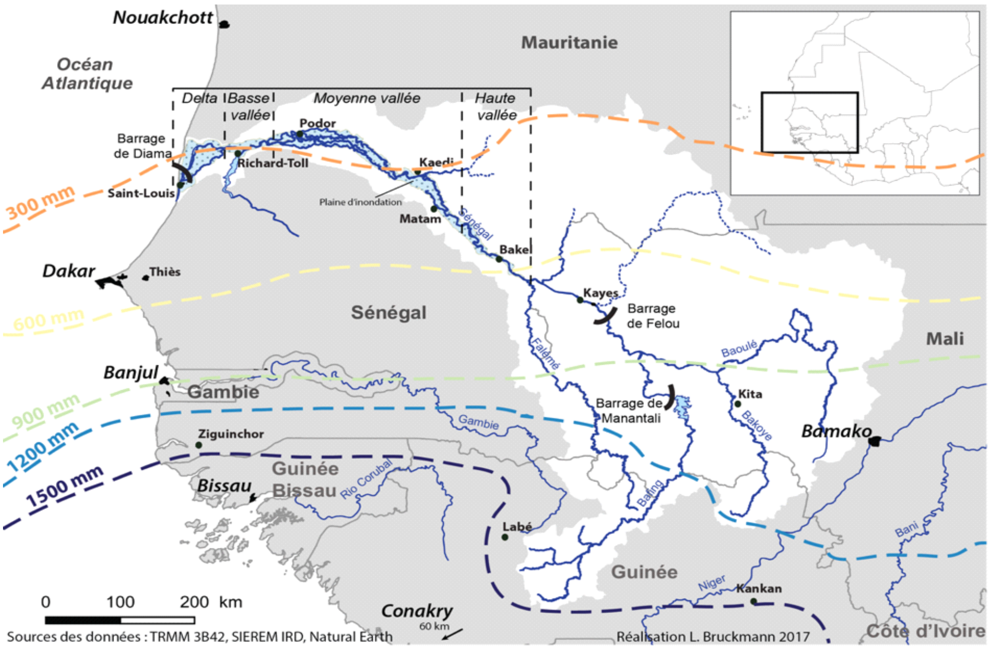
In Senegal, the agricultural sector has seen several types of public intervention as part of development strategies. First, the period of public intervention in the agricultural programme (1960-1980) was mainly characterised by a policy of subsidising agricultural exports through the provision of inputs, equipment and credit, which undermined rural development strategies. This was followed by the period of structural adjustment programmes, which began in the 1980s and led to the reduction of all direct production subsidies, the gradual reduction of subsidies to farmers and their total elimination in 1989. It was not until the late 1990s that the government resumed a policy of supporting access to inputs through a national "deep fertilisation" programme, which consisted of distributing heavily subsidised phosphates to producers in addition to subsidising seeds and equipment. An analysis of the different policy phases reveals their strengths and weaknesses: the interventionist phase (1960-1985) established structures but potentially stifled private initiative and did not generate sufficient growth (Seneplus, 2023); the liberalisation phase (1986-2000) led to an increase in imports and competitiveness challenges for local producers (Dahou, 2008); The phase of renewed state intervention (2001-present) with programmes such as GOANA, PNAR and PRACAS has led to significant increases in production, but challenges in implementation and achieving self-sufficiency remain (Fall, 2015). The development of rice cultivation is hampered by many interconnected challenges:

climate variability, soil degradation (salinisation) (Diedhiou, 2021), limited access to quality inputs and credit (FAO, 2022), inadequate infrastructure (irrigation, post-harvest) (CARD, 2012), low rainfed yields (practices, limited technology adoption) (Cirad, 2019), competition from imported rice (Dahou, 2008), weaknesses in the value chain (marketing, processing) (Fall, 2015), and programme implementation/criticism challenges (Seneplus, 2023).

Over the past 10 years, the focus has been on acceleration programmes and plans such as the Programme for Accelerating the Pace of Senegalese Agriculture (PRACAS) as part of the Emerging Senegal Plan (PSE), targeting rice self-sufficiency through a participatory approach to strategic value chains (Ngalane, 2014; PRACAS, 2014). The National Rice Development Strategy (2020-2030) sets out the future direction (PNAR, 2019). Several projects have been implemented, such as the PDCVR (private sector support), PAPRIZ3 (Valley, productivity/marketing), rain-fed projects (seed systems, value chains), PPPs such as 3PRD, and the successful CASL (AfDB, 2015; FAO, 2022; MASAE, 2024). Thanks to these efforts, production exceeded one million tonnes after 2015, and efforts to improve seed availability and quality are continuing (Fall, 2015). However, challenges remain, such as slow progress in irrigated areas and the vulnerability of rain-fed agriculture (Del Villar, 2019). Mechanisation remains a key driver (CARD, 2012).

Government subsidy programmes for agricultural inputs are key policy tools (USDA, 2020). The PNSIA makes fertilizers, seeds and agricultural equipment more affordable (USDA, 2025). The aim is to encourage the adoption of modern inputs, increase productivity and achieve food security, particularly in rice production (GRAIN, 2017). Subsidies involve price reductions (often subsidised at 87-90%) for farmers (USDA, 2025). Distribution is carried out by private companies, often reaching farmers through cooperatives (GRAIN, 2017). Studies show positive effects of subsidies, increasing the technical efficiency of rice farmers (GRAIN, 2017). But despite the significant resources mobilised to support rice farming, the productivity of smallholder farmers remains low and unstable overall. Subsidised agricultural inputs are widely distributed as part of national agricultural policies. However, their real impact on yields remains uncertain and uneven, particularly in the least favoured agroecological zones (World Bank, 2020; MAER, 2021).

Figure 3. Illustrated diagram of rainfall isohyets in Senegal



Source : L. Bruckmann, 2017

This issue is fully in line with the strategic orientations of current Senegalese public policies under the 2050 Reference Framework. The Emerging Senegal Plan (PSE), the former reference framework for the country's economic development, gave agriculture a prominent place as a lever for structural transformation. Through sectoral initiatives such as the PNAR and the Programme for Accelerating the Pace of Senegalese Agriculture (PRACAS), the government sought to strengthen local production and reduce dependence on imports, particularly in the rice sector (MAER, 2021). However, the effectiveness of these programmes depends heavily on the quality of their implementation and the concrete impact of subsidised inputs on productivity. A rigorous assessment of their effects is therefore essential in order to adjust public interventions, make them more inclusive and adapted to local realities, and capable of producing sustainable economic and social results.

Methodology

1. Theoretical literature on the stochastic frontier model

The analysis of agricultural productivity and the technical efficiency of producers requires econometric tools capable of capturing both variations due to inputs and those related to management inefficiencies. The stochastic frontier model (SFA), introduced by Aigner, Lovell and Schmidt (1977), is ideal in this context because it explicitly distinguishes between random effects linked to external shocks (climatic conditions, measurement errors) and those linked to technical inefficiency.

The choice of the Stochastic Frontier Analysis (SFA) model is part of an analytical approach aimed at simultaneously measuring the productive performance and technical inefficiencies of farms. Unlike classical ordinary least squares econometric models, which assume that all production units operate at an optimal level, the stochastic frontier model makes it possible to distinguish production gaps attributable to technical inefficiency from those resulting from exogenous factors such as climatic conditions or production shocks (Kumbhakar et al., 2021; Greene, 2023). In the context of small rice farms in Senegal, characterized by high heterogeneity and exposure to risk, this decomposition capability constitutes a decisive analytical advantage.

More specifically, the use of SFA makes it possible to assess the extent to which factors of production (inputs, labor, capital) are used efficiently, while also identifying potential areas for improvement. Recent work has widely used this approach to analyze agricultural productivity in sub-Saharan Africa, highlighting its effectiveness in capturing performance gaps between farms and informing public policy, particularly regarding agricultural subsidies (Ogundari, 2021; Abdulai & Tietje, 2022). In this respect, the stochastic frontier model is particularly relevant to the objective of this study, which aims not only to explain productivity but also to propose ways to optimize support policies.

From an epistemological standpoint, this research adopts a positivist approach, based on the assumption that economic and productive phenomena can be observed, measured, and modeled using empirical data. This approach prioritizes objectivity, quantification, and the search for causal relationships between variables, employing rigorous econometric tools (Creswell & Creswell, 2023). The SFA model, as a parametric statistical tool, fits fully into this logic by allowing the testing of hypotheses relating to the production function and technical inefficiency.

Empirical literature on rice farming confirms the relevance of this approach. Khai and Yabe (2011) in Vietnam and Ogundari et al. (2006) in Nigeria show that factors such as mechanisation, the use of mineral fertilizers (urea, NPK) and water availability are key determinants of productivity gains. These studies illustrate the SFA's ability to isolate the specific effect of inputs while measuring the relative technical efficiency of producers. In the West African context, Arouna et al. (2017) emphasise that the use of certified seeds significantly improves rice yields, by around 20 to 30%, thus confirming the structuring role of input quality in agricultural performance.

Beyond productive inputs, the issue of agricultural subsidies is a key lever for analysis. Several studies (Garrone et al., 2018; Góral, 2015; Zhu and Lansink, 2010) show that subsidies, when well targeted, facilitate access to improved seeds, fertilizers and mechanisation, and contribute to increasing technical efficiency. However, the meta-analysis by Minviel and Latruffe (2017) reveals that these effects remain ambiguous: while 24% of studies show a positive impact, 60% indicate a negative effect, often explained by dependency or a reduction in productive effort.

This diversity of results suggests that the effectiveness of subsidies depends heavily on how they are implemented, how they are targeted and the institutional environment.

In the case of Senegal, where the government devotes a significant portion of its agricultural spending to subsidised inputs (certified seeds, fertilizers, mechanised ploughing services), a rigorous assessment of their impact on the productivity of small rice producers appears crucial. The use of the stochastic frontier model is all the more justified as it not only makes it possible to measure the technical efficiency of farms based on the use of these inputs, but also to analyse the differentiated effect of subsidies according to producer profiles and agroecological contexts. The literature therefore shows that the model generally used is the stochastic frontier model to quantify the effect of production factors on the productivity of small producers, and that the quantity of urea and NPK fertiliser generally has a positive effect on rice productivity. Cultivated area also plays an important role, often with a positive effect on technical efficiency, as a larger area can allow for better resource allocation. Household size influences the availability of labour, thus impacting productivity, although this effect may vary depending on the socio-economic context. Finally, agricultural subsidies, by facilitating access to inputs, mechanisation and credit, can help to increase productivity.

2. Stochastic Frontier Analysis (SFA) model specification

Formulated by Aigner et al. (1977), the *Stochastic* Frontier *Analysis* (SFA) model is a parametric approach for assessing producers' technical efficiency. This model is based on a Cobb-Douglas production function, which can be expressed as follows :

Yit =F(Xit, β) exp (Vit) exp ($-Uit$) (1)

Where :

- Yit represents the output of producer i at time t;
- Xit denotes the vector of inputs used by producer i at time t;
- β is the vector of parameters to be estimated;
- $Vit \sim N(0, \sigma v^2)$ represents the random error term;
- $Uit \sim N^+(\mu, \sigma u^2)$ represents the technical inefficiency term.

The inefficiency term U follows a truncated (or half-normal) normal distribution with constant variance σ_u^2 and mean μ, which depends on additional explanatory variables :

$\mu = \alpha z$ (2)

Where α is the vector of parameters to be estimated.

According to the standard approach, the determinants of technical efficiency can be estimated simultaneously from the production frontier defined in equation (1) and an inefficiency model specified by Battese & Coelli (1995) as follows :

$Uit = g(\mu it, \alpha)$ (3)

Thus, the technical efficiency (TE) of producer i is expressed as follows :

$ET_{it} = Y_{it} / Y^*_{it} = \exp(-U_{it})$ (4)

Where :

- $Y^*_{it} = f(X_{it}, \beta) \times \exp(V_{it})$ represents potential (boundary) production without inefficiency;
- $Y_{it} = f(X_{it}, \beta) \times \exp(V_{it} - U_{it})$ represents observed output with inefficiency.

By linearising the Cobb-Douglas production function and the inefficiency function, we obtain:

$\ln(Y_{it}) = \beta_{it} + \Sigma\beta_i \ln(X_{it}) + V_{it} - U_{it}$ (5)

The term of inefficiency can be modelled as follows: U $U_{it} = \alpha_0 + \alpha_i Subv + \Sigma\alpha_i M_i + Z_i$ (6)

Where:

- Y_{it} represents rice production;
- X_{it} is the vector of production inputs;
- β_i, α_0,and α_i are the parameters to be estimated;
- M_i represents the set of control variables;
- U_{it} denotes technical inefficiency (truncated normal distribution);
- V_{it} is the random error term (normal distribution);
- Z_i is the error term of the inefficiency model;
- Subv corresponds to the agricultural subsidies received by the producer.

To determine the existence of inefficiency, Battese & Coelli (1995) recommend examining the gamma parameter (γ) after estimating the stochastic frontier. The log-likelihood function is parameterised as follows:

$\sigma^2 = \sigma u^2 + \sigma v^2$ et $\gamma = \sigma u^2 / (\sigma u^2 + \sigma v^2)$ avec $0 < \gamma < 1$ (7)

The value of γ measures the share of total variance attributed to inefficiency (Bravo-Ureta et al., 2012). A value of γ close to 1 means that inefficiency dominates total variance, while a value close to 0 indicates negligible inefficiency.

In this study, given the presence of numerous zero values in the fertiliser quantity variable, logarithmic transformation was performed with a shift of +1 in order to avoid the loss of observations. The estimated empirical model is written as follows:

$\ln(Yield + 1) = \beta_0 + \beta_1 \ln(Seed\_dose + 1) + \beta_2 \ln(Area + 1) + \beta_3 \ln(Fertiliser\_quantity + 1) + \beta_4 (Type\_tillage) + \beta_5 (Certified\_seed) + \beta_6 (Government\_subsidy) + (V_i - U_i)$ (8)

Inefficiency is therefore included in the residual term and captured globally by gamma $\sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$ with $0 < \gamma < 1$, which measures the proportion of total variance attributable to technical inefficiency:

The SFA model was estimated using R software, according to the three-step methodology proposed by Coelli et al. (1996):

1. Estimation of the production function using ordinary least squares (OLS);
2. Application of a double threshold procedure to estimate $\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$, using the coefficients β (except β_0), with adjustment of β_0 and σ^2 according to Coelli et al. (1996);
3. The values obtained in the first step serve as initial values for an iterative procedure (the Davidon-Fletcher-Powell quasi-Newton method) to obtain the final maximum-likelihood estimate.

3. Data source

The data used in this study comes from Senegal's Annual Agricultural Survey (EAA), also known as the AGRIS survey, conducted by the Department of Agricultural Statistics Analysis and Forecasting (DAPSA) for the 2021-2022 agricultural season. The AGRIS survey is a modular, multi-year agricultural survey programme established as part of the FAO's global strategy to improve agricultural and rural statistics.

The AGRIS methodology provides both a source of reliable data and a consistent framework for the design, monitoring and evaluation of policies and investments in the agricultural and rural sectors. It also makes it possible to produce the data needed to monitor certain Sustainable Development Goal (SDG) indicators.

Since the 2017 campaign, DAPSA has benefited from the AGRIS Survey programme, which aims to broaden the scope of the Annual Agricultural Survey in order to collect and disseminate more varied agricultural data, adapted to the realities of developing countries. Its implementation in Senegal has resulted in the adaptation of the CEA (Agricultural Survey Committees) system to a multi-year modular approach, the basic module of which was introduced during the 2017-2018 campaign.

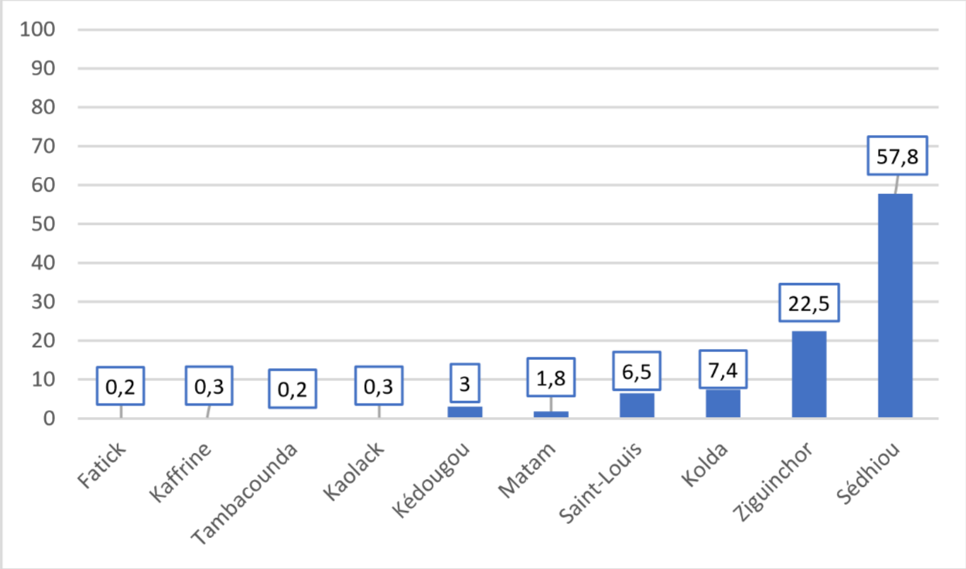
The 2021-2022 EAA database includes a total of 396 agricultural plots farmed throughout the country, with rice as the main crop.

Results and Discussion

4. Descriptive analysis of the database

The distribution of respondents by region (Figure 3) shows that the sample of rice farmers is mainly composed of households from Sédhiou (61%), Ziguinchor (27.4%), Kolda (6.2%) and Kédougou (3.3%). Casamance (Ziguinchor, Sédhiou and Kolda) accounts for 94.6% of the sample of rice farmers.

Figure 4. Respondents by region (%)

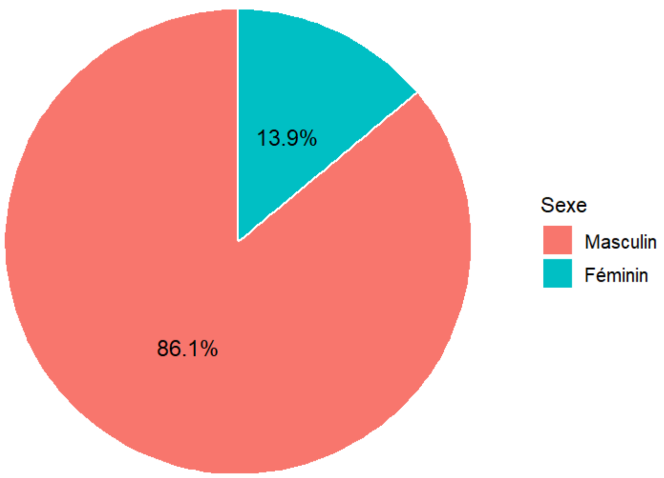


Source : DAPSA, 2022

Figure 4 shows that the low representation of northern regions such as Saint Louis and Matam is justified by the fact that this area is mainly planted with irrigated rice during the dry season. This allows for better yields with better control of water, weeds and pests. The northern zone receives mainly fertilizer but no seeds. During the rainy season, the Casamance area, consisting of Sedhiou, Ziguinchor and Kolda, is much more heavily cultivated.

Rice cultivation is an activity mainly dominated by men, as shown in Figure 5. The distribution of respondents by gender reveals that most respondents are men (86.1%).

Figure 5. Respondents by gender (%)

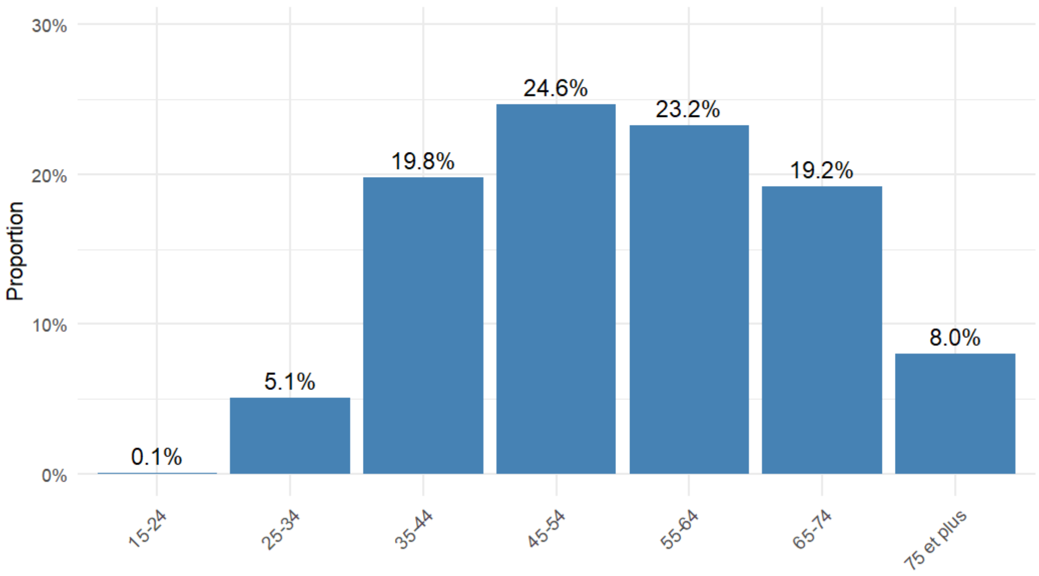


Source : DAPSA, 2022

Historically, rice production in the Senegal River Valley and Casamance has been mainly carried out by men, who have priority access to irrigated land and productive resources (Seck et al., 2013). This distribution can also be explained by social and land tenure norms that give men responsibility for the main food crop (Douthwaite et al., 2016). However, the low representation of women in this sample does not mean that they play no role in the sector. On the contrary, women play a decisive role in post-harvest operations, particularly rice husking, processing and marketing, thereby contributing to food security and added value (FAO, 2018). Several studies show that their direct participation in production is more visible in rain-fed areas and lowlands, where they often grow subsistence rice on small plots (Carney, 2008; Diagne et al., 2014).

The distribution of farmers by age group (Figure 6) reveals that those aged 45 to 54 are in the majority. They represent 24.6% of farmers, followed by the 55-64 age group with 23.2% and the 35-44 age group (19.8%). This means that the majority of farmers are relatively mature adults.

Figure 6. Distribution of plot manager respondents by age



Source : DAPSA, 2022

The low level of engagement of young people under the age of 35 in rice farming is a recurring finding in agricultural assessments. Rural youth, faced with unemployment and precariousness, are showing growing interest in non-agricultural activities that are considered more profitable, often in urban areas or abroad (Filmer & Fox, 2014). This imbalance poses a challenge to the sustainability of the sector, as the ageing of the agricultural population risks compromising succession and long-term competitiveness (Jayne et al., 2019).

The database used for this study includes a sample of 396 rice-producing plots. The main descriptive statistics for the key variables are shown in Table 1.

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Table 1. Statistics on quantitative variables

Variable	Mean	Standard	Min	Max
Seed rate	86.8	37.5	40.0	160.0
Area (ha)	0.5	0.4	0.2	4.0
Fertiliser quantity	7.7	27.7	0.0	190.0
Yield	2,469.8	996.8	725.8	5,127

Source : DAPSA, 2022

Table 1 shows that the average seed rate is estimated at 86.8 kg/ha, with a range of 40 to 160 kg/ha and a standard deviation of 37.0, reflecting considerable heterogeneity in cultivation practices. The average area sown is 0.5 hectares, ranging from 0 to 4.0 hectares, with a standard deviation of 0.4. The average amount of fertiliser applied is 7.7 kg per hectare, with significant variation (values ranging from 0 to 190 kg). Finally, the average yield observed is 2,469.8 kg/ha, ranging from 725.8 to 5,127 kg/ha, with a standard deviation of 996 kg/ha, revealing significant variability in performance between households. The variation observed in yields (725.8 to 5,127 kg/ha) reflects significant differences in productivity between households, linked to differential access to inputs, equipment and farming techniques (Saito et al., 2015). Although the average yield of 2.47 t/ha remains higher than the rainfall average, it is still below the varietal potential and the performance obtained under optimal conditions as said in others papers like Wopereis et *al.* (2008). These findings confirm the need to strengthen technical support and equitable access to inputs in order to reduce performance gaps and improve the overall productivity of rice farming in Senegal.

Table 2. Statistics on qualitative variables

Variable	Modality	Number	Proportion
Type of ploughing	1 = Deep ploughing	36	9.1
	0 = Shallow/shallow ploughing	360	90.9
Certified seed	0 = No	374	94.4
	1 = Yes	22	5.6
State subsidy	0 = No	479	97.2
	1 = Yes	14	2.8

Source : DAPSA, 2022

The analysis in Table 2 shows that almost all of the households surveyed (91.1%) practise ploughing, whether deep or shallow, confirming its central role in soil preparation and water management in rain-fed production. This high proportion indicates the importance attached to this cultivation operation in rice farming. In addition, it appears that 94.4% of producers do not use certified seeds in rain-fed production, which could have significant implications for yields and production quality. The almost universal absence of certified seeds reflects a persistent dependence on farm-saved seeds, which are often of variable quality, limiting yield potential and resilience to climatic hazards. These findings are confirmed by the research of Diagne et al. (2013) and Wopereis et al. (2008) on the use of uncertified rice seeds in rainfed cultivation, which is the primary cause of poor performance.

Finally, the data reveal that only 2.8% of households have benefited from a state subsidy, highlighting the low coverage of public support in the area studied. Access to subsidised inputs is an essential lever for improving productivity and encouraging the adoption of innovations (Seck et al., 2012). This finding highlights the need to strengthen support mechanisms for producers, in particular through better distribution of certified seeds and more equitable coverage of subsidies.

5. Technical efficiency of rice producers in Senegal

Table 3 shows that, of the 396 plots included in the model, the average technical efficiency score is 0.724, with values ranging from 0.374 to 0.921. This indicates that, overall, Senegalese rice farmers could increase their current production level by about 27.6% without increasing the level of input with existing technology if they operated at full capacity. This result is consistent with that of Beye et al. (2018), who estimated a technical efficiency score of 0.534 for family farmers in Senegal.

Table 3. Technical efficiency score of rice producers.

Variable	No. of observations	Mean	SD.DEV	Min	Max
Efficiency	396	0.724	0.125	0.374	0.921

Source : DAPSA, 2022

The stochastic frontier model estimation reveals that certain agricultural practices and inputs are strongly associated with higher yields, suggesting an improvement in the technical efficiency of rice farms.

The coefficient for "semence_certNo" is negative ($\beta = -0.5239$, $p < 0.001$), indicating that not using certified seeds reduces yield. Thus, producers using certified seeds tend to approach their maximum potential yield. Similarly, the coefficient for "subv_semence2" is positive ($\beta = 0.8317$, $p < 0.001$), indicating that a farm receiving the seed subsidy achieves a higher yield and is closer to the production frontier.

For continuous inputs transformed into logarithms (1 + X), the coefficients represent the marginal effect on yield. A 1% increase in cultivated area (Q1_3a_16) leads to a slight decrease in yield per unit area (β = -0.2019, p = 0.044), reflecting a marginal decline in technical efficiency. Conversely, a 1% increase in the amount of fertiliser (Q_fertiliser) increases yield by approximately 5.2% (β = 0.0521, p = 0.002), slightly improving technical efficiency. However, a 1% increase in seed dose (dose_seed) reduces yield by approximately 40.7% (β = -0.4077, p < 0.001), decreasing the producer's proximity to the production frontier.

With regard to farming practices, deep ploughing appears to be a determining factor for technical efficiency. Not ploughing reduces yield by approximately 16.1% (β = -0.1614, p = 0.035), highlighting the importance of this technique for optimising production and improving the technical performance of farms.

Table 4. Technical efficiency score of rice producers by modality.

Variable	Estimate	Std. Error	z value	Pr(>|z|)	Signif.
(Intercept)	9.912909	0.244949	40.4693	<2.2e-16	***
Area (Q1_3a_16)	-0.2019	0.100078	-2.0174	0.043656	*
Q_fertiliser	0.052141	0.016843	3.0956	0.001964	**
seed_dose	-0.40766	0.051909	-7.8533	4.05e-15	***
typelabour (no ploughing)	-0.16143	0.076609	-2.1072	0.035099	*
certified seed (No)	-0.5239	0.105806	-4.9515	7.36e-07	***
seed subsidy (2)	0.831676	0.168517	4.9353	8.00e-07	***
sigmaSq	0.266362	0.039324	6.7735	1.26e-11	***
gamma	0.745325	0.091156	8.1764	2.92e-16	***

Source : DAPSA, 2022

Explanation of results :

The SFA model analysis made it possible to assess the performance of rice producers and test the effect of inputs, farming practices and public support on technical efficiency. The average efficiency score of 0.724 indicates that, on average, producers could increase their yield by around 27.6% without increasing inputs, simply by adopting optimal practices.

Regarding the first hypothesis, the results show that the use of certified seeds significantly improves yields and brings producers closer to their maximum potential yield (β = -0.5239, p < 0.001). This highlights the importance of promoting quality seeds to improve productivity.

The second hypothesis, that receiving seed subsidies improves technical performance, is also verified. Producers receiving subsidies achieve higher yields ($\beta = 0.8317$, $p < 0.001$), suggesting an improvement in their technical efficiency.

Finally, the fourth hypothesis, concerning the effect of inputs and farming practices, is partially confirmed. The application of fertiliser slightly increases yields, while deep ploughing is a key factor in optimising production, with the absence of ploughing reducing yields by around 16.1% ($\beta = -0.1614$, $p = 0.035$). Conversely, an excessive increase in cultivated area or seed dose can slightly reduce yield per unit area, reflecting the importance of optimal management of inputs and farming practices.

Overall, these results highlight the need to combine institutional support (subsidies and certified seeds) with technical assistance (appropriate farming practices and optimal use of inputs) to sustainably improve rice productivity in Senegal. Targeted interventions and good agricultural practices enable farms to approach their maximum potential yield, suggesting an improvement in technical efficiency.

6. Proposed adjustment to the subsidy programme

Since the 2000s, Senegal has reintroduced subsidy programmes for agricultural inputs (seeds, fertilizers, equipment), notably through GOANA (2008) and then PRACAS (2013). This scheme, which accounts for nearly one-third of the Ministry of Agriculture's budget, has helped improve access to inputs, but its effectiveness and fairness remain controversial (Ricome et al., 2021; IPAR, 2015).

The agricultural input subsidy programme in Senegal (PSIA) is universal, meaning that it is supposed to be accessible to all producers. In reality, the quantities of subsidised inputs available are relatively limited, which means that targeting is carried out de facto at the level of the transfer committees, set up for each local authority and headed by the mayor, which set the criteria for access according to the quota for the municipality or village. This traditional approach is still in use today, limiting the programme's potential and allowing fraud. In order to find better solutions, a workshop was held with the stakeholders and the aforementioned results were presented.

The main findings are during the workshop is:

- low effectiveness on agricultural yields despite increased use of inputs at the national level;
- targeting problems, with a high probability of capture by elites (wealthier producers, politicians, religious leaders);
- crowding out effects on commercial input markets, reducing the incentive for private investment;

• logistical challenges: delivery delays, poor-quality seeds, overly restrictive quotas. lack of programme evaluation and monitoring of donated inputs.

Studies show that PSIA has increased the use of fertilizers and certified seeds, but without a significant effect on yields or gross margins (Ricome et al., 2021). This can be explained in part by unfavourable agro-ecological conditions, but also by a lack of complementarity with other factors (access to water, credit, technical training). Inputs alone are not enough; farmers need to know how to use them, and PSIA does not provide training in this area. It should also be noted that access to inputs is skewed towards large producers: in 2015, 53% of farmers with more than 5 hectares received 62.7% of subsidised inputs (IPAR, 2015). Small producers, who represent the majority, receive too little to bring about real change. The lack of transparency in distribution (role of local commissions, favouritism) also fuels mistrust.

There is also a high level of budgetary dependence, which impacts the programme's sustainability. The programme mobilises around 0.5% of GDP and nearly a third of the agricultural budget (Boulanger et al., 2018), to the detriment of structural investments (irrigation, research, training). This budgetary burden calls into question its long-term sustainability. Senegal has allocated a budget of 130 billion CFA francs for the 2025-2026 agricultural season.

During the workshop, participants highlighted the recurring difficulties during production campaigns:

- The mismatch between the subsidised inputs received (particularly seeds) by the commissions and the real needs of farmers (often focused on fertilizers);
- Failure to take into account producers' preferences in terms of varieties;
- Delays in the delivery of seeds and fertilizers due to supplier failures ;
- Insufficient quantities of inputs distributed (certified seeds, mineral fertilizers) and poor quality (not certified seed) noted in certain areas ;
- Delays in the availability of notifications and implementation schedules, and repeated changes that make monitoring difficult ;

After the workshop, the following recommendations were adopted with the aim of improving the effectiveness, efficiency and equity of the PSIA programme :

• Further professionalise the agricultural input supplier profession and strengthen the overall selection process in order to improve the quality of inputs received by farmers;

• Finalise the adoption of a legal and regulatory framework establishing and organising the role of agricultural input suppliers, defining the conditions for implementation and access to the subsidy programme and the penalties provided for;

- Strengthen the alignment between the subsidised inputs offered under the subsidy programme and the needs of farmers, with a greater focus on the provision of fertilizers;
- Promote transparency in access to subsidised inputs and notify future beneficiaries of the types and quantities obtained, then disseminate climate information on the various platforms before the start of cultivation work;
- Map and allocate a quota of fertiliser and seeds to each head of household in all villages in Senegal, in collaboration with sub-prefects, village chiefs and town halls, using the tax register;
- Rehabilitate seccos and build new storage facilities, then further promote village grain banks (BCVs) and multifunctional platforms;
- Digitise the input distribution process, from the selection of suppliers to the use of inputs by beneficiaries, by introducing an identity card for each beneficiary with a unique identification number containing key information.
- Entrust the distribution of subsidised inputs to the Société d'Aménagement et d'Exploitation du Delta du Fleuve et de la Vallée du Fleuve Sénégal (SAED) and the Société de Développement Agricole et Industriel du Sénégal (SODAGRI). These two organisations are more familiar with rice producers and provide them with support in the field.

Conclusion

This study is part of an effort to analyse the effect of the main factors of production (government subsidies, certified seeds, type of ploughing and agricultural inputs) on the productivity of small rice producers in Senegal, with a view to optimising subsidies and improving technical efficiency. Analysis of the effect of production factors on the productivity of small rice producers in Senegal reveals that agriculture is still marked by technical inefficiency, with an average score of 0.724, indicating that yields could increase by 27.6% without increasing inputs.

The SFA model shows that the use of certified seeds and the receipt of seed subsidies contribute significantly to reducing inefficiency, while optimising input doses and adopting deep ploughing are important levers for improving efficiency. These results suggest that there is substantial room for improvement and that optimising subsidies and farming practices can bring farms closer to their maximum yield, strengthen the competitiveness of the sector and secure producers' incomes.

In this context, the national agricultural input subsidy programme needs to be readjusted to enhance its effectiveness, equity and sustainability. The priority adjustments concern the professionalisation and quality control of input suppliers, the digitisation of the distribution process, transparent and equitable allocation of resources, and close technical support. If implemented, these reforms would help to strengthen the competitiveness of the rice sector, secure producers' incomes and bring Senegal closer to its goal of rice self-sufficiency.

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