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Research Article

# Effect of Soil and Water Conservation Techniques' Adoption Intensity on Farmers' Technical Efficiency in Burkina Faso: A Stochastic Meta-Frontier Approach

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## Abstract

In the context of soil degradation, resilient and sustainable production systems are needed to address the challenges of food security and poverty reduction in rural areas. In this prospect, farmers adopted various soil and water conservation techniques (SWCTs) in their production systems. The objective of this article was to estimate and compare technology gap ratio (TGR) and meta-frontier technical efficiency (MTE) between three groups of cereal producers in Burkina Faso. They were divided regarding the adoption intensity of SWCTs (low, medium and high). The data used was collected by questionnaire survey on a sample of 335 farmers from May to July 2022. Meta-frontier approach was applied in order to deal with the heterogeneity of techniques' intensity of adoption. The results showed that medium or high intensity farmers have a TGR equals to 1. Conversely, their MTE (60%) is lower than that of low-intensity farmers (70%). This evidence implies that SWCTs intensive producers are technically less efficient compared to less intensive ones. It comes out that the adoption of several SWCTs leads to a suboptimal use of a set of factors. These results suggest that agricultural development stakeholders should develop the agricultural counselling system oriented to the optimal use of production factors.

## Keywords

Meta-frontier Technical Efficiency, Technology Gap Ratio, Soil and Water Conservation, Farmers, Burkina Faso

## 1. Introduction

Many studies conducted in Burkina Faso showed that farmers' agricultural production is situated between 50% and 80% from the optimal production [1]. This implies that there is a potentiality to improve their production up to 20% at less, whilst keeping production inputs constant. According to some authors, farmers' technical inefficiency is partly due to soil degradation [2-4] and climat change effect [5].

To combine agricultural production improvement and natural resources management for rural household's livelihoods improvement purpose as showed by [6]. Rural farmers in the Sahelian zone are constantly invited to adopt several soil and water conservation techniques (thereafter referred as SWCTs). Those promoted in Burkina Faso to reach this objective include stone bund, grass strips, compost, mulching, half-moon, zaïand so on [7]. Indeed, SWCTs' adoption is largely recognized as a way for farmers' technical efficiency improvement

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[2-4]. To combat soil degradation, rural farmers intensify SWCTs' adoption on their farmland. In fact, they often adopt more than one available techniques [8]. So, in this paper, adoption intensity is defined as the number of SWCTs used by a given farmer.

The effect of SWCTs' adoption intensity on farmers' technical efficiency is examined in past empirical studies [9]. Using the standard stochastic production frontier approach [10, 11], these authors did not take into account farmers' heterogeneity about their production frontiers according to SWCTs' adoption intensity. Thus, their empirical results seem biased. Stochastic meta-frontier approach enables to take into account farmers' heterogeneity.

In Burkina Faso, farmers differ according to their SWCTs' adoption intensity level. As a result, farmers are expected to have a specific production frontier according to their SWCTs' adoption intensity. This possibility gives an opportunity to analyze the effect of SWCTs' adoption intensity on farmers' technical efficiency using stochastic meta-frontier approach. Hence, the research question addressed by this study is: what is the effect of SWCTs' adoption intensity on farmers' technical efficiency?

The purpose of this study is to analyze the effect of SWCTs' adoption intensity on farmers' technical efficiency. The hypothesis tested is that the most intensive farmers in SWCTs' adoption are more efficient technically. Previous studies [12, 13] have enabled to identify farmers with the most techniques' adoption intensity, but did not provide a useful information on the relationship between the best technology used and technical efficiency. The present article tries to fill this gap. It contributes to the debate on the effect of SWCTs' adoption on farmers' technical efficiency in their production activities. In comparison to past studies on this subject, its originality comes from farmers' heterogeneity based on the adoption intensity of those technologies' consideration. The expected results may serve to further enlighten agricultural development stakeholders about actions to be taken to improve the performance of farmers involved in soil and water and conservation.

It could contribute to the agricultural development in Burkina Faso by improving its productivity. That is important to rural communities and national economy. Moreover, the study is setting on the X-efficiency theoretical framework proposed by [14], which deals with the misuse of resources within a production unit.

The rest of the article is structured into four main sections. The first section reviews the theoretical and empirical literature. The second section presents the research methodology. The third section presents the results which are discussed in the four one. A conclusion and policy implications closes the study.

# 2. Methodology

## 2.1. Data Collection

The data were collected from a sample of 335 farmers randomly selected in the northern sudanian and southern sudanian agro-climatic zones of Burkina Faso from May to July 2022. The sample is distributed into four rural municipalities. Agricultural production data therefore covered the 2021/2022 rainy-season. The aim was to collect information on the production of the various crops, their cultivated areas, the quantity of fertilizers used and also the different SWCTs adopted. During data collection, the unit of observation was the household, with the head of household as the primary respondent.

## 2.2. Analytical Framework

In their production systems, farmers use several factors such as land, fertilizers, seeds and labor to obtain a quantity (Q) of crop. Theoretically, production factors used are grouped into two categories: labor (L) and capital (K). Farmers' production function defines the relationship between the factors used and the output obtained: Q=f(L, K). They are efficient technically when Q corresponds to the maximum possible output given K and L quantities used. However, according to the theory of X-inefficiency, farmers may not be as efficient in their farming systems towards the optimum. Reference [14] refers to inefficiency deriving from the misuse of any resource within production unit. In technical efficiency analysis way, the gap between the $i^{th}$ farmer production and the optimum is considered to be explained by his own inefficiency ($\mu_i$) and unobservable factors ($v_i$).

## 2.3. Stochastic Meta-frontier Approach

In this paper, SWCTs' adoption intensity level has served to classify farmers into three groups: low-level adopters (at most one SWCT), medium-level adopters (with two SWCTs) and high-level adopters (at less three SWCTs). This classification is based on the SWCTs' number adopted by farmers. Following [15], a stochastic meta-frontier approach consists in using firstly the stochastic frontier method to estimate farmer's technical efficiency in each group, then predicting their outputs in order to use them in the second step to estimate the meta-frontier by the stochastic frontier regression again. The stochastic group-specific production function is specified as:

$$y_{iz} = f_z(\delta, x_{ijz})e^{(v_{iz}-u_{iz})}, \text{ with } i = 1,2,3, n_z \quad (1)$$

In equation (1), $y_{iz}$ is the agricultural production achieved by the $i^{th}$ farmer from the $z^{th}$ group, $x_{ijz}$ indexes the $j^{th}$ production factor quantity, δ is a vector of parameters for the $z^{th}$ group to be estimated, $f_z$ is the group-specific production frontier, $v_i$ is a positive random variable normally distributed with parameters $(0, \sigma_v^2)$: $[v_i \sim N(0, \sigma_v^2)]$. It captures random variations in production, due to factors beyond the farmer's control, $u_i$ is also a positive random variable following either semi-normal or exponential distribution. It represents the technical inefficiency of production due to factors controlled by the farmer. In all cases, $v_i$ and $u_i$ are independent.

The $i^{th}$ farmer from group $z$ technical efficiency ($ET_{iz}$) is measured by the ratio between the output obtained ($y_{iz}$) and the optimal production ($y^*_{iz}$), given the production factors used according to the equation (2):

$$ET_{iz} = \frac{y_{iz}}{y^*_{iz}} = \frac{f_z(\delta_z; x_{ij})e^{(v_{iz}-u_{iz})}}{f_z(\delta_z; x_{ij})e^{v_{iz}}} = e^{-u_{iz}} \quad (2)$$

The $i^{th}$ farmer is technically efficient as soon as his technical efficiency index $ET_{iz}$ is equal to 1. This means that $u_{iz} = 0$. Otherwise, he is inefficient. According to [16], technical inefficiency model is expressed by equation (3).

$$\mu_{iz} = \varphi_{0z} + \sum_{j=1}^{J} \varphi_{jz}\, q_{ijz} + \tau_{iz} \quad (3)$$

Where $q_{ij}$ is a vector of variables which explain the $i^{th}$ farmer from group $z$ technical inefficiency, $\varphi_{jz}$ is a vector of the model parameters to be estimated, $\tau_{iz}$ is the error term following the normal distribution with parameters $(0, \sigma_\tau^2)$: $[(\tau_i \backsim N(0, \sigma_\tau^2)]$.

Following [15], the second step uses the adjusted production of each group $[\widehat{f_{iz}}(x_{ij};\ \delta_z)]$ to formulate the common meta-frontier production function that underlies all groups defined as $f_M(x_{ij};\ \delta_M)$. By definition, the meta-frontier $f_M(x_{ij};\ \delta_M)$ envelopes all individual group's frontier $f_z(\delta, x_{ijz})$. Their relationship is specified as:

$$f_z(\delta, x_{ijz}) = f_M(x_{ij};\ \delta_M)e^{(-u_{iM})} \quad (4)$$

Where $u_{iM}$ is the component of farmers' meta-inefficiency and $u_{iM} \geq 0$. This implies that $f_M(x_{ij};\ \delta_M) \geq f_z(\delta, x_{ijz})$. The ratio of the $z^{th}$ group's production frontier to the meta-frontier can be defined as the technology gap ratio (TGR) expressed as:

$$TGR_{iz} = \frac{y_{iz}}{y_{iM}} = \frac{f_h(\delta_z; x_{ij})}{f_M(\delta_M; x_{ij})} = e^{-u_{iM}} \leq 1 \quad (5)$$

Where $y_{iM}$ is the adjusted production for all farmers. According to Ng'ombe (2017), a TGR value that equals to 1 implies that the farmer adopted the most advanced technology to produce outputs, while a TGR value $< 1$ means that he failed to adopt the most advanced technology due to any reason.

As noted by [12, 13], farmer's technical efficiency with respect to the meta-frontier production ($MTE_{iz}$) verifies the following relation:

$$MTE_{iz} = TGR_{iz} * ET_{iz} \quad (6)$$

## 2.4. Empirical Modelling

### 2.4.1. Variables Used in the Empirical Model

The present study employed ordinary inputs and variables supposed to influence the level of farmers' technical efficiency. Those variables are identified mainly through empirical previous studies. Following [12, 17], the output variable in the production function is measured by the aggregated value of main cereals (maize, millet and sorghum) produced by farmers in FCFA. Inputs variables included cultivated area in hectares, the quantity of chemical fertilizer measured in 50 kilograms bags, labor used in man-days and asset value in FCFA. Indeed, under the assumption that farmers are located in the first production zone, we deduce that each factor's marginal product is positive ($f'_{(x)} > 0$). ($x$ designs inputs aforementioned).

Concerning the technical efficiency explanatory variables, most of the previous authors distinguished two categories: the group-specific variables used in the first step and those related to what basis farmers are classified into groups. In this specific case study, the variables used in the inefficiency model (equation 4) were classified into three main groups, such as socioeconomic, institutional and location-specific variables. These variables are used to estimate the first stage of group-specific frontiers. For the second stage of the meta-frontier, variables employed are related to differences in terms of SWCTs' intensity of adoption. The techniques considered are compost, grass strips, half-moon, mulching, stone bund and zaï

### 2.4.2. Model Specification

The likelihood ratio test will indicate whether the Cobb-Douglas production function or the Translog production function is more suitable to the data. Before this test, each group-specific production frontier and the meta-frontier are given by equations (7) and (8), respectively.

$$lny_{iz} = \beta_{0z} + \sum_{j=1}^{4} \beta_{jz} lnx_{ijz} + (v_{iz} - u_{iz}) \quad (7)$$

$$ln\hat{y}_i = \beta_0 + \sum_{j=1}^{4} \beta_j lnx_{ij} + (v_{iM} - u_{iM}) \quad (8)$$

In equations (7) and (8) $ln$ is the Log, $y_{iz}$ is the value of cereal production achieved by the $i^{th}$ farmer in the $z^{th}$ group (in FCFA), $x_{ijz}$ is the vector of production factors $(j = 1,2,3,4)$, $\beta_{jz}$ is the vector of parameters of the model to be estimated, $v_{iz}$ is the random error term, $u_{iz}$ is farmers' of group z technical inefficiency, $\hat{y}_i$ is the meta-frontier formed by the adjusted productions of the three farmers' groups, $v_{iM}$ is the random error term of the meta-frontier and $u_{iM}$ is the technical inefficiency of farmers according to the meta-frontier.

Following [16], the model to explain farmers' inefficiency ($u_{iz}$) can be specified as:

$$u_{iz} = \varphi_0 + \sum_{l=1}^{L} \varphi_{il} q_{ilz} + w_{iz} \quad (9)$$

Where $q_{ilz}$ ($l = 1\ to\ 8$) are group-specific technical inefficiency explanatory variables, $\varphi_{il}$ are explanatory variables coefficients to be estimated, $w_{iz}$ is the model error term.

## 2.5. Estimation Method

Following [12], the one-step maximum likelihood estimation method proposed by [16] is used in this study. In the first stage, the production function and the technical inefficiency function are estimated simultaneously for each farmers' group, and then the predicted production values for each group are used to estimate the meta-frontier production function. Stata software is used for the estimations.

# 3. Results

## 3.1. Descriptive Statistics

From table 1, the average value of cereal production is estimated at 844,850 FCFA for the sample. The average area allocated to cereal production in the sample is around 5 ha. Agricultural equipment owned by households and used in agricultural production is valued at 169,637 FCFA on average. The amount of labor involved in the various farming activities is equivalent to 81 man-days on average. The majority of farmers are adults with an average age of 46. Only 33% of farmers report having access to credit. According to agricultural extension, 61% of farmers have access to its services. In addition, farmers who have attended at least the primary cycle of the formal educational represent 41% of the sample. Each farmer farms an average 2 fields for agricultural production. More than half of the farmers (54%) are members to farmers' organization. Households size is established at 10 members in average. Overall, the mean values of the variables considered lie between their minimum and maximum values found in the empirical literature.

***Table 1.*** *Variables' descriptive statistics parameters.*

| Variables | SWCTs adoption intensity | | | |
|---|---|---|---|---|
| | Lower | Medium | Higher | Sample |
| Cereals value | 762561 | 894376 | 864184 | 844 850 |
| Inputs | | | | |
| Area (ha) | 4.89 | 4.93 | 4.30 | 4.68 |
| Asset value | 187437 | 161553 | 163959 | 169 637 |
| Labor | 72.68 | 80.37 | 88.933 | 81.43 |
| Fertilizers | 9.60 | 9.99 | 10.376 | 10.03 |
| Farmers technical inefficiency explanatory variables | | | | |
| HH. head age | 45.80 | 45.50 | 49.38 | 46.48 |
| Field number | 2.05 | 2.29 | 2.56 | 2.33 |
| Household size | 9.90 | 9.59 | 11.44 | 10.37 |
| Access to credit | 0.48 | 0.36 | 0.18 | 0.33 |
| Extension services | 0.46 | 0.66 | 0.66 | 0.61 |
| HH. education | 0.38 | 0.49 | 0.37 | 0.41 |
| Group membership | 0.53 | 0.49 | 0.59 | 0.54 |
| Agro-climatic zone | 0.18 | 0.29 | 0.63 | 0.39 |
| Meta-frontier second stage variables | | | | |
| Grass strips | 0.03 | 0.08 | 0.33 | 0.16 |
| Compost | 0.57 | 0.79 | 0.76 | 0.72 |
| Stones boon | 0.14 | 0.61 | 0.89 | 0.59 |
| Half-moon | 0 | 0.03 | 0.35 | 0.14 |
| Mulching | 0.11 | 0.35 | 0.49 | 0.34 |
| Za ï | 0.03 | 0.10 | 0.6 | 0.27 |
| Observation | 93 | 117 | 125 | 335 |

Source: Author, using survey data, May-July 2022

Concerning SWCTs' adoption, compost is the most widely adopted, with a relative frequency of 72%. Stone bund occupies the second position with 59% adoption rate. Mulching comes in the third place with 34% adoption rate. Za ï is adopted by 27% of the farmers. Half-moon has the lowest adoption rate, with only 14%. In table 1 we have the mean for continues variables and frequency for binary variables.

## 3.2. Estimation of Stochastic Meta-frontier Parameters

Stochastic meta-frontier's estimated parameters are presented in table 2. The results show that all production factors have significant effect at 1% level on cereal production. Referring to [13, 14], these results highlight the central role played by the production factors included in the model on the level of the technological gap ratio (TGR) in cereal production. The negative coefficients of capital and chemical fertilizers mean that ceteris paribus, an additional unit of capital (chemical fertilizers) would result in fall in TGR. However, the positive coefficients of cereals cultivated area and household asset endowment indicate that when other factors are held constant, additional unit of cereals area (asset endowment) imply an increase in TGR.

Under SWCTs' adoption variables, all parameter estimated are significant at 1% level, except half-moon. This suggests that SWCTs' adoption variables have a crucial role concerning the distance between the production-specific frontier and the meta-frontier. Logically, the negative coefficient associated to all of SWCTs' adoption variables (dummy) implies that farmers adopting one of these techniques are closer to operating to the meta-frontier than otherwise.

***Table 2.*** *Stochastic meta-frontier parameters.*

| Variables | Coefficient | Statistique-z | P>\|z\| |
|---|---|---|---|
| Inputs for production | | | |
| Log Labor (*lnlab*) | -0.09 | -5.74 | 0.00 |
| Log area (*lnsup*) | 0.24 | 19.61 | 0.00 |
| Log capital (*lnk*) | 0.05 | 4.31 | 0.00 |
| Log fertilizers (*lneng*) | -0.07 | -8.17 | 0.00 |
| Constant | 13.80 | 183.05 | 0.00 |
| SWCT adoption variables | | | |
| Compost | -3.73 | -8.12 | 0.00 |
| Stones boon | -4.21 | -9.45 | 0.00 |
| Mulching | -3.63 | -8.18 | 0.00 |
| Za ï | -3.05 | -4.76 | 0.00 |
| Half-moon | -7.28 | -0.88 | 0.38 |
| Grass strips | -4.75 | -5.36 | 0.00 |
| Constant | 1.55 | 3.33 | 0.00 |
| Numbre of observations | 335 | | |

Source: Author, using survey data. May-July 2022

### 3.3. Various Measures of Farmers' Efficiency

Average values of meta-frontier technical efficiency (MTE) and technology gap ratio (TGR) for each farmer's group are computed and their results reported in table 3.

About the TGRs, farmers from low-level adoption intensity have the lowest average (0.98). This means that on average, farmers with at more one SWCT in their production systems produce about 98% of the potential output given the overall SWCTs available in the study area. The mean TGR of farmers from medium-level and high-level adoption intensity equal to unit (1). They produce 100% of the potential output given the overall SWCT available in the study area. In other words, their specific stochastic frontiers are tangent to the meta-frontier. Then, they have adopted the most advanced cereals production techniques including SWCTs.

Results in table 3 indicate also how efficient technically farmers in each group are, according to their operations with respect to the overall cereals farming in the study area. This information is elicited by the meta-frontier technical efficiency (MTE) mean values. It is clear that farmers with low-level adoption intensity are more efficient technically in operation with respect to the overall cereals farming. Their average MTE value is established at 67%. Each of the two others farmer's groups has an average MTE value equal to 57%. This situation highlights that the overall production efficiency by farmers with low-level SWCTs' adoption intensity is superior to those with medium-level or high-level.

***Table 3.*** *Technical efficiency scores and technology gap ratios.*

| Farmers group | Mean values | |
|---|---|---|
| | TGR | MTE |
| Lower | 0.98 | 0.67 |
| Medium | 1 | 0.57 |
| Higher | 1 | 0.57 |

Source: Author, using survey data. May-July 2022

## 4. Discussion

The superiority of the farmers with low-level SWCTs' adoption intensity can be explained in two ways. On the one hand, the result reflects an upward shift of the production frontier for medium-level and high-level technology-intensive farmers. This increases the gap between their actual production and optimal production, as they do not exploit this opportunity. On the other hand, we suppose a misuse of some production factor. This second assumption can be explained from a theoretical and the survey context elements.

Theoretically, X-inefficiency theory is a useful reference. Indeed, we can deduce that in the current context, adoption of several SWCTs induces a misuse of X production factor. Furthermore, given financial, human and material constraints faced by rural farmers, they are more apt to effectively implement a single technology based on their expertise. In this case, the technology plays its role adequately. This resulted in a better management of their scarce productive resources. In contrast, adoption of several technologies implies, on the one hand, a split of farmers' resources like labor and, on the other, the implementation of technologies which deviate from recommended technical standards. For example, only 10% among the farmers surveyed had received training on SWCTs setting. The consequences of this situation are the misuse of resources and the inefficiency of the technologies adopted. The result is a decline in farmers' technical performance.

At institutional level, 48% of farmers with low-level adoption intensity have access to credit, compared with only 15% of farmers with high adoption intensity. In table 3, we observed that access to credit is the most important factor in farmers' technical efficiency explanation. Credit enables farmers to buy quality inputs or high-performance agricultural equipment. On the organizational level, 82% of low-level adoption intensity farmers engage in non-agricultural activities. The income from these activities is able to be used in agricultural production investment by acquiring good quality inputs in sufficient quantities, such as seeds of improved varieties. In short, both agricultural credit and off-farm income strengthen farmers' capacity to manage production factors [13].

The result highlighted in this article corroborates those of [13] on Zambian maize farmers. This author also found that farmers using less technology proved to be technically more efficient than those with more technology. He attributes this result to the exceptional productivity of low-level technology farmers. In addition, he assumes that these farmers are striving to make maize their main agricultural product, so they invest consequently to realize their full potential.

Farmers explained this result in terms of technical, organizational and cultural factors. Indeed, farmers feel that they are left to their own devices in the conduct of production activities. They feel that they do not benefit adequately from technical support that meets their needs. In fact, farmers would like to be monitored on an ongoing basis with regard to the use of production factors. This applies in particular to the choice of crops in relation to soil type, input's quality and quantity and the timing and manner of their application. In addition, farmers stated that they do not necessarily take into account their actual capacities and available factors, such as fertilizers and labor, in relation to their farms' size. Also, they indicated that during the dry season, they join forces to take turns setting the SWCTs in their fields. That strategy enables them to cover large areas. However, during the rainy season, each household manages as best he can about labor and other production's factors. They added that the exploitation of large areas of land is not always oriented really towards production, but rather to mark the household's imprint in terms of space's ownership. Consequently, after sowing, some fields are transformed into grazing land.

## 5. Conclusions

Farmlands in Burkina Faso are characterized by erosion and other forms of soils' productive capacity decline. This issue implies food insecurity and rural household poverty increase. In this context, soil and water conservation techniques' adoption is necessary. Indeed, some farm households have adopted many of these techniques. The present study aimed to assess the effect of SWCTs' adoption intensity on farmers' technical efficiency in the country. Stochastic meta-frontier approach has been used to analyze data obtained from cross-sectional questionnaire survey.

Empirical results surprisingly showed that farmers with low-level of SWCTs' adoption intensity are more technically efficient than those with medium or high-level adoption intensity. This paradoxical result highlighted the sub-optimal use of production factors by households who adopt several SWCTs in their farmlands. Currently, farmers do not take sufficient advantage of the potential associated to soil and water conservation to increase their production.

Results highlighted in this study allow formulating economic policies that should improve farmers' technical efficiency through SWCTs' adoption intensification on the one hand. In fact, practitioners should undertake to train SWCTs' adopters on the optimal use of their scarce productive resources to boost their technical efficiency when adopting SWCTs. One the other hand, they enable to realize some relevant subjects for future studies. For example, it is necessary to highlight the factors which are used sub-optimally within agricultural households in relation with the adoption intensity of soils and water conservation technologies. In addition, future work should identify the better option of soils and water conservation technologies combination which improve the technical efficiency of farmers. Finally, size of household farms adapted to their available resources is essential to be defined.

## Abbreviations

| | |
|---|---|
| FCFA | Francs de la Communauté Française d'Afrique |
| MTE | Meta-frontier Technical Efficiency |
| SWCTs | Soils and Water Conservation Technologies |
| TE | Technical Efficiency |
| TGR | Technology Gap Ratio |

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## Author Contributions

Hadji Adama Ouédraogo is the sole author. The author read and approved the final manuscript.

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## Data Availability Statement

The data is available from the corresponding author upon reasonable request.

## Conflicts of Interest

The author declares no conflicts of interest.

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