

The determinants of fertilizer microdosing adoption and impact on sorghum and maize yields in Burkina Faso

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Abstract

Fertilizer microdosing was developed in order to increase farmers' income through improvement of fertilizer use efficiency and investment cost reduction in the drylands of West Africa. The purpose of this study is to identify the determinants of fertilizer microdosing fertilization and to analyze its impact on sorghum and maize yields in Burkina Faso. Using endogenous treatment regression model with data collected on 1057 famers in 2011, the findings reveal that access to warrantage credit, participation in training and labor availability are the main factors in the adoption of fertilizer microdosing. In terms of impact, the study shows that fertilizer microdosing contributed to significantly increase sorghum and maize yields by 55% and 37% respectively. The results of this study challenge us to accelerate the process mechanization of fertilizer microdosing fertilization, the establishment of infrastructure such as warrantage shops and farmers' capacity building.

Keywords: fertilizer microdosing, endogenous treatment regression, sorghum, maize, Burkina Faso.

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1. Introduction

Agricultural technologies play a crucial role in improving agricultural productivity and income in semi-arid regions in West Africa and particularly in Burkina Faso. In these countries, the production system is mostly extensive and characterized by low use of mineral fertilizers and organic amendments, which are essential for increasing agricultural yields (FAO, 2013; Bado *et al.*, 2007). In addition, this low fertilization rate and technology adoption are often due to physical and financial inaccessibility and some farmers' misunderstanding (Holtzman *et al.*, 2013). Thus, agricultural research has focused on the development of innovative agricultural practices such as microdose, which are adapted to agronomic, socio-economic and institutional context.

Fertilizer microdosing or hill placement technology, introduced in the 1990s, consists of applying small amounts of mineral fertilizer per hole at planting or a few days after emergence (Hayashi *et al.*, 2018; Tabo *et al.*, 2007). Its application is very useful to agricultural farmers, especially small farmers. This technology helps to minimize fertilizer costs and increase use efficiency of fertilizer (Aune and Bationo, 2008).

In general, the results of some studies evaluating the economic impact of fertilizer microdosing fertilization found a significant increase of farmers' income and an improvement in their food security (Bagayoko *et al.*, 2011; Fatondji *et al.*, 2016; Okebalama *et al.*, 2017; Tabo *et al.*, 2007). However, analysis of these studies shows that the approaches used (partial budget benefit-cost ratio and net income) used did not make it possible to assess the real impact of fertilizer microdosing on yields because of its interaction with socio-economic and agronomic factors. In other words, the analyses essentially considered the farmers as a homogeneous group up to some heterogeneity factors. In fact, heterogeneous technical, economic, biophysical and environmental factors and a wide range of production objectives (Vanlauwe *et al.*, 2014) characterize farmers. In addition, farmers face many constraints such as inaccessibility to input, labor unavailability and lack of information, which could justify the rate of fertilizer microdosing adoption and explain its yield effect.

The purpose of this study is to identify the determinants of fertilizer microdosing adoption and to assess its impact on sorghum and maize yield. In other words, we use a production function approach to identify socio-economic and institutional factors of fertilizer microdosing adoption and to measure its impact on crops yield.

2. Theoretical framework of production function

The production function is a quantitative relationship between inputs and outputs. By introducing a new technology, the analysis tries to estimate its influence on production using a regression method often used to measure the impact of inputs on total production.

Mathematically, $Y=f(X)$ where Y is the production, X the vector of inputs, f the form of the relationship between Y and X . This method makes it possible to estimate the marginal products of inputs, the elasticities and regression coefficients. One of weaknesses is the identification of exogenous factors that can explain the production. Other approaches such as instrumental variables, fixed-effects or random-effects models, linear regression models with endogenous treatment effects could be used to handle this shortcoming (Wooldridge, 2010).

In this study, we use production function approach to assess the relevance effect of fertilizer microdosing and identify the determinants of fertilizer microdosing adopters. The relationship between performance and these explanatory factors is defined as:

$$Y_{ij} = \alpha X_{ij} + \theta M_{ij} + \varepsilon_{ij} \quad (1)$$

with, Y_{ij} standing for farmer i yield from plot j , X_{ij} for agronomic, socio-economic and other production factors, M_{ij} for a binary variable taking 1 if the farmer i applied fertilizer microdosing on the plot j and 0 otherwise; ε_{ij} is the error term, α parameters vectors of covariates, θ average fertilizer microdosing effect on yield. M_{ij} cannot be considered as an exogenous variable. In fact, the decisions to apply fertilizer microdosing and expected output are done simultaneously. Moreover, the unobserved factors included in the error term that explains the yield are linked also to fertilizer microdosing application decision. Indeed, based on previous studies, the fertilizer microdosing application was linked directly to socio-economic factors such as access to credit called warrantage (Tabo *et al.*, 2007; Fatondji *et al.*, 2016). Warrantage is a system that facilitates access to credit, agricultural products and input markets. In addition, Fatondji *et al.* (2016) showed that training such as agronomic trials and demonstrations are key factors that could explain farmer's decisions to apply fertilizer microdosing. Some farmers pointed out that the lack of training was one reason why they did not apply fertilizer microdosing apart from financial and physical inaccessibility of fertilizer. Labor availability is also a key factor in fertilizer microdosing adoption decision (Okebalama *et al.*, 2017; Liverpool-Tassie *et al.*, 2015).

Thus, the relationship between fertilizer microdosing application and those factors is:

$$M_{ij} = \delta D_{ij} + \mu_{ij} \quad (2)$$

with D_{ij} Vector of explanatory variables of fertilizer microdosing adoption by the farmer i on the plot j , μ_{ij} error term, δ parameters vector. Because of endogeneity of M_{ij} , Ordinary Least Square cannot be used to estimate equation 1 (Wooldridge, 2010). To purge this variable of its endogeneity, we use a model called « endogenous treatment-regression model » (Cong and Drunker, 2001). From equation (1) and (2) the model is:

$$\begin{aligned} Y_{ij} &= \alpha X_{ij} + \theta M_{ij} + \varepsilon_{ij} \\ M_{ij} &= \begin{cases} 1, & \text{if } \delta D_{ij} + \mu_{ij} > 0 \\ 0, & \text{otherwise} \end{cases} \end{aligned} \quad (3)$$

The model is composed of equations of the yield Y_{ij} and the endogenous treatment M_{ij} . We assume that the covariates of equations (1) and (2) are uncorrelated to error terms. In addition, the error terms ε_{ij} and μ_{ij} are bivariate normal with mean zero. The parameter θ is the average treatment effect (ATE). It is the average effect of fertilizer microdosing application on crop yield. When there is no interaction between M_{ij} and one of Y_{ij} covariates, the ATE is equal to the average treatment effect on the treated (ATET).

The translog production function is used because it does not imply a fixed elasticity of perfect substitution between the production factors nor the perfect functioning of the production factor market; also, its application makes it possible to determine the optimal level of the production factors with a tractability comparable to the Cobb-Douglas production function (Kouka *et al.*, 1995; Pavelescu, 2011). However, interaction variables will not be included due to multicollinearity issue (Pender *et al.*, 2008).

3. Study area and data

The study was conducted in the provinces of Oubritenga, Nahouri, Ziro, Kouritenga and Boulgou in Burkina Faso.

Annual average rainfall is comprised between 600 and 1200 mm. These different provinces are fertilizer microdosing diffusion areas and characterized by low soil fertility. In these regions, farmers cultivate maize and sorghum as main staple foods.

We used data from socio-economic surveys carried out in 2011 by the Institute for Environment and Agricultural Research (INERA) to assess the impact of the AGRA-Fertilizer microdosing project funded by the Alliance for the Green revolution in Africa (AGRA) implemented from 2008 to 2012 in Burkina Faso. The purpose of this project was to increase the production of millet, sorghum, cowpea and maize by 50% and the income by at least 30% for 130,000 agricultural households in Burkina Faso through large-scale dissemination and adoption of fertilizer microdosing and warrantage system. A sample of 1057 agricultural households was selected using stratified sampling method. The household heads were the only ones to be interviewed. In the absence of the household head, another family member who was able to answer has replaced him or her.

The data collected are farmer's socio-economic characteristics, agricultural practices and the agronomic characteristics of plots. In terms of adoption factors, access to credit is a key factor in developing countries (Martey *et al.*, 2013; Akpan *et al.*, 2012; Simtowe *et al.*, 2014). In our case, we used the warrantage credit that boosted the adoption of fertilizer microdosing by facilitating access to mineral fertilizers (Tabo *et al.*, 2007; Fatondji *et al.*, 2016). Moreover, access to warrantage credit was linked to the specific characteristics of farmers. Thus, the distance of warrantage shops from the farmers' residence place and being membership of rural organization were used as proxies for access to credit. Access to extension services is also a key factor in the decision to adopt agricultural innovations (Diirro, 2013; Amare *et al.*, 2011; Alene *et al.*, 2000; Muzari *et al.*, 2012). The effect of this variable on fertilizer microdosing adoption is assessed through participation in demonstration plots and agronomic trials. As fertilizer microdosing is a labor-intensive technology, total acreage of cropland could have a negative effect on the probability of adoption. In addition, control variables such as age, level of education, gender, agro-ecological area; may also influence the probability of fertilizer microdosing adoption (Feder *et al.*, 1985; Adesina *et al.*, 1995; Fufa and Hassan, 2010; Liverpool-Tasie *et al.*, 2015; Mwangui and Kariuki, 2015). To assess the impact of fertilizer microdosing, we control for the biophysical characteristics of plots according to farmers' perceptions and the effects of inputs on yield (Pender *et al.*, 2008). Amongst the characteristics of the plots, we have crop rotation, type of soil, topo sequence, intercropping, distances of plots from residence, plot-ploughing, access to land and sowing period. For the inputs use, we have the quantity of fertilizer (kg/ha), the application of manure and fertilization periods. Socio-economic include farmers' assets, livestock value, marital status, age, gender, level of education and off-farm income.

4. Results and discussion

4.1. Fertilizer application methods on sorghum and maize plots

Table 1 represents the fertilization methods used by farmers. Farmers are prone to fertilize maize plots compared to sorghum plots, particularly in Nahouri and Ziro provinces. These findings can be explained by the favorable climate conditions for maize production in Burkina Faso. Moreover, maize farmers are market-oriented and their income selling maize sometimes finance their family expenses. Across fertilizer method, most farmers spread fertilizer in spot. However, in the Plateau-Central, most of them applied fertilizer microdosing compared to other regions. Indeed, in the past, fertilizer microdosing was widely disseminated in plateau central region.

Table 1: Fertilizer application methods across provinces in percentage

Area and crops Fertilization methods	Centre-Ouest (Nahouri, Ziro)		Plateau Central (Oubritenga, Ganzourgou)		Centre-Est (Boulgou, Koulpelogo, Kouritenga)	
	Sorghum	Maize	Sorghum	Maize	Sorghum	Maize
Without fertilizer	58.37	37.57	68.03	52.38	68.34	47.13
Fertilizer microdosing(buried)	12.67	18.05	14.34	28.57	9.11	13.52
Spot application (not buried)	28.96	44.39	17.67	19.05	22.55	39.34

4.2. Analysis of yield distribution by crop

Table 2 presents the distribution of crop yields across fertilization methods and area. Overall, most fertilized plots have a higher average yield than unfertilized plots. The average yields of sorghum were above 500 kg/ha in almost all regions. The highest yields of sorghum were observed in the Centre-Est region estimated at about 800 kg/ha (fertilizer microdosing). For maize, fertilizer microdosing plots have the highest production per hectare estimated at 745 kg in the Centre-Est region. Across fertilizer application methods, all yields of fertilizer microdosing plots are greater than 550 kg/ha in all regions compared to spot fertilization methods for both crops.

Table 2: Average yield across fertilization methods (kg/ha)

Fertilization methods	Area and crops	Centre-Ouest (Nahouri, Ziro)		Plateau Central (Oubritenga, Ganzourgou)		Centre-Est (Boulgou, Koulpelogo, Kouritenga)	
		n	Average yield (standard-deviation)	n	Average yield (standard-deviation)	n	Average yield (standard-deviation)
Without fertilizer	Sorghum	129	470.83 (376.32)	166	415.18(353.50)	300	604.05(430.82)
	Maize	77	564.84(412.98)	33	607.45(445.65)	115	454.40(405.52)
Spot application	Sorghum	64	571.18(391.53)	43	566.72(400.24)	99	590.05(441.38)
	Maize	91	687.07(478.21)	18	658.33(481.42)	96	512.83(376.03)
Fertilizer microdosing	Sorghum	28	528.95(284.86)	35	615.57(401.26)	40	796.29(511.49)
	Maize	37	568.94(423.34)	12	637.78(284.40)	33	745.35(475.11)

4.3. Model estimation

Table 3 represents the estimation of the model using maximum likelihood method. On the one hand, we have fertilizer microdosing adoption factors and on the other hand, the effect of fertilizer microdosing and other covariates on sorghum and maize yield.

Firstly, Wald's test indicates that the model fits well overall and is statistically significant. In addition, based on Likelihood ratio test, we can reject the hypothesis of no correlation between the treatment errors and the outcome errors. In other words, we could note the decision to adopt the fertilizer microdosing and the production decision are not separable.

Secondly, the endogenous treatment equation estimation shows that the distance from farmers' place of residence to input shops influences negatively and significantly the probability of applying fertilizer microdosing to sorghum. This finding is consistent with the results of some previous studies, which highlighted that access to warrantage helps farmers overcome the inputs constraints (Tabo *et al.*, 2007; Ouattara *et al.*, 2018; Pender *et al.*, 2008). Being a member of rural organization can improve positively and significantly the probability of applying fertilizer microdosing to maize and sorghum. Indeed, the farmers who are members of rural organization were more likely to obtain credit through warrantage (Tabo *et al.*, 2007; Garrido and Sánchez, 2015). In addition, farmers who are members of an organization are often more likely to participate in fertilizer microdosing training set up by the project. The partial effect of cropland is negative and significant on decision to apply fertilizer microdosing to both crops. This is consistent with the findings of some studies (Pender *et al.*, 2008; Liverpool-Tasie *et al.*, 2015). As fertilizer microdosing is labor-intensive technology, farmers with labor constraints are likely to adopt traditional methods, especially those with large farms. In terms of access to fertilizer microdosing training, participation in demonstrations plots of fertilizer microdosing and participation in agronomic trials have a positive and significant effect on the probability to apply fertilizer microdosing. These farmers had greater accessed to information regarding the fertilization methods. Farmers living in Ziro province will be more likely to apply fertilizer microdosing to sorghum and maize plots due to the access to fertilizers. Indeed, these farmers receive fertilizers on credit from Cotton Company for their cereals like maize in order to avoid the diversion of fertilizers intended for the production of cotton (Maître d'Hôtel and Porgo, 2018). However, there is a significant negative effect on the probability of adopting the fertilizer microdosing under maize in Kouritenga province.

In terms of impact, the average treatment effect of fertilizer microdosing is positive and significant on both maize and sorghum yields. As there are no interaction variables between application of fertilizer microdosing and others covariates in the production function, this effect is the average treatment effect on the treated. We carried out a test by putting an interaction term and re-estimated the model. We found that the average treatment effect of fertilizer microdosing on the treated and the average treatment effect are closed¹. Hence, the average treatment effect of fertilizer microdosing for the adopters is similar to the average treatment effect for whole farmers. The average treatment effect of fertilizer microdosing on sorghum and maize yield are 55% and 37% respectively. In other words, fertilizer microdosing application on sorghum can on average increase the yield approximately by 55% given others factors. This is consistent with the findings of studies which highlighted that fertilizer microdosing increased significantly crop yield (Pender *et al.*, 2008; Sime and Aune, 2014; Okebalama *et al.*, 2016). Tabo *et al.* (2007) using data from farm test field, found that sorghum yield under fertilizer microdosing was 106% greater than the control in Burkina Faso. In Ghana, Okebalama *et al.* (2016) obtained that fertilizer microdosing treatment increase maize yield by 32 to 99 % across cropping system and soil types.

In addition, the analysis shows that other agronomic and socio-economic factors have significant positive or negative effects on the yield level of sorghum and maize. As agronomic and other fixed factors, sandy-clay and silty soils have a positive and significant effect on sorghum and maize yields respectively. Sowing in May has a negative and significant influence on the average crop yield compared to June. However, sowing in July seems adequate because there is a positive and significant average effect on maize yield estimated at 14% but not significant on sorghum's yield. For fertilizer application, its average effect on the yield of both crops is positive and significant. When the amount of fertilizer per hectare increases by 10%, on average the yield of maize and sorghum increases approximately by 0.40% and 0.60% respectively. These results show that mineral fertilization may lead to get higher yields. Although the average effect is not significant, the use of organic fertilizers such as compost or manure can increase the yield level of sorghum and maize. For socio-economic variables, the results highlight that male plot managers have higher yields than women do, but the effect is not significant. The average effect of livestock's value on the yield is positive and significant in accordance with the literature on both crops. Indeed, livestock represent financial resources that can facilitate access to inputs and organic manure to maintain soil fertility. Given other factors, increasing at 10% the value of livestock on average leads increasing maize and sorghum yield to 0.32% and 0.40% respectively. In fact, the revenue from livestock selling is sometimes used to purchases fertilizers or farm labor. Compared to Boulgou, the farmers from the provinces of Kouritenga and Ziro could increase their production level of sorghum than those of Oubritenga and Nahouri. In addition, maize's farmers living in Ziro province could also increase the average yield due to favorable rainfall conditions and market-oriented production.

Table 3: Endogenous treatment-regression model estimation

Variables	Sorghum		Maize	
	Coefficients	z-score	Coefficients	z-score
Crop rotation (yes/no)	-0.03	-0.61	0.12	1.54
Clay	0.003	0.05	0.09	1.03
Soil type (ref. sandy)				
Sandy and clay	0.12	1.77*	-0.06	-0.67
Loam	0.10	1.06	0.44	2.53**
Top	-0.02	-0.40	0.09	0.96
Valley	-0.02	-0.38	-0.20	-2.25**
Topo sequence land (ref. slope)				
upslope	0.36	3.24***	-0.22	-1.04
downslope	0.23	1.03	0.07	0.29
Valley and upslope	0.11	0.60	-0.69	-2.76***
Distance from residence (ref. 0.5 km)				
1 km	0.07	1.03	0.14	1.34
>1 km	0.00	0.12	0.13	1.35

¹ The average treatment effect on the treated (ATET) of fertilizer microdosing on sorghum and maize yield are 0.56 and 0.37 respectively.

Plot access (cf inherited)	Rented	-0.24	-1.32	-0.03	-0.11
	Mortgaged	-0.28	-1.32	0.21	0.86
Ploughing (yes/no)		0.10	1.35	0.14	1.45
Sowing period (ref. June) : yes/no	May	-0.09	-1.47	-0.20	-1.92*
	July	0.05	0.52	0.14	1.67*
Intercropping (yes/no)		0.18	3.26***	0.16	2.05**
Organic manure (yes/no)		0.01	0.25	0.10	1.36
Ln (quantity of fertilizer /ha)		0.04	2.59**	0.06	2.83***
Fertilizer application period (ref. 1st weeding): yes/no	At sowing	-0.15	-1.30	-0.07	-0.48
	2 nd weeding	-0.17	-0.88	-0.20	-1.01
Ln (Labor-to-land ratio :person/ha)		0.20	6.70***	0.15	3.55***
Age(years)		0.00	0.18	-0.00	-0.70
Gender (Male/female)		0.00	0.03	0.26	1.62
Marital status (married/no)		-0.11	-0.72	0.15	0.66
Education level (ref none) : yes/no	Primary	0.02	0.35	0.01	0.15
	Secondary	0.10	0.83	-0.01	-0.05
	Literacy training	0.03	0.45	0.07	0.61
Main activity (ref. farmers)	Off-farm activity	0.06	0.83	-0.07	-0.84
Ln (value of livestock /FCFA)		0.03	2.59***	0.04	2.94***
Ln (off-farm income/FCFA)		-0.01	-1.36	0.00	0.74
	Kouritenga	0.18	2.06**	-0.52	-3.94***
Provinces (ref. Boulgou) : yes/no	Oubritenga	-0.25	-2.87***	-0.21	-1.65
	Nahouri	-0.12	-1.21	-0.19	-1.56
	Ziro	0.15	1.63	0.10	0.95
Fertilizer microdosing (yes/no)		0.55	2.93***	0.37	1.66*
Constant		5.11	21.39***	4.50	14.26***
Fertilizer microdosing adoption factors					
Age		-0.01	-2.24**	0.00	0.59
Gender (Male/female)		0.06	0.23	-0.03	-0.12
Education level (ref. none) : yes/no	Primary	-0.01	-0.08	0.29	1.42
	Secondary	-0.38	-1.00	-0.45	-0.85
	Literacy training	0.09	0.50	0.33	1.37
Members of farmers' organization (yes/no)		0.25	1.71**	0.42	2.42**
Ln (distance to warrantage shop /km)		-0.02	-2.30**	-0.02	-1.72*
Participation in fertilizer microdosing demonstration (yes/no)		0.25	3.47***	0.37	3.90***

Participation in fertilizer microdosing application trials (yes/no)		0,76	5.47***	0.52	2.91***
Ln (plot area/ha)		-0.41	-4.44***	-0.51	-4.21***
Ln (Value of livestock/FCFA)		0.02	0.52	-0.00	-0.05
Ln (off-farm income/CFA)		0.00	0.62	-0.01	-0.66
	Kouritenga	0.05	0.27	-0.69	-2.24**
Provinces (ref. Boulgou): yes/no	Oubritenga	0.19	1.01	-0.33	-1.26
	Nahouri	0.18	0.76	0.11	0.51
	Ziro	0.51	2.29**	0.40	1.78*
Constant		-1.70	-3.18***	-1.79	-3.37***
Rho (ρ)		-0.39		-0.32	
Sigma (σ)		0.70		0.32	
Number of observations		904		512	
Wald chi2(36)		235.73		148.05	
LR test of indep. eqns. (rho = 0)		Chi(1)=5.55	Prob>chi2=0.01	Chi(1)=2.80	Prob>chi2=0.09

Note: ***, **, * denote significance at 1%, 5% and 10% respectively.

5. Conclusion and recommendations

The purpose of this study was to identify the determinants of fertilizer microdosing fertilization and to evaluate its impact on sorghum and maize yields in Burkina Faso using a production function approach taking into account farm-level heterogeneity.

Using the endogenous treatment-regression model, the estimation of the model highlighted that access to credit through warrantage, participation in fertilizer microdosing application demonstrations and agronomic trials are the main factors of fertilizer microdosing adoption by rural farmers. However, large farms tend to follow the traditional method because it requires less labor. In terms of impact, fertilizer microdosing has a positive and significant average effect on sorghum and maize yields given other factors. In other words, fertilizer microdosing application can lead to achieve higher yields than traditional fertilizer method. In addition, the findings shows the importance to mechanize the application of fertilizer microdosing, which could lead a large adoption by the farmers. We also note the importance of setting up credit access mechanisms such as warrantage with the built of warrantage shops, capacity building to facilitate access to fertilizer and information's and mechanization of fertilizer microdosing application. Future studies should use a panel data model to investigate the continued use of fertilizer microdosing in order to assess its impact on farmers' agricultural production and income over time.

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