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Farmers' perceptions of fertilizer micro-dosing adoption and continued use in Burkina Faso

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This study analyzes fertilizer micro-dosing adoption and focuses on farmers' perceptions. Data used are from households selected based on agroecological characteristics. The bivariate probit model estimation results show that fertilizer microdosing adoption is a process. After the first adoption, 22.67% of farmers continued to apply fertilizer micro-dosing compared to 33.25% who discontinued. In addition, analysis results show that agronomic and economic performance and compliance with current practices from farmers' perceptions affect fertilizer micro-dosing adoption and continued use. That implies that in studies of agricultural innovations adoption, it would be relevant to consider decision-making stages by including farmers' perceptions.

Key words: Fertilizer micro-dosing, bivariate probit, farmers' perceptions, Burkina Faso.

INTRODUCTION

Fertilizer micro-dosing, a technique of using mineral fertilizers in small quantities, has been implemented to respond to rural world concerns (Chianu et al., 2012; Hayashi et al., 2008). Studies have shown that its application can improve agricultural productivity and income by decreasing mineral fertilization financial costs (Aune and Bationo, 2008; Sawadogo-Kaboré et al., 2009; Tabo et al., 2007).

Although significant results from agronomic trials, adoption rates are lower than expected. That is due to inaccessibility to mineral fertilizer, labor unavailability and lack of training (Blessing et al., 2017; ICRISAT, 2009). Thus, organizations and research institutes have developed strategies such as (i) warrantage to facilitate access to inputs through credit facilities; (ii) delaying application period, which can be after planting, to partially address high labor demand issue; (iii) training approaches "learning by doing" to train more farmers and (iv) awareness-raising activities through broadcast media (Fatondji et al., 2016; Hayashi et al., 2008; Sawadogo-Kaboré et al., 2009; Tabo et al., 2011, 2007). At the end, some farmers were willing to apply it in their fields.

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However, one further question remains to explore, farmers' attitudes after adoption, that is, continued adoption. Previous studies did not address it and focused on adoption factors (Sanogo et al., 2020a; Sigue et al., 2018; Traore et al., 2019). In these studies, non-adopters are those who neither tried the technology nor abandoned it after adoption. By aggregating in this way, the analysis may hide differences that could help to understand the real motivations for adoption, rejection and continued use (Doss, 2006).

Thus, it was highlighted that technology adoption is a process with different decision steps where farmers can decide to adopt or not, continue to apply or abandon after adoption. According to Rogers (1983), technology adoption is a process that goes beyond adoption or rejection after learning about its attributes and characteristics. Lambrecht et al. (2014) showed that in agricultural technology adoption process, three decision-making stages should be identified: (i) technology awareness; (ii) trial in one's own field; (iii) continued use after trial. From a study in Burkina Faso, Sanou et al. (2017) noted that improved maize seed adopters could use or abandon it for local seed. Similar results in Ethiopia, where Tura et al. (2010) studied determinants of adoption and continued adoption of improved maize seed. Aune and Bationo (2008) argued that sub-Saharan African countries could achieve agricultural intensification through fertilizer micro-dosing continued adoption with some adjustments.

In contrast, studies that addressed the continued adoption issue have not explicitly considered farmers' perceptions. Studies found that perception factors are relevant to technology adoption decisions and scaling up (Adesina and Baidu-Forson, 1995; Adesina and Zinnah, 1993; Mwinuka et al., 2017; Roussy et al., 2015; Sissoko, 2019). In a study from Burkina Faso and Guinea, Adesina and Baidu-Forson (1995) argued that perceptions of farmers, although subjective, should be included in future studies of technology adoption factors. In Sierra Leone, Adesina and Zinnah (1993) emphasized that farmers' perceptions were important in the decision-making process regarding agricultural technologies adoption and intensification. According to Ntshangase et al. (2018), farmers who adopted no-till conservation agriculture appreciated it. In Mali, Sissoko (2019) noted that farmers' perceptions affect their decision to adopt fertilizer micro-dosing on sorghum and millet. Roussy et al. (2015) suggested that in addition to observable determinants, we should include unobservable determinants such as farmers' perceptions in the analysis of agricultural innovation adoption. In their opinion, this approach allows for better identification and understanding of potential adopters' motivations and constraints.

Farmers' perceptions could also explain their attitudes at different decision-making stages regarding given technology. Concerning fertilizer micro-dosing, some farmers are reluctant to apply it because of the requirement to sow the mineral fertilizer compared to traditional fertilization practices.

In addition to more common constraints, a second major constraint is labor, with an imperfect labor market and households with low-income levels (Porgo et al., 2017). After experimentation or participation in a project's field experience dissemination activities, we assume farmers' agronomic and economic performance perceptions influence adoption decisions and compliance with current agricultural practices.

The purpose of this study is to show that it would be relevant to understand the fertilizer micro-dosing adoption process. In addition, this study aims to analyze the effects of farmers' perceptions on the decision-making process. Indeed, it will highlight farmers' real motivations for fertilizer micro-dosing.

Perceptions and adoption of agricultural innovations

Perceptions are one of the psychological factors that can influence an individual's behavior, and it is the process by which an individual select, organizes, and interprets information (Sheth and Mittal, 2004). Perceptions are subjective. Farmers may make decisions based on what they perceive rather than on objective reality (Adesina and Zinnah, 1993; Bennani and Saad, 2018). For example, the labor intensity of fertilizer microdosing is not a concern for some farmers because of its relative advantage (economic profitability) over traditional methods, which could be motivation and affects their perceptions. The higher the farmer's motivation, the greater the likelihood that farmer will adopt innovation. According to the theory of reasoned action developed by Fishbein and Ajzen (1967) (Fishbein, 2008), an individual decision to engage in a behavior (fertilizer micro-dosing adoption, for instance) is the outcome expected to achieve a behavior result. From this theory, individual current behaviors are a function of their pre-existing attitudes and behavioral intentions. These two determinants are related to the individuals' motivation to act.

Moreover, considering farmer heterogeneity and subjectivity, perceptions may be endogenous. Indeed, they depend on unobservable and specific factors due to farmer heterogeneity and production environments (Roussy et al., 2015). Omitting perceptions in adoption analysis would bias effects estimation of other explanatory variables correlated with farmers' perceptions on adoption and use probabilities (Wooldridge, 2012).

Considering-Y decision variable, X the explanatory variables, W* specific unobserved factors, μ error term, we have the following structural equation:

$$Y = a + bx + cW^* + \mu \quad (1)$$

Equation 1 is not estimable because W* are unobservable. Let be the reduced form:

$$Y = a + bx + \varepsilon \quad (2)$$

Equation 2 is estimable, and b is unbiased if COV (X, ε) = 0, with ε the error term. If COV (X, ε) ≠ 0, b is biased (omitted variable bias). This omitted variable here is the farmer's perception. If perceptions partially affect adoption decision Y and are correlated with X, then COV (X, ε) ≠ 0, violating the exogeneity assumption of explanatory variables and X endogenous. As perceptions Z are endogenous and can be related to X and W*, we can write the following auxiliary equation:

$$Z = g + hX + kW^* + v \quad (3)$$

By including perceptions in the adoption decision, we can rewrite Equation 1

$$Y = \alpha + \beta X + \gamma Z + \eta \quad (4)$$

By substituting Equation 3 in Equation 4, we get:

$$Y = (\alpha + \gamma g) + (\beta + \gamma h) X + (\gamma k) W^* + (\gamma v + \eta) \quad (5)$$

By equivalency between Equations 1 and 5:

$$a = \alpha + \gamma g; \quad b = \beta + \gamma h; \quad c = \gamma k; \quad \mu = \gamma v + \eta$$

Theoretically, the sign of k in Equation 3 is unknown. If k > 0, then sign (γ) = sign (c). That is attenuation bias. In practice, Β will be close to b if X is strictly exogenous.

Since Z is impossible to instrument because it is unobservable, the proxy is an option to mitigate bias for Z (Wooldridge, 2012). Coefficient b is also unaltered for X. The relative benefit (profitability, adaptability) can be a proxy measured from a binary variable if the farmer either does or does not perceive innovation value (Roussy et al., 2015).

MATERIALS AND METHODS

Study areas and data

The study data are from Burkina Faso in Oubritenga, Sissili and Zondoma provinces that were MICROFERTI project sites from 2018 to 2021 (Figure 1). Oubritenga and Zondoma provinces are located in Central Plateau and Northern regions, respectively, in the Sudano-Sahelian area, with annual rainfall ranging from 600 to 900 mm. The main crops are cereals such as sorghum, millet and maize. The province of Nagreongo is one of the bases for the first fertilizer micro-dosing on-farm trials. Sissili province has southwestern climate and annual rainfall of over 900 mm. The main crops in this province are cash crops (cotton, sesame) and cereal crops (maize and sorghum).

Three villages were selected in each province based on agroecological characteristics to establish trial fields. The survey, which took place in 2020, involved participants in agronomic trials and non-participating farmers. The selection of trial participants was based on land availability, labor availability and willingness to follow the project design. Then define other criteria, such as experience in fertilizer micro-dosing application and gender to set up survey for the sample. Based on these criteria, 400 farmers were selected, including 275 who attended agronomic trials and 125 selected by interviewers amongst cereal farmers (sorghum, maize) in line with criteria established. The semi-open-ended questionnaire surveyed heads of households in local languages. The information collected did not consider data from agronomic trials. Data collected focused on socio-economic factors, maize and sorghum plots characteristics, crop yields, cropping practices, and fertilizer micro-dosing farmers' perceptions.

Definition: Adoption, non-adoption and continuing adoption

According to Doss (2006), an adopter is a farmer who has already tried technology and continues to use it. In contrast, a non-adopter is someone who has never tried the technology. That assumes that the farmer should continue applying technology at all times once adopted. That is plausible because it is possible that after adopting, the farmer may or may not continue to use it. Tura et al. (2010) define adopters as farmers used technology at least once in past farming seasons. A continuous user has used technology every season without any break since the first year of adoption. This definition seems consistent with our understanding of fertilizer micro-dosing adoption and continuous use. Through this study, fertilizer micro-dosing adopter is a farmer who has already tried the technology in his/her field, whether or not he/she participated in a technology dissemination study. Trials, farmer field schools, demonstrations, and showcase fields are technology dissemination channels for testing in fertilizer micro-dosing context (Fatondji et al., 2016; Tabo et al., 2007). Thus, we can assume that farmer willing to try it in a part of his/her field is more likely to apply it partially or totally to his/her entire cropping area in the coming years.

Model definition

In terms of modeling such farmer decisions, models with qualitative dependent variables are adequate (Greene, 2012). The dependent variable, in this case can, be a binary variable with 1 when the farmer adopts and 0 otherwise. In the present study, there are two steps where the farmer is led to decide. The first decision is whether or not to adopt fertilizer micro-dosing after learning about its attributes and characteristics. The second decision is whether or not to continue to use fertilizer micro-dosing after adoption. If both decision steps are independent, probit or logit models could be applied to each decision stage separately. However, if the decisions are linked, such a specification could provide biased model estimators by ignoring a possible correlation of unobservable factors accounted for in error terms. Thus, the bivariate probit model is better suited to perform this modeling with observation selection (Greene, 2009). This model is similar to Heckman's selection model, where the probit model appears in the first equation (selection). However, the probit model appears in both decision steps of selection. The first probit model selects the adopters. The second model is those who will continue to adopt.

Assume U_i is unobserved expected utility associated with fertilizer micro-dosing adoption. Farmer's adoption decision is from maximizing expected utility U_i subject to constraints such as land availability, credit, force labor, mineral fertilizer quantity and many others (Feder et al., 1985). A farmer applies technology if and only if unobserved expected utility is positive. Considering U_i^*, the farmer unobserved expected utility who has adopted microdosing fertilizer, and U_2^*, expected utility associated with the decision to continue applying it, farmer decides to adopt microdosing fertilizer if $U_i^*>0$ and continues it if $U_2^*>0$.

The latent variable y_1^* depends on a set of explanatory factors X such that $Y_1=1$ if $y_1^*>0$. Y_2 is observed if and only if Y_1 (adoption)=1. The model is composed of two equations. The first equation

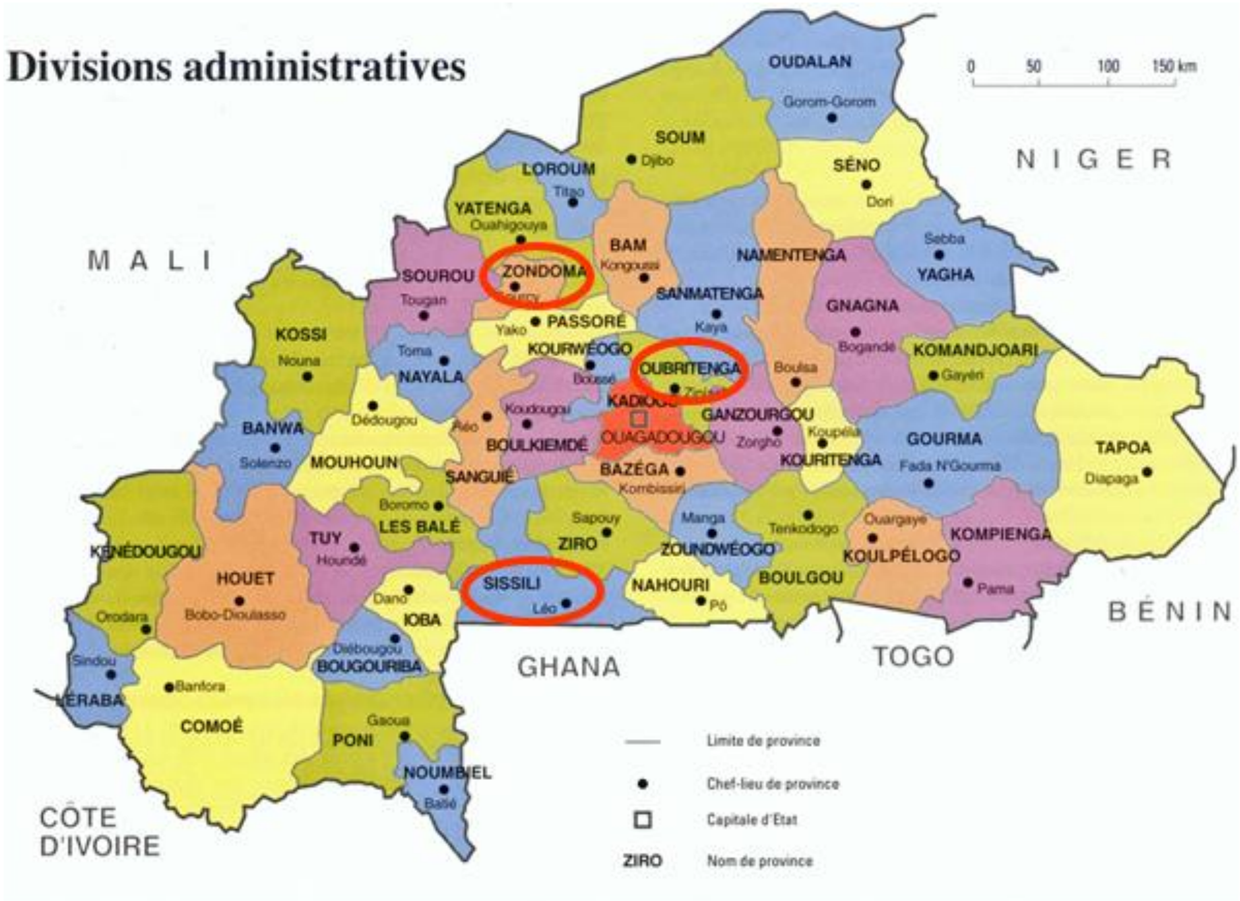

Figure 1. Map of Burkina Faso showing the studied provinces.
Source: MICROFERTI (2020).

represents the decision to adopt fertilizer micro-dosing and includes all the observations, both adopters and non-adopters. However, in the second equation, there is observation censoring. The fertilizer micro-dosing adopter farmers only accounted. Indeed, this equation models farmer's behavior after adoption (continuous use). This censoring of observations induces self-selection in the adoption step that must be addressed to ensure correct parameters estimation in the model (Greene, 2009).

The probit model with selection is as follows:

$$y_1^* = X_1^* \beta_1 + \epsilon_1 \begin{cases} y_1 = 1, if\ y_1^* > 0 \\ y_1 = 0, otherwise \end{cases} \quad (1)$$

$$y_2^* = X_2^* \beta_2 + \epsilon_2 \begin{cases} y_2 = 1\ if y_1^* > 0\ and\ y_2^* > 0 \\ y_2 = 0\ if\ y_1^* > 0\ and\ y_2^* < 0 \\ y_2 = 0\ if\ y_1^* < 0 \end{cases} \quad (2)$$

Where y_1* and y_2* are unobserved latent variables, β and x represent model parameters and explanatory variables, respectively. Both ϵ_1 and ϵ_2 errors are normality bivariate distribution.

A Hausman test is to validate the model specification. It will compare the simple probit model to the bivariate probit model. As mentioned earlier, both decisions can be correlated or not. We apply an error correlation test to choose the appropriate estimation method. Greene (2012) suggests Lagrange Multiplier (LM) test carries out an error correlation test. The null hypothesis, ρ=0≠, means independence of two equations and could be estimated separately as probit regressions. We could estimate Equation 1 using probit regression with the whole sample and Equation 2, by probit regression with a subset of the sample (adopters). If ρ≠0, the maximum likelihood method is used to estimate parameters and the standard deviations with a robust heteroskedastic covariance estimator.

For explanatory variables definition, we carry out a Chi-square test (dummy variables) and a Fisher test (continuous variables) to see if there is a significant difference between adopter groups.

Definition of variables

The data collected over three years include farmers with experience in fertilizer micro-dosing. The sample constituted farmers who learned about fertilizer microdosing through the project's implementation. Thus, a farmer is counted as a fertilizer microdosing adopter if he or she has already applied the technology at least once on his or her own plot of land after participating in a trial or learning about it. Farmers who have partially applied micro dosing fertilizer as adopters were also counted. Some farmers, who adopted fertilizer micro dosing for the first time, tend to use it only on a small portion of their land to evaluate the technology and decide whether to apply it to all of their lands in future farming seasons. This group also includes those who use both micro dosing fertilizer and another fertilization technique because of a lack of fertilizer or labor during the fertilization period, leading them to switch to less labor-intensive methods. Non-adopters are farmers who have exclusively applied another fertilization technique (broadcast, for instance). Continuous adoption refers to farmers who, after a first application (adopter), have continued it for years with no break.

Previous studies showed that farmers' perceptions of agricultural technologies affect adoption decisions (Amaza et al., 2008; Mondo et al., 2019; Roussy et al., 2015; Sissoko, 2019). In this study, perceptions focus on agronomic and economic effectiveness and suitability to current agricultural methods. The perception of agronomic performance involves farmers' assessment of factors such as plant growth or emergence, yield level relative to fertilization techniques and rainfall effect after fertilization. The variable is set to 1 if the farmer believes that fertilizer micro dosing induces rapid growth or good emergence of the plant and 0 otherwise. Since, with fertilizer micro-dosing, the quantity per hectare is substantially reduced. Logically, the cost is also reduced. Therefore, it makes sense that this assessment would support fertilizer micro-dosing adoption and continued adoption application by farmers. According to Sissoko (2019), farmers' perception of fertilizer micro dosing reduced fertilizer costs, positively affects the adoption probability. The perception of labor demand is a binary variable, 1 when farmers judge that micro dosing fertilizer requires more labor or more time, and 0 otherwise. Many reluctant farmers to adopt or to express their unwillingness to continue with fertilizer micro dosing justify their adoption decision by labor requirement of this practice, which is often unavailable or lacking. The expected sign of this variable on both decision steps would probably be negative.

In addition, based on the literature review, socio-economic factors are likely to influence the probability that farmers will adopt or continue applying fertilizer micro-dosing could be: education level, gender, age, dependency ratio, household labor force member, market value of livestock, and off-farm activity (Ani et al., 2004; Doss, 2006; Feder et al., 1985; Fernandez-Cornejo et al., 2005; Nasser et al., 2014). Belonging to a farmer organization, access to mineral fertilizer and contact with an extension agent were institutional factors (Creusot, 2002; Kafle, 2010; Simtowe and Zeller, 2006). Other factors such as measurement tool, years of experience with fertilizer micro-dosing, size of the land area cropped, organic fertilizer use, land tenure, and the province to which the farmer belongs were included (Saba et al., 2017; Sanou et al., 2017; Sigue et al., 2018; Sissoko, 2019; Tura et al., 2010).

Gender, a binary variable, is a factor among adoption determinants and use of fertilizer micro-dosing access (Nasser et al., 2014). According to previous studies, women adopt fertilizer micro-dosing earlier than men. Women perceive fertilizer micro-dosing as a pathway to overcome input access constraints, especially mineral fertilizers. Indeed, women are less likely to access fertilizer, especially fertilizer quantity required under traditional fertilizer methods, due to their low capacity to redeem loans and the lack of collateral (land tenure) to access credit from even local financial institutions (Akouwerabou, 2020).

Household size can negatively or positively affect the technology adoption decision (Feder et al., 1985). The dependency ratio is ratio of non-working members to working members of the household. Non-working members are households aged less than 11 years and more than 55 years. Farmers with more people to feed will tend to favor less labor-intensive fertilization techniques. We included household working members to measure the effect of labor availability on adoption decisions. The working members were calculated by age and gender weighting[1].

Off-farm activity is one of many variables that explain farmers' preferences for agricultural innovation (Ani et al., 2004; Fernandez-Cornejo et al., 2005). In developing countries, off-farm income from income-generating activities is an important funding source for agricultural inputs, especially for mineral fertilizers purchase, seeds and hiring labor (Doss, 2006). In addition, livestock breeding is a source of financing for agricultural inputs. Many of the farmers surveyed revealed that they sell livestock to purchase fertilizer and finance farming operations.

Access to credit remains essential for agricultural technology adoption. The main challenge is to measure this variable in socio-economic studies, as it is generally endogenous (Simtowe and Zeller, 2006). In this study, belonging to a farmer organization is a binary variable set to 1 if the farmer is a member and 0 otherwise. This variable is a proxy for access to credit. Indeed, solidarity deposit is the main guarantee for accessing agricultural credit for input financing (Creusot, 2002). Thus, only farmers affiliated with a peasant organization are more willing or likely to obtain a loan. The constraints to accessing credit are lack of collateral or unavailability of lenders, or inability to repay. In addition, the research and partners put in place warrant age to boost fertilizer micro-dosing adoption. Following the process of setting up warrant age and conditions of participation, being a member of a farmer organization is mandatory to increase one's chances of receiving credit (Chetaille et al., 2011).

The distance from the farmer's homestead to the input sale will be used as a proxy to analyze the fertilizer access effect. The studies assume that the longer the distance, the lower the probability that farmers will have access to fertilizer or even apply mineral fertilizer. It is a distance of kilometers from the farmer's homestead to the nearest rural or urban market.

Contact with extension services is a factor in agricultural technology adoption. According to Sissoko's (2019) findings, there was a significant difference between adopters who had been in contact with public and private extension structures and non-adopters. This factor could positively affect both adoption and post-adoption decision. A similar situation exists with education. Formal education is also a way to access information (Kafle, 2010).

It was assumed that those who adopt it tend to use this familiar tool. Farming practices could be a determining factor in farmers' decision to adopt or continue using it. Indeed, fertilizer micro-dosing application induces a change in usual agricultural practices. Its application requires use of a tool (Coke bottle cap or pinch) to measure the quantity of fertilizer applied per hole. We suspect that farmers who use pinch, the fertilizer may quickly become familiar with and adopt fertilizer micro-dosing. The pinch is a common practice used by farmers during sowing to measure the quantity of some seeds per hole.

Experience in applying fertilizer micro-dosing would be decisive for continued application decisions (Tura et al., 2010). The more experienced farmer, the higher the probability of continuing.

Previous studies pointed to high labor demand as one of constraints to fertilizer micro-dosing non-adoption. This factor could also negatively affect continuous adoption decision. Based on this understanding, we expected that farmers with relatively large areas of land do not adopt fertilizer micro-dosing even after trials with successful results. Studies showed that farmers are willing to apply fertilizer micro-dosing on small plots (Sissoko, 2019). In contrast, in the study of socioeconomic determinants of fertilizer micro-dosing in three countries (Burkina Faso, Niger Benin), Nasser et al. (2014) showed that women apply fertilizer micro-dosing even in large land areas compared to men.

[1] labor power: male aged 15-55(1.0); male aged 11-115(0.742); female aged 15-55(0.805), female aged 11-115(0.732)

Land acquisition is a binary variable with a value of 1 for access by inheritance and 0 otherwise. Households that have inherited their plots are considered to have absolute ownership rights. Thus, they can make investments with a relatively long investment return period. In addition, those who acquired their field by rental or donation will be reluctant to make some investments insofar as the field returned to its owner if the latter expressed a need.

Following the approach of Sanou et al. (2017), provinces of belonging are a proxy for expected profit and production risk. Besides that, provinces allow for agroecological differences between farmers to be considered. The province of Sissili, unlike the provinces of Oubritenga and Zondoma, is a cotton-growing place and farmers are market-oriented, particularly regarding maize production. In contrast, the other two provinces have a dry climate and subsistence production. Due to the intensification of cotton production over time, farmers in Sissili are likely to opt for less labor-intensive fertilization methods. In contrast, in Oubritenga province, a positive sign is expected in both adoption and continued adoption. Indeed, since the fertilizer micro-dosing establishment in Burkina Faso, researchers have carried out projects in this area (Saba et al., 2017; Sigue et al., 2018).

RESULTS AND DISCUSSION

Farmers perceptions of fertilizer micro-dosing

Table 1 represents farmers' perceptions of fertilizer micro-dosing. We have three groups of adopters:

(1) The first group (22.67%) are farmers who after adoption continue to apply fertilizer micro-dosing in their own fields.
(2) The second group (33.25%) are farmers who discontinued fertilizer micro-dosing applications after adoption.
(3) The third group (44.08%) are farmers who have never applied fertilizer micro-dosing in their own fields outside agronomic trials.

Farmers' perceptions are summarized in three items: agronomic performance, economic performance, and farming operations compliance.

Farmers find fertilizer micro-dosing to be agronomically efficient. Its application contributes to soil fertilization improvement, good emergence of plants and resistance to harsh weather conditions, especially rain, which leads to increased yields. Indeed, compared to other fertilization techniques such as broadcasting or spot application, farmers find that this technique avoids run-off water washing away the mineral fertilizer. That allows the plant to get more out of fertilizer and facilitate its growth. Also, compared to returns from other fertilization techniques (broadcasting, spot application), farmers observe a significant difference.

From an economic view, farmers believe that fertilizer micro-dosing reduces mineral fertilizer quantity applied per hectare. That saves on mineral fertilizer and therefore reduces related costs. The mineral fertilizer quantity per hectare under sorghum is 62.5 kg against 100 kg for other fertilization techniques (Tabo et al., 2011). The quantity reduction quantity per hectare allows farmers, especially women, to fertilize most of their fields.

However, they find that fertilizer micro-dosing requires too much time and therefore, a high labor demand compared to previous techniques. Indeed, farmers estimate that, on average, it needs 48 h[2] to fertilize a hectare with fertilizer micro-dosing, compared to 8 h for broadcast fertilization and 24 h for spot application.

Description of model variables

Table 2 represents Chi-square and Fisher test results to examine whether there is a statistically significant difference between the three groups of adopters. Results show a statistically significant difference between adopters' groups in their perceptions of agronomic, economic performance and labor issues. In other words, perceptions may affect farmers' decisions in the fertilizer micro-dosing application process. Other variables such as the zone of residence, household head gender, education level, access to agricultural credit and extension service can explain farmers' attitudes toward fertilizer micro-dosing. In addition, regarding variables such as dependency ratio, number of household labor force members, and land size planted, variance significance test results show a statistically significant difference between the three categories of adopters.

Bivariate probit model estimation of fertilizer micro-dosing adoption and continued adoption

Table 3 represents the bivariate probit model estimation results. Hausman test results lead us to reject the hypothesis of no significant difference between estimators from the continuous adoption probit model and those from the bivariate probit. That means that not taking selection into account would yield biased estimators. Given the Wald test result, we reject the hypothesis of error term correlation. That confirms that the Maximum Likelihood method used to estimate the model is adequate.

Results focus on explanatory factors of adoption decision and continuous use of fertilizer micro-dosing. The predicted probability of continued adoption is estimated 22.91%, given explanatory factors. These results confirm that after fertilizer micro-dosing adoption, farmers can either continue or abandon it.

The model selection estimation shows that perceptions and socio-economic factors are most significant in fertilizer micro-dosing adoption decisions. In addition, institutional factors are significant relatively in the decision to continue applying.

Indeed, agronomic and economic performance

[2] We computed by assuming an average of 8 hours of work per day and multiplying by the number of Average days.

Table 1. Farmers' perceptions of fertilizer micro-dosing.

Farmers' perceptions	Adopters		Non-adopters (%)	Total (N)
	Continued (%)	Discontinued (%)		
	22.67	**33.25**	**44.08**	**397**
Agronomic				
Good yield	29.24	38.21	32.56	301
Good fertilization	44.44	50.00	5.56	18
Good emergency of plant	58.06	19.35	22.58	31
No loss of mineral fertilizer	32.92	30.00	37.08	240
Economic				
Mineral fertilizer saving	50.00	38.19	11.81	144
Fertilizer cost reduction	35.57	36.24	28.19	149
Farming practices				
High labor demand	1.43	28.57	70.00	140
Hard to apply	0.00	9.68	90.32	31

Source: Authors' computations

perceptions positively and significantly affect fertilizer micro-dosing adoption and continued use probability. Remember, agronomic performance is about good plant emergence and good yield. That good yield to other fertilization techniques or farming practices (without mineral fertilizer) is due to fertilizer micro-dosing facilitating good plant growth. Even when it rains, this approach avoids losses of mineral fertilizer due to run-off water. Among adopters who felt that crop yield was good, as opposed to those who did not, average sorghum yield is 725 and 593 kg/ha, respectively. For those who continue to apply and noted good yield, the average sorghum yield is 750 kg/ha versus 609 kg/ha for others who did not make this perception.

This finding is consistent with Sissoko (2019) in Mali who notes that farmers who applied fertilizer micro-dosing reported good plant emergence and strength. The result is also in line with previous studies (Demisie, 2018; Tabo et al., 2007), in which the yield from fertilizer micro-dosing can be higher than that from farmer practices.

Regarding farmers' perceptions of cost, this variable positively and significantly influences the adoption and continued use decisions at a threshold of 1%. Analyzing the marginal effect of perception on purchased cost, we obtain 0.10. In other words, when moving from a situation where farmers perceive fertilizer micro-dosing as resulting in low fertilizer costs, the probability that they will continue to use it after adoption increases by 0.10. That implies that decreasing fertilizer quantity used increases continued use probability. That means fertilizer quantity per hectare reduction diminishes purchased cost and investment risk while leading to better yields.

However, farmers who find fertilizer micro-dosing labor-intensive are more likely not to adopt it, or to abandon it after adoption. This factor has a statistically significant negative effect on adoption probability at a 1% level. That farmers' attitude is due to the time required to apply fertilizer micro-dosing, which is substantially longer than current practices such as broadcasting. As mentioned earlier, fertilizer micro-dosing needs an average of 48 h to fertilize 1 ha compared to 8 h for broadcast and 24 h for spot application. In effect, fertilizer micro-dosing occurs during a period when labor demand is higher. In addition, due to farmers' adaptation to climate change, they adopt mitigation strategies of potential risks such as spatial diversification of farming operations, thus requiring family labor to be allocated generally insufficiently (Cervantes-Godoy et al., 2013; Lawin and Tamini, 2017). Furthermore, due to low-income levels and credit constraints, farmers usually make less use of external labor, except for some farming operations such as harvesting compared to fertilization operations (Porgo et al., 2017). Sissoko (2019) obtained a similar result estimating an average of 45 man/day for fertilizer micro-dosing application time for sorghum plots in Mali with a significant difference from farmer practices.

Formal education positively and significantly affects fertilizer micro-dosing adoption and continued use. Educated farmers have easier access to information on technology's features and attributes. In general, learned farmers act as facilitators among their peers. Thus, they are more likely to participate in training and information sessions organized by projects and programs for beneficiaries. For field manager gender, findings of the analysis show that men are more likely to adopt fertilizer micro-dosing than women. In general, men are more likely to participate in agronomic trials. Indeed, men generally meet the criteria established by the research design. Among adopters and continuing adopters, men represent 75%. This finding seems in contrast to some studies that

Table 2. Independent variables.

Variable	Categorical	Non-adopters	Adopters		Chi-squared test
			Continued	Discontinued	
Categorical variable					
Good yield	Yes	83	9	52	7.36***
	No	92	81	80	
Mineral fertilizer cost reduction	Yes	128	9	50	101.86***
	No	47	81	82	
High labor demand	Yes	77	88	92	77.43***
	No	98	2	40	
Education level	None	82	25	54	16.78***
	Formal	47	19	30	
	Non-formal	46	46	48	
Household head gender	Female	24	21	35	8.39**
	Male	151	69	97	
Off-farm activities	Yes	119	45	93	11.27***
	No	56	45	39	
Rural organization member	Yes	108	29	75	21.70***
	No	67	61	57	
Access to extension service	Yes	63	2	19	46.07***
	No	112	88	113	
Punch use as measurement tool	Yes	163	26	70	121.20***
	No	12	64	62	
Experiences with fertilizer micro-dosing	At most 2 ans	56	28	54	3.32
	More than 2 ans	119	62	78	
Plot access by inheritance	Yes	120	58	95	1.42
	No	55	32	37	
Manure fertilizer application	Yes	83	23	71	18.29***
	No	92	67	61	
Province	Oubritenga	6	77	66	187.90***
	Sissili	93	9	45	
	Zondoma	76	4	21	
Continuous or discrete variables	**Unit**	**Mean (standard-error)**			**Fisher test**
Household head age	years	45 (12)	48 (11)	46 (10)	1.33
Dependency ratio	Ratio	0.88 (0.47)	0.69 (0.41)	0.65 (0.43)	11.82***
Household labor force members	Members	6 (4)	6 (3)	5 (3)	5.31***
Livestock value	Fcfa (Thousand)	286.139 (560.18)	203.381 (301.31)	131.047 (179.05)	5.38***
Distance from homestand to market place	km	1.9 (1.54)	1.81 (2.06)	1.65 (1.16)	0.96
Land size	Hectare	3.46 (2.87)	2.15 (1.56)	2.15 (1.58)	16.88***
Observations		175	90	132	

***, **, * denote significance at 1, 5 and 10%, respectively.
Source: Authors' computations

Table 3. Bivariate probit model estimation results.

Variable	Continue	Adoption
Good yield (yes/no)	0.569(0.618)	1.301***(0.409)
Mineral fertilizer cost reduction(yes/no)	0.923***(0.335)	0.684***(0.216)
Labor intensive (yes/no)	-1.493***(0.458)	-1.346***(0.274)
Formal Education (yes/no)	0.835***(0.293)	0.596*(0.305)
Non-formal education (yes/no)	0.423*(0.252)	0.532*(0.290)
Gender (female/male)	0.189(0.257)	-0.607*(0.333)
Plot manager age (years old)	-	0.0193*(0.0116)
Dependency of ratio (ratio)	1.065***(0.324)	-0.0798(0.353)
Household labor force member (member)	0.0838(0.0614)	-0.0291(0.0445)
Log of livestock value (FCFA)	-0.0199(0.0492)	-0.105***(0.0400)
Off-farm activity (yes/no)	-0.0412(0.224)	-
Rural organization member (yes/no)	0.390(0.266)	-0.248(0.270)
Log of distance from home stand to market place (km)	-0.490(0.311)	-0.630***(0.229)
Access to extension service (yes/no)	0.734(0.492)	1.424***(0.380)
Punch use as measurement tool (yes/no)	1.601***(0.294)	2.962***(0.450)
More than two years of experiences (yes/no)	0.461*(0.245)	-
Land size (ha)	0.661**(0.259)	-0.0390(0.0639)
Square of land size (ha)	-0.0597**(0.0300)	-
Plot access by inheritance (yes/no)	-0.221(0.256)	1.289***(0.291)
Manure fertilizer application (yes/no)	0.350(0.283)	0.578*(0.302)
Province of Sissili (yes/no)	-0.0849(0.444)	1.442***(0.355)
Province of Oubritenga (yes/no)	1.854***(0.437)	2.913***(0.425)
Constant	-6.737***(1.164)	-3.431***(0.846)
Hausman test of difference in coefficients not systematic	30.84**	
Wald test of ind. Eqns (rho=0)	6.03**	
Observations	397	

***, **, * denote significance at 1, 5 and 10%, respectively. Robust standard errors in parentheses.
Source: Authors' computations

estimate that women are 25% more likely to adopt fertilizer micro-dosing than men (Ibro et al., 2014).

Dependency ratio and land size positively and significantly statistically affect continued probability. Indeed, households with less labor tend to discontinue fertilizer microdosing even adoption and switch to previous techniques. However, this result is due to this relatively young category of household heads (up to 40 years old), willing to change, may continue to use fertilizer micro-dosing because additional benefits (higher yields, lower fertilizer costs) outweigh additional costs (labor). The marginal effect of the dependency ratio on the probability of continuing to apply fertilizer micro-dosing is 0.12. Results from Sanogo et al. (2020b) analysis showed that despite labor opportunity costs, fertilizer micro-dosing remains economically profitable for some farmers in Burkina Faso.

Results for access to inputs are consistent with our hypothesis that farmers who do not have access to mineral fertilizer will tend to substitute fertilizer micro-dosing for traditional techniques. The distance to reach the inputs shop negatively and significantly statistically influences adoption decision probability. We assumed that the longer the time spent to find an input shop or sales point, the higher the costs associated with the input purchase because of transportation costs.

Contact with an extension worker is to assess whether information access affects positively and significantly fertilizer micro-dosing adoption probability and not significantly continued use probability. Contact with an extension worker is one way to access information about technology. For example, during an agronomic trial, an agricultural extension agent is in close contact with farmers to ensure that trial ongoing and respected research design. Therefore, they acted as trainers or coaches for farmers, enabling them to own the innovation. This result is similar to Ntshangase et al. (2018) findings, which showed the importance of this factor in the promotion or diffusion of new production technologies in South Africa.

The measurement tool, that is, the pinch, positively and significantly affects at 1% threshold both adopting and continuing probabilities to apply fertilizer micro-dosing. This result confirms our expectation regarding this variable effect in the adoption process. Indeed, farmers used this tool for sowing. Therefore, it cannot be a barrier to fertilizer micro-dosing application. That is in line with the assertion that innovation adaptability to the current system encourages farmers to adopt innovations (Roussy et al., 2015).

In our analysis, years of experience identifying farmer qualifications and skills in fertilizer micro-dosing application positively affect adoption and continued adoption probabilities. This result is consistent with expected results. We assumed that more experienced farmers are more knowledgeable and a better technical understanding. The change in probability value for a non-experienced farmer having at least two years of experience is 0.05. This analysis corroborates Adesina and Baidu-Forson's (1995) finding, which noted that household heads with more experience in Sierra Leone were more receptive to change.

Regarding land size, once a farmer decides to shift from previous methods to fertilizer micro-dosing after adoption, there is a greater chance that the farmer will continue the application. For one additional hectare, the probability a farmer will continue to apply fertilizer micro-dosing increases by 0.045, assuming other factors are constant on average. However, incorporating land size squared into the model shows that the sign is negative and significant. That means there is a turning point (threshold) of land size beyond which farmers might abandon fertilizer micro-dosing application despite adopting it. By doing sensitivity analysis, we found that beyond 5 ha, the probability of continuing to apply fertilizer micro-dosing in one's own field decreases.

Compared to Zondoma farmers, those in Sissili and Oubritenga provinces are more likely to apply fertilizer micro-dosing. The two are among the first places where fertilizer micro-dosing has been established and disseminated in Burkina Faso since the 2000s. However, in terms of adoption, it is more likely farmers in Oubritenga will continue to apply fertilizer micro-dosing than those in Sissili. Despite labor demands, Oubritenga farmers have developed local initiatives such as reducing land size or networking. That enables them to overcome time constraints and continue fertilizer micro-dosing. In addition, compared to those in Sissili, they have relatively small areas and are production-oriented towards self-consumption, but also have difficulty accessing inputs such as mineral fertilizer. In this study, the average land size is 1.6 ha in Oubritenga province compared to 4.1 ha in Sissili.

Conclusion

Through this study, we aimed to answer the issue of farmers' attitudes after fertilizer micro-dosing adoption focusing on farmers' perceptions.

Using a bivariate probit model and data collected from farmers in three provinces of Burkina Faso, results show that farmers can either continue or abandon fertilizer micro-dosing after adoption.

Among adoption determinants, farmers' perceptions of agronomic and economic performance as well as consistency with current agricultural practices significantly affected fertilizer microdosing decisions of adoption and continued use. Farmers who adopted and continue to use fertilizer micro-dosing believe that its application improves yields and reduces mineral fertilizer costs. In addition, they noted a good emergence or growth of crops after application following recommendations from extension agents. On the other hand, those who do not adopt or who abandon it after adoption consider its application to require high availability of labor, generally family labor, which is insufficient to meet their needs.

In light of this analysis, agricultural innovation adoption remains a process in which we outlined several decision-making stages. The study's results confirm the relevance of farmers' perceptions in assessing agricultural innovation adoption processes to understand better their motivations, impediments and constraints. That implies that in agricultural innovation adoption studies, it would be relevant to consider decision-making stages while including farmers' perceptions.

For future studies, the analysis should include risk perceptions to examine the role of risk aversion, a factor that several studies have identified as decisive in agricultural technology adoption.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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