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Linkage between and determinants of organic fertilizer and modern varieties adoption in the Sahel

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Abstract

In this paper, the authors analyze the linkage between and the determinants of organic fertilizer and modern varieties (MVs) adoptions in Burkina Faso. Using simultaneous recursive and endogenous switching probit models, we found a positive joint determination along with a negative endogeneity between the two technologies, indicating controlling for observable variables adoption decisions of the two technologies are positively correlated, but unobserved factors that affect one decision are negatively correlated with the other, or vice versa. After controlling for jointness and endogeneity, we found a significant positive effect of organic fertilizer application on MVs adoption. But, the two technologies are reversely affected by household head's attending formal education and the incidence of soil fertility problem within the farm. The size of good land holding appears to have a positive effect on both adoption decisions. Other factors that significantly affect MVs adoption with positive effect are number of cashcrop grown and remittances. The study suggests that organic fertilizer can serve as enabling factor for greater adoption of MVs, especially in less favourable climate areas. In areas where farmers invest less in inorganic fertilizer because of higher climate and market risks, organic fertilizer can serve as an effective alternative to replace inorganic fertilizer in the adoption process of MVs. Policies to promote green revolution technologies in Sub-Saharan Africa could be more effective if jointly associated with the promotion of conservation agriculture technologies.



1. Introduction

After several decades of significant efforts in promoting agricultural technologies, the gap between developing and developed countries in terms of productive performances and welfare remains huge. Agricultural production in Sub-Saharan Africa (SSA) remains low-input based with low productivity compared to the other regions of the world. SSA realizes only 20 percent of its potential crop yields. Inorganic fertilizer use is estimated to be 12 times lower than the world average, also substantially lagging behind other developing regions (Mainardi, 2011). Many studies pointed out this poor performance of the agricultural sector as the major explanation of the persistence of large rates of poverty and hungry people in developing countries, especially in SSA (Christiaensen et al., 2011; Gollin et al., 2002). Most of the undernourished people currently live in developing countries, namely in Africa and south Asia where the rate of malnutrition has increased over the last 20 years, although improvements have been achieved at the global level (FAO, 2010).

For several economists (Rodrik, 2013; Lin, 2011; Gollin et al., 2002), removing the barriers to the adoption of modern agricultural technologies in poor countries is required to let them follow the same development pathways with the nowadays developed countries through a structural economic transformation led by high agricultural productivity. The need for faster agricultural growth in developing countries raised a large body of literature on agricultural technology transfer and adoption. But the focus has been primarily given to Green Revolution and other conventional innovations such as modern varieties, inorganic fertilizers, pesticides, credit, insurance and subsidies. Studies on alternative non-conventional innovations are much more limited.

It is well documented that adoption of conventional high-yielding agricultural technologies requires some complementary inputs that small-farmers in SSA do not own. For instance, adoption of new seeds is facilitating when farmers can easily access to some complementary inputs such as fertilizers, credit, irrigation and technical support (Doss, 2006). Credit is often a prerequisite for the adoption of improved seeds and commercialized fertilizers (Doss, 2001). But SSA farmers often lack access to credit while they unfortunately pay higher prices for inorganic fertilizer than do farmers in other regions of the world (Jayne et al., 2003). SSA Farmers also face serious production risks due to market failure and climate variability that yields adoption of new technologies inopportune. In less favorable climate conditions such as the Sahelian one, adoption of improved seeds is very risky, particularly when it should involve or go with adoption of other market-based inputs such as inorganic fertilizer or

pesticides. Climate uncertainty in drought-prone areas increase crop failure and raise the dilemma whether commercialized fertilizer and other complementary modern inputs can actually serve as enabling factors for the adoption of new varieties. This question has been somehow raised in some previous studies that failed to find evidences of positive effect of inorganic fertilizer use on modern seeds adoption in some parts of SSA (Musembi, 2011; Doss and Moris, 2006; Fisher and Kandiwa, 2014). More recently, Arlan et al., (2015) reported, based on a case study in Zambia, that the effectiveness of modern input use (seeds and fertilizer) is significantly conditioned by climatic variables. The concern is of greater interest when the new seeds are regarded to non-commercialized crops or subsistence farming. In Ghana, Doss and Moris (2006) found no evidence of impact of inorganic fertilizer use on improved maize seed adoption. Similar findings were also found by Fisher and Kandiwa (2014) regarding adoption of new maize seeds in Malawi. But as adoption of modern seeds is often associated with inorganic fertilizer use, these previous authors missed the opportunity to investigate the alternative solution that farmers may be using to minimize the risks associated with modern seed adoption, and thereby to influence the classic agricultural policies and theory on technologies adoption in SSA.

Furthermore, the paradigm of modern agricultural growth based on increased use inorganic inputs is nowadays questioned regarding the increased degradation of natural resources and environmental services (Dorin et al., 2013; Foley et al., 2005; MEA, 2005; IAASTD, 2008). Increased use of inorganic fertilizer leads to environment degradation and long-term decline of soil fertility (Musembi, 2011; Oades, 1984). In Asia, agricultural production systems may be closer to productivity limits due to the wider use of improved crop varieties, synthetic fertilizers, pesticides, irrigation, and mechanization (Branca et al., 2014). Some evidences indicate serious and growing threats to the sustainability of the yields in the regions where the Green Revolution took place in Southeast Asia (Pingali and Rosegrant, 1998), and even greater evidence of decline in the rate of yield growth (Cassman, 1999; Mann, 1999; Pingali and Heisey, 1999).

Given the global ongoing efforts on sustainable and conservation agriculture, a great interest is now given to more traditional and environmental friendly agricultural practices. But these practices are supposed to evolve within a same farming system along with several modern technologies. Therefore, understanding the linkage between the two types of technologies and factors governing that relationship deserves greater attention.

A body of studies have been conducted on adoption of modern varieties across SSA. But most have emphasized on the dual modern varieties and inorganic fertiliser adoption. To the best of our knowledge, studies on linkage between organic fertilizer use and modern varieties adoption are rare. Literature on adoption of conservation agriculture technologies also still lacks strong empirical studies (Knowler and Bradshaw, 2007)), particularly the ones that focus on the link between green revolution and traditional technologies.

Against this background, the authors of this paper analyzed the linkage between and the determinants of organic fertilizer and modern varieties (MVs) adoptions with a case study from the West-African Sahel where farmers are facing unfavourable weather patterns that may yield higher the probability of technology to fail. We assume that in such conditions, farmers' adoption decisions of MVs should be affected by their ability to mobilize non-conventional inputs, namely organic fertilizer instead of commercialized inorganic fertilizer.

Its contribution is from four perspectives. First relies on the methodological approach combining classic simultaneous probit models and endogenous switching model to provide rigorous empirical evidences on the determinants of adoption/dis-adoption of organic fertilizer and MVs. Endogenous switching probit approach is one of the more relevant technique recently suggested in literature to cope with some shortcomings of standard probit models (see Rabe-Hesketh et al., 2006). But its application in adoption studies of agricultural technologies has been very limited so far. As far as we know, this is the first study to employ such approach to investigate potential relationship between MVs and organic fertilizer adoptions as well as the determinants of each adoption decision. Second, while previous adoption studies have been essentially focusing on the dual inorganic fertilizer-modern varieties, we rather interest in this paper on organic fertilizer and MVs. Third, the case study is conducted in the Sahelian area where harsh climate conditions limit small farmers interest in new technologies, and understanding mechanisms and factors underlying farmers' adoption decisions in such condition is necessary to scale-up agricultural technologies adoption in SSA, especially in less climate favourable areas. Fourth, most adoption studies give limited interest in the sources and natures of the relationship between the different technologies under evaluation. Contrary to them, we investigate in this paper the sources, directions and extents of potential causal relationship between organic fertilizer use and MVs adoption. Such exercise is required to enhance the synergies between the two technologies, and consequently between green revolution and conservation agriculture technologies.

2. Theoretical model

Literature abounds on technology adoption behavior of farmers with numerous econometric modeling techniques to mimic adoption decision. In economic theory, farmers' decision to adopt a given technology is assumed to be derived from the maximization of the expected utility from both adopting the new technology and not adopting it conditional upon the agro-ecological, economic and social conditions of the farm. But when it comes to understanding the relationship between two or more adoption decisions, that exercise becomes more complicated as there are many overlapping factors governing that relationship and may sometime lead to confusing interpretations. Knowing the sources of the correlation and the way it occurs is an important step toward choosing suitable methods for adoption decision analysis of two or more decisions suspected of being correlated.

Let consider the case of two adoption equations M and Y as determinist functions of a set of explanatory variables. In case of this paper, M and Y stand for binary variables indicating whether or not the farmer uses MVs and organic fertilizer, respectively.

Under uncorrelated choice assumptions, both adoption decisions can be estimated separately using, for instance, univariate modeling approaches. But one may ask why the use of organic fertilizer and MVs adoption might not be correlated, and there are several reasons to assume such a correlation in our case. First, there are different ways of achieving the same end, and usually, farmers make several behavioral and technical adjustments in order to maximize their utility function conditional upon the various constraints they are facing. Farmers may be aware that a joint adoption of both organic fertilizer and MVs may provide more utility than single adoption of only one of the two technologies. Also, in Salel, farmers adopt MVs first to deal with recurrent and severe drought and water stress. But, it also comes from many studies that organic fertilizer prevents the rapid infiltration of water and plays an important role in on-farm water and soil humidity control, particularly in semiarid areas (Herrero et al., 2010; McIntire and Gryseels, 1987). The two technologies may be therefore, jointly or separately, used for a same purpose. Furthermore, unobserved factors such as risk altitude, managerial capacity, conservation behavior as well as traditional values of the farmers may also influence adoption decision of both MVs and organic fertilizer. Additionally, time and resources constraints might imply that is one technology is adopted, the farmer may have few possibilities to adopt the other. In these different cases, adoption decision of each technology is related with the other, hence should not be treated separately (Greene, 2008). Analysis that

does not control for such an interdependence may therefore under- or over-estimate the influence of various factors on adoption decision.

Against this background and following Skrondal and Rabe-Hesketh (2007), the relationship between adoption decisions of the two technologies can potentially be illustrated through the Figure 1.

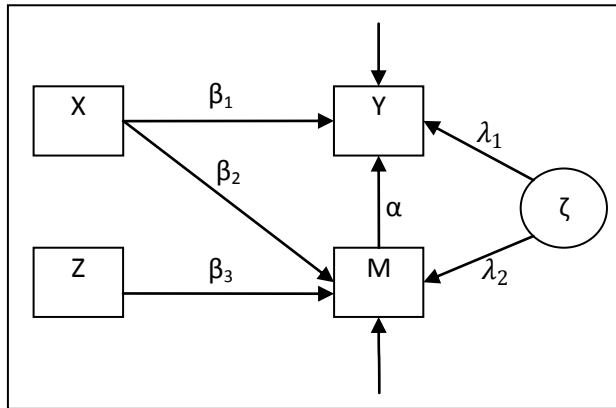


Figure 1: Sources of relationship between two endogenous dependant variables

Potential relationship between the two decisions may come from three major sources. The first source comes from X which represents a set of known and measurable covariates expected to jointly affect the two decisions through two different specific effects β_1 and β_2 . In our case, X may include variables such as cash, asset endowments, labor and other technical constraints that may simultaneously affect the adoption of MVs and organic fertilizer. If statistically $(\beta_1, \beta_2) \neq (0, 0)$, then Y and M are assumed to be jointly determined; and failing to factoring such a jointness into empirical adoption models may lead to wrong estimates. As shown on Figure 1, the second source of a potential correlation between M and Y is indicated through the parameter β_3 , which represents the effect the exogenous covariates such as Z_i and other unobserved exogenous variables - short arrows pointing at M - that affect the outcome variable (Y) only through their effect on the switch endogenous variable (M). The third source is represented through the parameter λ_1 and λ_2 that represents the effect of unobserved factors that are simultaneously correlated with both adoption decisions. If statistically $(\lambda_1, \lambda_2) \neq (0, 0)$, then MVs and organic fertilizer adoptions are endogenously determined, as unobserved factors that affect one decision are also correlated with the other decision. In economic literature, this is known as omitting variables or endogeneity bias, and can be misleading if it is not properly accounted for in the estimation approach.

α is thus the aggregated effect of the endogenous variable M on the outcome variable Y , and encompasses the effects of β_2 , β_3 and λ_2 as well. Depending on the signs and the magnitudes of its different components (i.e., β_2 , β_3 and λ_2), α can be positively or negatively determined. To better understand the nature of the relationship between both adoption decisions, knowing the sign and the significance of α is enough to determine whether the two variables of interest are correlated as well as the direction (positive or negative) of that correlation (Wooldridge, 2002). When β_2 and λ_2 are statistically equal to zero, then endogeneity and jointness between the two decisions are excluded, and α includes only β_3 . In this case, the application of standard single regression models is efficient and consistent estimators of α (Dorfman, 1996).

In presence of jointness and/or endogeneity, single regression models are no longer consistent estimators of α . In such situations, the analysis of the relationship between two adoption decisions as well as of their determining factors requires stronger and advanced econometric methods. But, empirical economic models of agricultural technology adoption often focus a single technology with scant attention to jointness and endogeneity problems. To better model the link between MVs adoption and organic fertilizer use while gaining further insights into their individual determining factors, we employ in this paper several advanced methods including the ones suggested in recent econometric literature.

3. Empirical econometric models

This study aims to understand the relationship between and the determining factors of MVs adoption (Y) and organic fertilizer use (M). We assume that the two adoption decisions are correlated with M an endogenous explanatory variable of the outcome variable Y . In order to check and account for potential jointness and endogeneity in the two decisions, we first estimate a seemingly unrelated (SUR) bivariate probit model (Model 1) which assumes a joint determination of the two decisions with non-zero correlation in the disturbances. The fitted models can be explicitly defined as follow:

$$Y_i = \beta_1 X_i + \mu_i \quad (1)$$

$$M_i = \beta_2 X_i + \vartheta_i \quad (2)$$

where X represents a vector of observable covariates including economic, agro-ecological and social characteristics of the farmer, and μ_i and ϑ_i are the errors terms associated with Y and M , respectively.

In this first model, none of the two variables of interest do appear as a covariate at the right-side. But, both equations are assumed to be correlated through the error terms. To fit the model, we make the assumption that the error terms (μ_i, ϑ_i) have a bivariate normal distribution with zero means, unit variances and $\text{Cov}(\mu_i, \vartheta_i) = \rho_1$. The model can be estimated using maximum likelihood method. The associated log-likelihood provides estimates of β coefficients as well as of ρ_1 . The sign and significance of ρ_1 provide evidence on the potential joint determination of the two decisions along with the direction of that jointness. However, joint determination of the two adoption decisions does not mean that the two decisions are correlated. As noted by Francavilla et al. (2012), SUR procedure has the advantage of allowing to assess whether the observable explanatory variables have opposing or similar effect on the two decisions, but it is not capable of assessing the effects of organic fertilizer use on MVs adoption. This approach also does not allow to test and/or to address the issue of endogeneity between the two adoption decisions.

To account for endogeneity problem, we perform a recursive bivariate probit model (Model 2) that adopts the typical structure of the theoretical background developed in Figure 1. In so doing, we include organic fertilizer application as covariate in MVs adoption equation. The fitted equations in Model 2 are thus defined as:

$$Y_i = \alpha M_i + \beta_1 X_i + \mu_i \quad (3)$$

$$M_i = \beta_3 Z_i + \beta_2 X_i + \vartheta_i \quad (4)$$

where X , μ_i and ϑ_i stand as defined above. α is a the coefficient representing the estimated effect of organic fertilizer application (M) on MVs adoption (Y). For identification purpose, it is required to include in the organic fertilizer equation at least one variable that is excluded from MVs equation. Such a variable is known as instrument. Herein, we use the variable Z which is the binary variable indicating whether or not the household practices a mixed crop-livestock practice. We explain later the reasons behind the choice of that variable.

Model 2 is fitted, as Model 1, with maximum likelihood method. In this case, ρ_2 represents the correlation coefficient between the errors terms μ_i and ϑ_i , after controlling for jointness and endogeneity. It allows for endogeneity test of organic fertilizer use, while the sign and the size of α can be interpreted as evidence of the direction and magnitude of the correlation between organic fertilizer and MVs adoption decisions. We estimated both Model 1 and Model 2 using standard bivariate probit routine in STATA.

Although simultaneous bivariate probit models have been so far the most popular regression methods used to deal with endogeneity problem with binary outcome and explanatory variables, several concerns arise regarding the computational aspect of these models along with the normal distribution assumption behind them. Marra and Radice (2011), for instance, pointed out that the classic recursive probit model does not allow for flexible functional dependence of the outcome variable on the continuous covariates, and this may violate the joint distribution assumption of the error terms. Similar concerns were also raised by some other authors (see, Miranda and Rabe-Hesketh, 2006; Rabe-Hesketh et al., 2005). These concerns bring up some doubt about the consistency of Model 1 and Model 2 previously performed. In this regard, we employ the endogenous switching (ES) probit model (Model 3) recently recommended by Miranda and Rabe-Hesketh (2006) in order to properly account for joint determination and endogeneity problems. ES procedure has been applied in behavioral studies in various disciplines including in economics, sociology, statistics, ecology and management with analysis that involve fitting models in which the outcome variable depends on an endogenous switching or selection dummy variable. It can also be used in joint determination context.

Following Miranda and Rabe-Hesketh (2006), equations (3) and (4) can be formulated as a system of equation for two latent variables, whereby Y is assumed to be generated as:

$$Y_i = \beta_1 X_i + \alpha M_i + \mu_i \quad (5)$$

$$Y_i = \begin{cases} 1 & \text{if } Y_i^* > 0 \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

where Y_i^* is a latent continuous variable, β_1 represents a K x 1 vectors of coefficients of the covariates X, α is the coefficient associated with the endogenous dummy variable (M), and μ_i is the error term. Similarly, the endogenous switching variable can be specified as:

$$M_i = \beta_2 X_i + \beta_3 Z_i + \vartheta_i \quad (7)$$

$$M_i = \begin{cases} 1 & \text{if } M_i^* > 0 \\ 0 & \text{otherwise} \end{cases} \quad (8)$$

where M_i^* is a latent continuous variable underlying the observed dummy variable M_i , β_2 represents a L x 1 vectors of coefficients of covariate to be estimated, and ϑ_i is the error term. μ_i and ϑ_i are random errors assumed to follow a bivariate normal distribution. Instead of arbitrarily assuming the error terms (μ_i, ϑ_i) to be identically distributed as a bivariate normal

with zero means and unit variances like in standard probit models, Miranda and Rabe-Hesketh (2006) suggest to create a dependence between μ_i and ϑ_i by introducing a shared random effect, ε_i . The relationship between μ_i and ϑ_i is specified as follow:

$$\mu_i = \lambda \varepsilon_i + \tau_i \quad (9)$$

$$\vartheta_i = \varepsilon_i + \zeta_i \quad (10)$$

In equations (9) and (10), ε_i , τ_i and ζ_i are independently normally distributed with mean 0 and variance 1, while λ is a free parameter serving as a factor loading. The correlation coefficient between the error terms is given by:

$$\rho = \frac{\lambda}{\sqrt{2(\lambda^2 + 1)}} \quad (11)$$

As stated earlier, the above parameterization contrasts with that usually used for standard bivariate probit models. To align ES model estimates with the usual parameterization, we rescale all the estimated regressions coefficients by dividing equation (5) for Y_i^* by $\sqrt{\lambda^2 + 1}$ and equation (7) for M_i^* by $\sqrt{2}$, and use the delta method to obtain correct standard errors.

Model 3 can be fitted with two-step procedure or maximum likelihood method. In this paper, we fit the model with maximum likelihood method owing to its assumed advantages over the two-step procedure (see, Wooldridge, 2002, p. 276-277). Specifically, we used the Generalized Linear Latent and Mixed Method (GLLAMM) procedure in STATA, which maximizes the likelihood using a Newton-Raphson algorithm with adaptive quadrature (Rabe-Hesketh et al. 2005). ES procedure provides an easy way to test the exogeneity of the suspected endogenous switch variable. As with Model 2, the correlation coefficient of the error terms, ρ_3 , here stands as an endogeneity test of organic fertilizer application. Exogeneity is rejected when rho is significantly different from zero.

4. Variable and model specifications

Variable choices and model specification is based upon previous adoption studies. Actually, there is an abundant literature on adoption models, with a particular focus on the conditions in which the user of a given technology can be considered an adopter or not (see, Doss, 2006; Feder et al., 1985; Foster and Rosenzweig, 2010). Some studies distinguish between the rate of adoption (defined as the proportion of farmers that adopt a given technology, regardless of the level of use) and the intensity of adoption (defined in terms of the level of use of the technology, e.g. the proportion of the farmer's land planted to improved varieties or the

quantity applied of fertilizer). Those also differ from simple technology, such as adopting MVs, from complex technology such as inorganic fertilizer. Unlike simple technology, decision to adopt complex technology is difficult to quantify. For instance, Doss and Morris (2001) indicate that farmers that decide to adopt inorganic fertilizers must learn the names of different products, their nutrient composition, the correct application rates, the optional applications schedules and the right application method. In contrast, adopting MVs implies relatively few changes to the current farming practices. Therefore, establishing good measures and indicators of the variables of interest are important in adoption models.

Doss (2006) suggests that the intensity of adoption may be more relevant and useful in analyzing farmer's decision to adopt. But in practice, it is very challenging to get a good indicator of the adoption intensity, and failing to have a good understanding of the indicator could lead to worse results than using the simple rate of adoption. For instance in SSA, farmers simultaneously use several new seeds that they sometime mix with local seeds on a same land-plot as risk reducing strategy. In such conditions, it is not possible to get a clear measure of the intensity of adoption of new improved seeds. Also, estimating the amount of organic fertilizer applied by each farmer on a given land-plot is not an easy task in African farming. Farmers often hold several small plots of land and split the amount of available inputs over them following very specific and individual criteria. For these reasons, we decide to just focus on adoption rates as indicators of our two major interest variables, including adoption of MVs and organic fertilizer use.

For the control variables, X , our choice is based on the literature. These variables include the characteristics of the household, their endowment in resources such as land, labor and capital, livestock asset holding and their access to market and technical information and support. However, we go a little beyond the exiting literature by being more specific and innovative in the choices and specifications of these variables. For instance, regarding land availability we distinguish four variables such as the farm size, land per capita, degraded land area and amount of good land. This distinction is not common in adoption-related models, but is particularly important in Sahelian areas where people are facing serious land degradation because of erosion, nutrient imbalance and desertification. It could provide the opportunity to assess how land ownership and quality affects farmers' decision to adopt. For liquidity access, we consider farmers' access to formal credit as a dummy variable, but also whether or not the household benefit from remittances from migrating household's members. Actually, remittances could serve as alternative source for cash to farmers facing credit constraint. It

may give the farmer the opportunity to hire labor and also to buy both MVs and complementary inputs. Labor availability is included through total household's size, dependency ratio, household's active members and also the number of migrating household's members. Indeed, while migration may provide additional income to the household through remittances, it may also result in a smaller workforce for farming activities. Control variables also include a dummy variable indicating either or not the main farmer's production objective is prominently consumption-oriented. SSA farmers often produce for both household consumption and market sales (Doss, 2001). But, depending on the household's characteristics and endowment in resources, the main production objective of the farmer might be more market- or consumption-oriented, and could consequently determine his technological choices. We also consider household's interest in profit making proxy in terms of the number of cashcrops grown that may determine farmer's ability to mobilize cash. The number of cashcrops grown is also a proxy for market access.

Regarding technical information access, we consider not only the farmer's contact with public extension services, as common in adoption-related models, but also whether the farmer or a member of his household has attended a training related to climate change adaptation or soil and water management practices. To capture the effects of agro-ecological differences, we included a dummy associated with the agro-ecologic zone. Since Sahelian region of Burkina is shared by several ethnic groups, we included a dummy variable for six ethnic groups namely the Mossi, Foulse, the Bella, the Rimaiibe, the Gourmantche, the Fulani and minor ethnic groups. The ethnic dummy variable is supposed to pick up the impact of some cultural, moral and social variability on the adoption decision.

All variables defined above are included in Model 1. But for identification purpose, organic fertilizer equation in Models 2 and 3 includes in addition an instrumental variable indicating whether or not the household practices a mixed crop-livestock technique, such as using crop residue for animal feeding, stalling livestock or fodder cropping. To be relevant, the instrumental variable should be strongly correlated with the endogenous switching variable, while being uncorrelated with the outcome variable. Our choice is, therefore, guided by the goal of finding at least one variable that is correlated with use of organic fertilizer, while being uncorrelated with MVs adoption decision. Actually, the use of organic fertilizer depends primarily upon the availability of animal manure that is determined by farmers' capability to produce, to collect and to transport it into the fields (Abdoulaye and Sanders, 2005). Some authors showed that, unlikely with straying livestock systems such as transhumance and

straying animal raising, mixed crop-livestock practices facilitate some interdependence and matter flows between crop farming and livestock husbandry: the crop component provides feed to the animals while the livestock component provides manure and traction to crop farming (Herrero et al., 2010; McIntire and Gryseels, 1987). As result, we assume that practicing at least one of the mixed crop-livestock practices above mentioned should provide to farmers certain facilities in using organic fertilizer, but should not have a direct effect MVs adoption.

Moreover, we exclude from models³ some covariates that may obscure the effect of organic fertilizer application due to multicollinearity problem. Description of the variables used in the models is provided in Table 1.

5. Data

Data used in this study is drawn from an empirical survey carried out in the framework of cases studies implemented under African and Latin American Resilience to Climate Change (ARCC) initiative, which is a USAID funded project implemented by Tetra Tech ARD. The case studies were conducted in Kenya, Ghana and Burkina Faso with technical support of the African Climate Policy Center (ACPC) of the United Nations Economic Commission for Africa (UNECA). In Burkina Faso, the aim of the study was to identify key practices used by smallholders in response to the impact of recurrent droughts in the Sahelian region and to understand the factors determining famers' adaptive choices. Surveys were carried out by the *Association pour le Gestion de l'Environnement et le Développement (AGED)* and the *Institut National de l'Environnement et de la Recherche Agricole (INERA)* of Burkina Faso. A total of 500 households distributed across 16 villages of all the four provinces of the region of northern Burkina Faso were surveyed, and were asked to voluntary answer a questionnaire pertaining to how they are dealing with the adverse impacts of droughts and other agro-ecologic constraints in the region. Data collection lasted 45 days, from September 20 to November 5, 2013. A randomized procedure was used to select a representative sample of farmers. The questionnaire contains the socio-economic characteristics of the households, the effects of drought and other bio-physical constraints on farmers' livelihoods including crop and animal production, drought control practices such as land and water management techniques, and other adaptation strategies such as migration, off-farm activities, assess liquidation, etc. Farmers were also questioned about their access to agricultural information and technical services.

6. Empirical results

6.1. Correlation between organic fertilizer and MVs adoption decisions

In this section we are interested to investigate the existence and sources of a potential relationship between organic fertilizer application and MVs adoption. Table 2 reports on the significance tests of the correlation coefficients $\rho_j, j = 1, 2, 3$.

We observe that the rho's coefficients across the three models are significant at the conventional levels. These findings suggest that organic fertilizer and MVs adoption decisions are jointly and endogenously determined. The strong significance of ρ_1 indicates the presence of correlation between the errors terms μ_i and ϑ_i , after controlling for the observed covariates. Consequently, the explanatory variables included in the models concomitantly affect farmers' adoption decisions regarding the two technologies. The sign of ρ_1 indicates that the direction of that joint determination is positive. This means that ignoring omitted factors, and hence the resulting endogeneity bias, farmers that are more likely to apply organic fertilizers are also the ones that are more likely to adopt MVs. If this finding is to be believed, it would indicate that estimating organic fertilizer and MVs adoption equations using single regression models will be biased downwards, even if the effect of omitted variables is ignorable.

The estimated coefficients of ρ_2 and ρ_3 tell a different story about the nature of the relationship between organic fertilizer use and MVs adoption. We found that ρ_2 is strongly significant with a negative sign, after controlling for jointness and omitted factors. This evidence is also supported by ρ_3 , even though the coefficient of ρ_3 is significant at 10% level. These findings indicate that the two outcomes of interest are endogenous, meaning that unobserved variables that affect organic fertilizer use are also correlated with MVs adoption. Both ρ_2 and ρ_3 are negative. This suggests a negative effect for the hidden bias arising from the endogenous nature of both decisions. In other words, this means that, ignoring the effect of observable covariates, farmers more likely to apply organic fertilizer are less likely to adopt MVs. Actually, we recognize the existence of certain variables not included in our models, such as conservation attitude, traditional values, risk aversion among the farmers along with their interest in the modernity, as some potential relevant omitted variables, difficult or impossible to be measured, but that may have contrasting effects on the two

adoption decisions. For example and especially in SSA, one would expect farmers' conservation attitude or interest in the tradition to be positively correlated with organic fertilizer use and negatively correlated with MVs adoption, thus generating a negative correlation between the two equations. This evidence is in line with previous studies that showed that the presence of conservation attitude and traditional or moral concerns among farmers is positively associated with a greater probability to adopt conservation agriculture technologies (e.g., Warriner and Moul, 1992; Carlson et al., 1994; Mzoughi, 2011). Similarly and all else being equal, one could assume that more risk taker farmers, would show greater probability to adopt MVs, whereas less risk taker ones should show greater interest in organic fertilizer. This evidence could again generate a negative correlation between the two technologies.

With respect to these evidences, employing single regression models and even SUR procedure to understanding the determinants of and the relationship between organic fertilizer and MVs adoptions should be inconsistent and biased upwards, even if the two decisions are not jointly determined. The magnitude of the resulting induced aggregate bias is larger if the two sources of correlation – that associated with observables and that due to unobserved factors – go in opposed direction. If the omitting bias stemming from unobservables or endogeneity counteracts that based on jointness then eliminating only the latter bias – as we did with the SUR procedure – will increase aggregated bias (Ravallion, 2008). These results corroborate the interdependence hypothesis formulated earlier (Section 2) and the consequent choices of joint and endogenous switching models to better investigating the relationship between and the determinants of our two variables of interest. Owing to the opposing effects of the two sources of correlation (jointness and endogeneity) between the two decisions, one can expect the aggregate effect of organic fertilizer use on MVs adoption to be positive or negative depending on the magnitudes of jointness and endogeneity effects as well as that of the instrumental variable only included in the organic fertilizer equation. This issue is investigated in the next section.

6.2.Determinant analysis

6.2.1. Modern varieties equation

As explained in Section 3, the two adoption equations are simultaneously fitted through three different models: SUR bivariate probit (Model 1), recursive probit (Model 2) and endogenous switching probit model (Model 3). The maximum likelihood estimates of the MVs adoption

equation in the different models are presented in Column 1, 3 and 5 of Table 3. We first consider the estimates of the Model 1 as reported in Column 1. These estimates bring up some preliminary insights into factors that affect MVs adoption. An overview on these findings indicates that several estimates look consistent with the existing literature on MVs and other modern agricultural technologies adoption, though some differences are notable therein. Several regressors are statistically significant with the expected signs. In consistence with our expectation, formal education has a positive sign, but not significant at conventional level. Higher number of cashcrops and size of good lands also lead to greater likelihood to adopt MVs. Conversely, higher farm size has opposite sign, but is not significant. Ethnicity also seems to significantly influence farmers' probability to adopt MVs. Considering the Mossi as reference, being member of certain ethnics, such as the Foulse, the Rimaibe and the Fulani, significantly leads to higher probability to adopt MVs, whereas being member of the Gourmantche's ethnic group has an opposite effect, but not significant. Looking at extension services and technical information access, neither contact with extension services nor dummy for attending at least one training on climate change adaptation or water and soil management practices is statistically significant, even though both variables have expected signs.

On the other hand and with strong significance, households that get remittances sent by migrating family members are more likely to adopt improved technologies including MVs, whereas proxy for credit does not appear to have significant effect. In contrast and unexpectedly, application of inorganic fertilizer is negatively associated with adoption decision of MVs at 10% level. However, we consider Model 1 estimates with a grain of salt as we recognize with strong evidence from previous section that they may suffer from endogeneity problem.

To gain further confidence into the above results we report in Column 3 the estimates of the Model 2 for MVs equation. We note several differences with Model 1 estimates. One of the most important insights brought up here is related to the effect of our endogenous switching variable, e.g. organic fertilizer use, on MVs adoption. The sign of the coefficient of organic fertilizer tells on the overall direction of the relationship between organic fertilizer and MVs adoptions. Consistent with our hypothesis, the coefficient of organic fertilizer is positive and very strongly significant. Organic fertilizer use therefore increases the likelihood of farmers to adopt MVs. Importantly, the coefficient of organic fertilizer application is larger than the coefficients of all other explanatory variables, highlighting the magnitude of the role of organic fertilizer use in MVs adoption in the Sahelian area. The value of coefficient

represents the aggregate effect of organic fertilizer application on MVs adoption, and that combines the positive effect stemming from observable covariates (X), the negative effect of unobserved factors and the effect of the instrumental variable (Z), i.e., practicing a mixed crop-livestock technique. As the coefficient of Z is significantly positive in organic fertilizer equation (Table 4, Row 12), we can therefore deduce that its effect on MVs adoption through organic fertilizer equation is also positive. Given the aggregate effect of organic fertilizer use is significantly positive, one can deduce that the inverse effect of unobserved factors (endogeneity effect) on farmers' probability to MVs adoption and organic fertilizer is too weak to counterbalance the positive effect of all observable joint covariates (jointness effect) combined with the effect of the instrument Z.

Compared to Model 1, we also observe that the signs of the coefficients of some covariates, such as credit and sex, have changed. Furthermore, the coefficients of some covariates are no longer statistically significant, while those just lost in terms of significance level. The worthiest finding here is related to inorganic fertilizer application which has lost its explanatory power, even still holding a negative sign. The statistical significance of this variable as predicted in Model 1 was so unexpected and surprising because of the negative sign of the coefficient. Actually, it is largely hypothesized that farmers' decisions to adopt modern seeds are subject to their access to inorganic fertilizer (Duflo et al., 2011). Although some studies failed to show this hypothesis in some contexts (Doss and Morris, 2001), strong empirical opposing evidences are very rare in the literature. Model 2, therefore, reinforces the negative sign inorganic fertilizer has on MVs adoption in drought-prone areas in Burkina Faso, but with no evidence for a statically significance acceptance of that effect. Some ethnic groups have also lost their explanatory power, and only being member of the ethnic group of the Foulse appears to raise farmers' likelihood to adopt MVs. In contrast, attending formal education became significant at conventional level still with a positive sign.

The Column 5 of the Table 3 reports the estimates of the Model 3 performed as an alternative estimation approach to deal with the shortcomings of standard simultaneous probit models. Looking at the signs and significances of the coefficients, Model 3 estimates globally look similar with Model 2. These estimates strongly confirm the positive effect of organic fertilizer use on MVs adoption, whereas the use of inorganic fertilizer still holds a negative, but no significant, sign. Model 3 also confirms the significant positive effect of formal education on MVs adoption. But Model 2 seems to overestimate the magnitude of the effect of organic fertilizer use. Globally, important differences are noticed in the magnitudes of the

estimated coefficients: some coefficients appear to be underestimated with Model 2, whereas a reverse bias is noted with those covariates. These findings support the assumed bias reported about standards simultaneous and recursive models (Miranda and Rabe-Hesketh, 2006).

In sum, estimates indicate that, in addition of organic fertilizer application, number of cash crops grown, amount of good land owned, formal schooling and remittances significantly and positively affect farmers' adoption decision regarding MVs. But the impact of organic fertilizer use is larger than ones of all other variables included in the models. Conversely, a consumption-oriented farming system and incidence of soil infertility appear to have a significant negative effect. These finding are broadly consistent with the recent literature on adoption of green revolution technologies. For example, in Malawi, Fisher and Kandiwa (2014) found that there was a greater tendency to grow modern maize varieties on higher quality lands. The negative sign of incidence of soil fertility problem also support these evidences in a second way, as this finding suggests that poor and infertile land is associated with lower probability to adopt MVs.

On the other hand, greater market access or interest in profit making is associated with greater probability to adopt new agricultural technologies, while poor market access leads to subsistence agriculture, and therefore to lower incentive to adopt new technologies (Doss, 2001; Feder and Zilberman, 1985; Fisher and Kandiwa, 2014). It is also well known that African farmers are often credit-constrained, and/or adverse about marked-based credit because of unexpected market failure and climate risks that may yield the technology unsuccessful. Farmers may therefore be responding to the lack of credit by using some alternative and less risky sources for cash, such as remittances in our case. The strong significant positive sign of number of cashcrops grown also supports this evidence. Similarly, as use of inorganic fertilizer requires important budget, smallholder farmers may resort on organic fertilizer as alternative technology to the budget constraint that limits their access to inorganic fertilizer. Kassie et al. (2015) reports that credit constrained farmers are more likely to adopt manure and other soil and water conservation practices. Although surprising, the negative signs of proxies for inorganic fertilizer applications and credit access, though not significant across all the three models, are meaning. These findings actually contrast with what is largely known in the literature, but corroborate the significant positive effects reported on organic fertilizer and remittance. Such findings are justified in our context. Farmers mostly adopt MVs for staple crop farming including sorghum, maize or millet that

are not commercial crops. Around 84% of adopted MVs are regarded to staple crop seeds. As these crops are not market-oriented, farmers may prefer to resort to alternative non-market based inputs such as remittances and organic fertilizer for their production instead of market-based inputs including credit and commercial nitrogen fertilizer. In SSA, credit and inorganic fertilizer are generally used for cashcrops and commercialized farming. Discussions realized on the ground with various stakeholders including extension agents, researchers and farmers support that evidence, as it comes from these discussions that commercial nitrogen fertilizer is particularly used for cashcrops such as sesame, groundnuts and vegetables. Overall, these findings corroborate the theoretical background of this study, which assumed that in certain areas particularly vulnerable with crashed weather conditions, non-conventional innovations instead of modern market-based inputs should play an important role in adoption process of green revolution technologies including modern seeds.

None of the measures of labor availability are statistically significant across all the three models. But, except households' size, the coefficients of number of migrating members and active members per hectare have the expected signs. This might indicate that labor availability does not affect farmer's decision to adopt MVs, or might simply mean that the variables we used are not good indicators of labor availability in our context. For instance, household's size might actually not be a good indicator of labor availability as it not only includes active members of the household, but also inactive ones such as children, old and invalid people, and also those who are not involved in farming activities. In our context, the size of the household may describe the dependency of the household rather than labor availability. This may explain why the coefficients of both household's size and dependency ratio are negative, meaning that higher household's size and dependency ratio reduce the probability to adopt MVs. This finding may also imply that active members vs. inactive members ratio within households in Sahelian area is unbalanced in favor of inactive members including infants and old people. The region has actually experienced large migrating movements during the last decades owing to the increasing degradation of natural resource combined with the unfavorable agro-ecologic conditions and recurrent droughts. This should lead to an unbalance in the household composition in terms of gender and labor force.

Age and sex of household's head are significant in none of the models. These results contrast with Fisher and Kandiwa (2014). But they look consistent with other previous studies that found that gender differences in adoption process greatly result from differences between male and female (or young and adult/old) farmers in terms of asset holdings and information

access, and such differences disappear, once controls for access to land, labor, capital, extension services and markets are included in the models (Chirwa, 2005; Doss and Morris, 2001; Smale, 2011).

6.2.2. Organic fertilizer equation

Column 2, 4 and 6 of Table 3 report the estimates of organic fertilizer equations. Column 2 presents the estimates of Model 1. These first findings suggest that the size of good land owned, incidence of soil infertility, proxies for agro-ecologic zones as well as being member of certain ethnicities, such as Rimaibe and Fulani and other minority groups, appear to have a significant positive effect on organic fertilizer use. Conversely, proxies for formal schooling of the household's head, use of inorganic fertilizer and remittance seem to have significant disincentive effects, though inorganic fertilizer is only marginally significant ($p\text{-value} < 0.15$).

Column 4 presents the estimates of Model 2. The findings significantly changed the basic patterns of the results showed in Column 1. Several variables are no longer significant. Only amount of good land owned and incidence of soil infertility are significantly associated with greater probability to use organic fertilizer. Our instrumental variable, practicing a mixed-crop-livestock technique, is also strongly significant with a positive effect. The coefficients of dummies for household's head education, use of inorganic fertilizer and benefiting from remittance remain negative but insignificant. We also observe sign changes of some covariates, such as, household's size and proxies for consumption-oriented production. Column 6 reports the estimates of Model 3. In terms of significance, no major differences are noticeable between Model 2 and Model 3 estimates. Looking at the signs, consumption-oriented farming and number of active household's members have changed signs to be in line with our expectations. We also observe that the magnitude of the coefficients has experienced a slight change.

In conclusion, few variables seem to have significant effect on organic fertilizer adoption. These variables include amount of good land owned, practicing mixed crop-livestock farming and incidence of soil infertility that appear to have positive significant effects. Education, inorganic fertilizer and being member of the Foulse ethnic group appears to have an inverse effect, though only education seems strongly significant in Model 1 and marginally significant in Model 3. These findings corroborate with conclusions of Knowler and Bradshaw (2007) that revealed few variables as significant determinants of adoption of

conservation agriculture technologies in SSA. Our findings here indicate that the more the farmer is facing soil fertility problem, the greater its likelihood to use organic fertilizers. Some earlier studies also found farmers' awareness or perception of soil fertility problems to be positively correlated with the adoption of soil conservation practices (Napier and Camboni, 1993; Traore´ et al., 1998). Similarly, greater good quality of lands is associated with greater probability to use organic fertilizer. More generally, holding land of good quality improves the adoption of agricultural technologies. But, this finding also indicates that even if organic fertilizer is often described in the literature as a soil conservation/restoration practice, farmers are more likely to adopt it when they have access to good quality land. This may imply that applying organic fertilizer is not effective on very poor and degraded lands of the Sahel.

Inconsistent with earlier studies (Kassie et al., 2015; Marenja and Barrett, 2007), we found no evidence of any significant effect of neither number of cattle nor small ruminant holding per hectare, even though the signs of their coefficients are consistent with our expectations. This finding suggests that holding large livestock assets is not sufficient to apply animal manure to crops. The ability to collect and transport the manure is actually crucial; but large herders in the Sahel are often involved in long-distance and cross-country practice of transhumance seeking for better grazing and water. Mobilizing manure should be less easy for such people than farmers practicing fixed livestock husbandry with smaller herds. Läpple and Rensburg (2011) also found lower livestock density per hectare to be advantageous for adoption of organic farming, and non-adopters have significantly a higher livestock density than adopters. Another plausible explanation is that large herders survive essentially from livestock husbandry and pay less attention to crop farming for which they devote a very small part of their budget and resources. Knowler and Bradshaw (2007) argued that high-return alternative income sources could diminish the priority of crop farming within the household, thereby reducing interest in conservation technologies adoption.

Although holding a positive sign across all the three models, none of the measures of technical information access is statistically significant. This finding is inconsistent with Arslan et al. (2014), but is in line with Kassie et al. (2015), and further explains the inability of extension services to providing accurate and relevant technical support to farmers in some parts of SSA. Knowledge-intensive nature of conservation agriculture practices is frequently reported in the literature (Giller et al., 2009). But, extension system in Africa has so far mainly focused on promoting a package of commercial nitrogen fertilizer and improved seeds

with scant attention to other agronomic practices such as organic fertilizer and other conservation farming technologies. Giller et al. (2009) reported lack of access to appropriate technical information as one of the major constraints that smallholder farmers face with adoption of organic farming technologies in SSA. In eastern and southern Africa, Kassie et al. (2015) found that contact with extension agents increase the adoption of inorganic fertilizer, but does not have any significant effect on manure application and other conservation farming practices. These authors concluded that it is not the simple access to extension services that matters for adoption of sustainable agricultural technologies, but the quality of the service.

Moreover, we found that education and applying inorganic fertilizer are negatively associated with organic fertilizer application, even though only education seems highly significant in Model 1 and marginally significant in Model 3. But in the previous section, we reported a significant positive effect of formal schooling on MVs adoption. These findings, actually, recall an old debate concerning the effect of education on traditional vs. modern technologies adoption (Phillips and Marble, 1986; Cotlear, 1990; Phillips, 1994), and strongly support some recent studies (Kassie et al., 2015; Knowler and Bradshaw, 2007; Teklewold et al., 2013). Organic fertilizer is an indigenous or traditional technology; but education often has a *modernity effect* on farmers' behaviour, especially in SSA, by leading them to develop some preferences for modern or foreign technologies at the expense of traditional ones. As a result, educated farmers may consider organic fertilizer as an indigenous technology, and this could yield them less likely to adopt that technology than non-educated farmers. Another explanation of the negative effect of formal schooling is the conservation attitudes and moral and traditional concerns among farmers, which have been assessed to be positively associated with adoption decisions of conservation agriculture practices (Warriner and Moul, 1992; Carlson et al., 1994; Okoye, 1998; Mzoughi, 2011). But such conservation and moral attitudes are assumed to be more prominent among non-educated farmers than educated ones (Mzoughi, 2011), suggesting that the latter should have lower incentives in applying organic fertilizer than the former. The negative sign of inorganic fertilizer application may also be related to conservation attitudes. Modernity effect could lead educated farmers' towards inorganic fertilizer adoption while conservation attitude and traditional values should lead non-educated farmers keeping on organic fertilizer use. However, in conditions where farmers are well educated with appropriate technical information (e.g. developed countries), both modernity and conservation effects should disappear in favor to rational and evidence-

based decisions. Indeed, organic and chemical fertilizers can be jointly adopted as complements (positive correlation) or as substitutes (negative correlation) within the farm. If farmers are aware about synergies of both technologies in enhancing soil health, one should expect a positive relationship between both technologies, and high education level should normally contribute to reinforce that positive relationship because of the assumed link between schooling and cognitive capacity. Several studies reported higher education level to be positively associated with adoption of conservation agriculture practices (Marenya and Barrett, 2007; Burton et al., 1999; Mzoughi, 2011). But when that awareness and technical knowledge are lacking (e.g., SSA), farmers may consider effect of both organic and inorganic fertilizers as similar, hence take the two technologies as substitutes. This misunderstanding should lower their incentive to use organic fertilizer while applying inorganic one. Teklewold et al. (2013) found substitutability between organic and inorganic fertilizers in Ethiopia along with a positive effect of education on inorganic fertilizer use and a reverse effect on manure application. Some recent studies strongly support these contrasting effects that education may have, depending on the contexts, on adoption of organic farming practices. Knowler and Bradshaw (2007), for instance, reported that studies from North America tend to show a more positive significant effect of education on adoption of conservation agriculture technologies than do studies from Africa and Latin America. Positive or complementary effects are frequently reported between adoption of organic farming practices and formal education or inorganic fertilizer application in developed countries (Mzoughi, 2011; Knowler and Bradshaw, 2007), whereas inverse relationships are often noted in SSA (Kassie et al., 2015; Teklewold et al., 2013; Knowler and Bradshaw, 2007). This suggests that, unlikely in developed countries, African farmers are not aware of the complementary between organic fertilizer and inorganic fertilizer and still consider the two technologies as substitutes. It may be related to traditional and moral factors along with the low level and inappropriateness of education and extension systems in Sub-Saharan Africa.

7. Conclusion and policy implications

Efforts to transfer green revolution achievements in Sub-Saharan Africa during the last decades were essentially focused on seeds and inorganic fertilizers, considering inorganic fertilizer and other modern inputs as the only enabling factors of adopting new agricultural technologies including modern varieties. This approach yielded technology transfer and adoption inopportune and ineffective in the context where farmers have little access to

inorganic fertilizer, even though significant opportunities exist locally to mobilize various types of organic fertilizers. Although significant studies have been conducted on agricultural technology adoption in Sub-Saharan Africa, very little is known about the role of conservation agriculture technologies in enhancing the adoption of green revolution innovations. To shed some light on this important question while contributing to the existing adoption literature, we investigated in this paper the linkage between and determinants of organic fertilizer and MVs adoptions using cross-sectional data from the driest region of Burkina Faso. Using both standard simultaneous and endogenous switching probit models, we came with strong evidences that the two adoption decisions are strongly linked with strong positive effect of organic fertilizer application on MVs adoption. We also found a positive joint determination among with a negative endogeneity between the two technologies, indicating controlling for observable variables both technologies are positively correlated, but unobserved factors that affect one adoption decision are negatively correlated with the other. Moreover, unexpectedly and inconsistently with classic literature, there are some evidences of a negative effect of inorganic fertilizer application on MVs adoption in the Sahel.

The strong positive relationship between organic fertilizer and MVs along with a potential negative effect of inorganic fertilizer on MVs adoption suggests that conservation agriculture technologies can serve as enabling factors for greater adoption of green revolution technologies, especially in less favourable climate areas. In areas where farmers have no access to inorganic fertilizer or are averse about because of higher climate and market risks, organic fertilizer can serve as an effective alternative to replace the role of inorganic fertilizer in the adoption process of modern technologies. This implies that conventional policies to promote green revolution technologies in SSA should change the way they use to be conducted, as they could be more effective if jointly associated with the promotion of conservation agriculture technologies. In other words, policies that support chemical fertilizer and modern seed use must also provide concomitant support for sustainable agronomic practices including organic fertilizer. For instance, in Malawi the subsidized distribution of organic fertilizer concomitantly with improved maize varieties and chemical fertilizer has played a big role in the widespread use of these inputs and in the increase of grain production (Holden and Lunduka, 2012). These evidences highlight and strongly support the argumentation behind the need to breed crop varieties suitable for organic fertilizer (Wolfe et al., 2008; Lamnerts van Bueren et al., 2011).

Significant research efforts are therefore needed to establish further knowledge regarding nutrient composition, complementarities and optimal application rates and schedules of various types of organic fertilizers in order to facilitate their incorporation in extension systems. In Sahelian area where agro-sylvo-pastoralism farming is common, it is important to enhancing the ability of the farmers to capitalize on the interactions between the different components within the farming system to sustain their livelihoods. This should involve promoting ruminant-livestock, but also developing relevant knowledge about various techniques to make organic fertilizer from crop residues, green leaves, animal manure and composts.

However, the magnitude of the effect of organic fertilizer MVs adoption seems to be lowered by some unobserved factors that bring an inverse correlation between the two technologies. Regarding the exogenous nature of MVs whereas organic fertilizer is an endogenous technology, these omitted factors should likely be related to some contrasting perception, risk attitude and moral motivations among the farmers regarding the two technologies, and that can be addressed through an effective extension and education systems. Therefore, understanding these factors that bring opposing correlation between the two technologies is an important area for further research and efforts for greater complementarities between green revolution and conservation agriculture technologies.

We also brought some insights into the other determinants of both technologies. In this regards, we found that the size of fertile land, number of cashcrop grown, remittances and formal schooling have significant and positive effects on MVs adoption, while consumption-oriented farming system and soil fertility problems have opposed effect. Few factors seem to have significant effect on organic fertilizer application. Size of fertile land, incidence of fertility problem and practicing a mixed crop-livestock technique are positively associated with greater probabilities to adopt organic fertilizer, while formal education appears to have negative effect. This result suggests that while formal education can accelerate MVs adoption, it is likely to be a barrier to organic fertilizer use, as educated farmers may consider organic fertilizer as a traditional or old practice. Another explanation could be that educated farmers may have easier access to inorganic fertilizer, and this may reduce their incentives to use organic fertilizer. Including conservation and sustainable farming practices into training curricular along with effective extension systems may therefore contribute to revert this situation. Given good quality of land is still an important factor in farmers' adoption decision

making, further investments in land and soil restoration are highly needed in a Sahel facing increase land degradation that is being speeded by severe climate conditions.

As farmers in Sahelian areas are usually credit-constrained, the study suggests that facilitating farmers' access to alternative opportunities for cash such as remittances from migrating family members and commercialized farming should play an important role in the adoption process of modern agricultural technologies. This requires effective measures to facilitate and secure both sending and receipt of the remitted funds.

In Sahelian countries where subsistence farming is prominent, one could also promote new cashcrops suitable to the local climate conditions. After the disastrous failure of cotton production following the severe droughts of 1980s in the Sahelian area, farmers have been also seeking for alternative cashcrops suitable for the crashed weather conditions of the region. During the recent few years, their interest in sesame and cowpea crops is being growing owing to the suitability of these crops to drier climate conditions as well as the growing local and regional market opportunities. Future policies to enhance Sahelian farmers' livelihoods and resilience to climate should look at promoting these new promising crops to farmers. This could help them mobilize cash, and hence to release somewhat the credit-constraint and enhance their ability to use improved-higher-yielding-technologies.

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Table 1: Descriptive statistics

Variable	Description	All (n=442)		MV adopters (n=145)		Organic fertilizer adopters (n=386)	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Household characteristics							
Sex	Dummy = 1 if household head is male	0.96	0.19	0.97	0.18	0.96	0.20
Age	Age of the household head (years)	47.98	14.00	50.56	13.53	48.61	13.83
Formal education	Dummy =1 if household head attended to formal schooling	0.11	0.31	0.13	0.34	0.10	0.29
Household size	Total size of household	12.07	8.26	12.66	6.90	11.93	7.23
Consumption-oriented farming	Dummy= 1 if production objective is prominently consumption oriented	0.92	0.28	0.79	0.41	0.92	0.27
Farm characteristics							
Farm size	Total size of landholding in hectare	5.83	8.44	8.21	12.15	5.84	8.76
Good land	Size of good land holding in hectare	1.17	2.74	2.28	4.28	1.26	2.89
Degraded land	Size of degraded land holding in hectare	1.47	2.68	2.09	3.85	1.44	2.76
Land per capita	Landholding size per capita	0.47	0.43	0.60	0.59	0.48	0.44
Incidence of soil fertility problem	Dummy = 1 if soil fertility is ranked among the three major agro-ecological constraints facing the farm	0.62	0.49	0.53	0.50	0.62	0.49
Mixed livestock-crop system	Dummy = 1 if household belongs uses at least one mixed livestock-crop practices	0.88	0.32	0.94	0.24	0.91	0.28
Labor							
Active members	Size of active members within the household	5.86	4.45	6.32	4.39	5.79	4.16
Dependency ratio	Number of inactive household’s members (children and old members) per active member	1.66	3.51	1.38	0.91	1.64	3.45
Migrating household’s members	Number of migrating household’s members	0.43	1.19	0.44	0.91	0.39	0.95
Information and technologies access							
Modern varieties (MV)	Dummy=1 if household uses a modern seed	0.33	0.47	1.00	0.00	0.35	0.48
Inorganic fertilizer	Dummy=1 if household applies inorganic fertilizer	0.20	0.40	0.20	0.40	0.18	0.38
Organic fertilizer	Dummy=1 if household applies organic fertilizer	0.87	0.33	0.94	0.24	1.00	0.00
Extension	Dummy =1 if at least household have contact with to public extension services	0.48	0.50	0.58	0.50	0.50	0.50

Training on adaptation and soil/water management	Dummy =1 if a household's member attended training on climate change adaptation or soil/water management	0.52	0.50	0.67	0.47	0.53	0.50
Credit and cash							
Credit	Dummy =1 if at least a household's member access to credit	0.16	0.37	0.21	0.41	0.16	0.37
Number of cash crops	Number of cash crops grown	1.05	0.99	1.40	1.06	1.05	1.00
Remittance	Dummy=1 if household benefits from remittance	0.22	0.42	0.37	0.49	0.23	0.42
Number off-farm activities	Number of off-farm activities of household	1.93	0.80	2.03	0.77	1.93	0.82
Livestock asset holding							
Oxen holding	Number of cattle herds per hectare	0.19	0.34	0.19	0.37	0.20	0.36
Small ruminant holding	Number of small ruminants (goat and sheep) per hectare	0.49	0.71	0.43	0.55	0.52	0.74
Southern Sahel	Dummy = 1 if household belongs to the agro-ecological zone of Southern Sahel						
Environment and cultural factors							
Agro-ecological zones	Dummy =1 if household belongs to the agro-ecological zone of:						
	Northern Sahel	0.34	0.47	0.36	0.48	0.32	0.47
	Sahel	0.35	0.48	0.46	0.50	0.38	0.49
	Southern Sahel						
Ethnicity	Dummy = 1 if household belongs to the ethnic group of:						
	Mossi						
	Foulse	0.18	0.38	0.23	0.42	0.15	0.36
	Bella	0.11	0.31	0.08	0.28	0.12	0.32
	Rimaibe	0.21	0.41	0.23	0.43	0.23	0.42
	Gourmantche	0.10	0.31	0.03	0.18	0.09	0.29
	Fulani and other minor ethnic groups	0.26	0.44	0.30	0.46	0.28	0.45



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Table 2: Likelihood ratio test of rho coefficients

	Coef.	Chi2 (1)	Prob> chi2
Rho1	0.389** (0.146)	6.440	0.011
Rho2	-0.903** (0.147)	4.071	0.044
Rho3	-0.654* (0.054)	2.87	0.090

Table 3: Model estimates of MV and organic fertilizer equations

	Model 1		Model 2		Model 3	
	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Household characteristics						
Sex	-0.174 (0.395)	-0.568 (0.629)	0.110 (0.394)	-0.750 (0.648)	0.011 (0.393)	-0.818 (0.658)
Age	0.009 (0.006)	0.002 (0.008)	0.007 (0.006)	0.006 (0.008)	0.008 (0.006)	0.004 (0.008)
Formal education	0.401 (0.274)	-0.548* (0.291)	0.458* (0.253)	-0.385 (0.285)	0.484* (0.266)	-0.411 (0.285)
Dependency ratio	-0.045 (0.062)	-0.010 (0.025)	-0.027 (0.057)	-0.001 (0.037)	-0.035 (0.060)	0.001 (0.038)
Consumption-oriented farming	-0.799** (0.315)	0.262 (0.391)	-0.728** (0.305)	-0.038 (0.390)	-0.796*** (0.309)	0.046 (0.388)
Farm characteristics						
Farm size	-0.020 (0.024)	0.016 (0.042)	-0.013 (0.023)	0.003 (0.040)	-0.016 (0.023)	0.004 (0.041)
Good land	0.225*** (0.061)	0.221** (0.103)	0.148*** (0.056)	0.205** (0.088)	0.170*** (0.058)	0.204 (0.092)
Degraded land	0.033 (0.053)	-0.062 (0.068)	0.022 (0.049)	-0.044 (0.064)	0.027 (0.052)	-0.044 (0.066)
Land per capita	0.157 (0.403)	0.433 (0.556)	0.029 (0.379)	0.609 (0.516)	0.082 (0.393)	0.636 (0.536)
Incidence of soil fertility problem	-0.328** (0.159)	0.481** (0.205)	-0.433*** (0.148)	0.344* (0.196)	-0.426*** (0.156)	0.374* (0.198)
Mixed livestock-crop system	0.449 (0.281)	1.010*** (0.268)		0.819*** (0.267)		0.906*** (0.261)
Labor						
Household size	-0.014 (0.023)	-0.001 (0.022)	-0.018 (0.021)	0.004 (0.021)	-0.015 (0.022)	0.003 (0.022)
Active members	0.003 (0.039)	-0.004 (0.039)	0.011 (0.036)	-0.011 (0.024)	0.007 (0.038)	-0.011 (0.024)
Migrating household's members	-0.045 (0.072)	-0.074 (0.069)	-0.013 (0.070)	-0.075 (0.065)	-0.014 (0.072)	-0.071 (0.065)
Fertilizer use						
Inorganic fertilizer	-0.405* (0.243)	-0.402 (0.258)	-0.244 (0.221)	-0.159 (0.240)	-0.302 (0.232)	-0.173 (0.243)
Organic fertilizer			2.086*** (0.278)		1.740*** (0.266)	
Technical information access						
Extension	0.122 (0.165)	0.154 (0.219)	0.038 (0.155)	0.149 (0.203)	0.066 (0.160)	0.138 (0.208)
Training on adaptation and soil/water management	0.245 (0.166)	-0.063 (0.221)	0.243 (0.155)	-0.045 (0.201)	0.254 (0.162)	-0.041 (0.208)
Credit and cash						
Credit	0.002 (0.226)	0.293 (0.295)	-0.094 (0.212)	0.025 (0.282)	-0.055 (0.219)	0.132 (0.279)
Number of cash crops	0.373***	-0.111	0.345***	-0.115	0.376***	-0.116

	(0.100)	(0.118)	(0.094)	(0.108)	(0.096)	(0.110)
Remittance	0.674***	-0.481*	0.659***	-0.188	0.710***	-0.189
	(0.193)	(0.289)	(0.187)	(0.231)	(0.189)	(0.244)
Number off-farm activities	-0.050	-0.072	-0.047	0.013	-0.043	0.003
	(0.107)	(0.142)	(0.099)	(0.144)	(0.104)	(0.142)
Livestock asset holding						
Oxen holding	0.173	0.762	0.000	0.619	0.065	0.736
	(0.265)	(0.569)	(0.254)	(0.557)	(0.256)	(0.573)
Small ruminant holding	-0.023	0.132	-0.077	0.105	-0.048	0.112
	(0.144)	(0.202)	(0.136)	(0.187)	(0.135)	(0.193)
Environment and cultural factors						
Agro-ecological zones						
Northern Sahel	0.431	0.754**	0.410		0.366	
	(0.306)	(0.388)	(0.277)		(0.289)	
Sahel	0.254	1.062***	0.168		0.163	
	(0.234)	(0.357)	(0.202)		(0.222)	
Southern Sahel (reference)						
Ethnicity						
	0.817**	-0.569	0.875***	-0.601*	0.954***	-0.588*
Foulse	(0.345)	(0.385)	(0.323)	(0.342)	(0.331)	(0.346)
	0.496	-0.079	0.230	0.136	0.365	0.147
Bella	(0.368)	(0.449)	(0.356)	(0.415)	(0.352)	(0.424)
	0.602**	0.642*	0.293	0.261	0.397	0.328
Rimaibe	(0.287)	(0.342)	(0.272)	(0.325)	(0.275)	(0.327)
	-0.292	-0.094	-0.029	-0.554	-0.151	-0.584*
Gourmantche	(0.379)	(0.389)	(0.349)	(0.356)	(0.357)	(0.356)
Fulani and other minor	0.624	0.676*	0.303	0.419	0.431	0.490
ethnic groups	(0.290)	(0.391)	(0.283)	(0.371)	(0.279)	(0.374)
Mossi (reference)						
Constance	-1.628**	-0.375	-2.795***	0.525	-2.607***	0.446
	(0.757)	(0.944)	(0.723)	(0.830)	(0.756)	(0.867)
Number of obs		440		440		442
Wald chi2(58)		167.810		193.070		179.230
Prob> chi2		0.000		0.000		0.000
Log likelihood		-319.012		-324.962		-325.562

Standard errors in parenthesis.

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.