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Understanding the process of agricultural technology adoption: mineral fertilizer in eastern DR Congo

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Abstract

While there is a large literature on agricultural technology adoption, evidence from the poorest countries is still lacking and the decision-making process of farmers is still poorly understood. We empirically analyze mineral fertilizer adoption among poor and food insecure smallholder farmers in South-Kivu, eastern DR Congo, after its introduction by a research and extension program. We disentangle the adoption process in an awareness step, a tryout decision, and a continued adoption decision. We show that variables commonly used to explain agricultural technology adoption, and the different program interventions, have a different impact on the different steps in the adoption process.

Key words: mineral fertilizer; Sub-Saharan Africa; eastern DR Congo; technology adoption; soil fertility

JEL classification: O33, O13, Q12, Q16, Q24

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1. Introduction

For decades researchers have tried to explain agricultural technology adoption (Lee, 2005; Feder, Just, & Zilberman, 1985; Doss, 2006). A major part of this literature consists of empirical studies focusing on technology adoption by smallholder farmers in developing countries. Different factors, ranging from biophysical plot characteristics to socio-economic farm-household characteristics and institutional factors have been investigated for their impact on technology adoption.

Yet, specific questions remain. First, little is known about agricultural technology adoption in the poorest countries and regions. The adoption of Green Revolution (GR) technologies, such as improved seeds and mineral fertilizer, has most intensively been studied in middle-income countries (Feder & Umali, 1993). Studies on agricultural technology adoption in Sub-Saharan Africa (SSA) are scarce and concentrated in countries home to major agricultural research centers. As good as no evidence is available on the adoption of improved agricultural technologies in extremely poor countries like Congo D.R., Burundi, Liberia, Somalia and Central African Republic. Yet, it is in poor countries in SSA where yields are lagging behind and where the largest gains, in terms of productivity and output growth, are expected from agricultural intensification and improved technologies (Pingali, 2012; The World Bank, 2007).

Second, the decision-making process of farmers with respect to the adoption of new technologies is still poorly understood (Doss, 2006). Most previous studies focus on a one-time dichotomous adoption decision or on the intensity of technology adoption (Feder et al., 1985; Doss, 2006). Only very few studies disentangle the adoption process of farmers in different intermediate steps. For example, Diagne and Demont (2007) and Asuming-

Brempong et al. (2011) disentangle between exposure and adoption to more accurately estimate technology adoption rates and investigate the factors determining adoption. Kabunga, Dubois, and Qaim (2012) further distinguish between awareness exposure (having heard about a technology) and knowledge exposure (understanding the attributes of a technology) to estimate adoption. Some studies have distinguished between tryout and continued adoption (or disadoption) and analyzed the determinants of these decision steps (Kijima, Otsuka, & Sserunkuuma, 2011; Moser & Barrett, 2006; Neill & Lee, 2001).

In this paper we analyze the adoption of mineral fertilizer among poor and food insecure farmers in South-Kivu, eastern D.R. Congo. Due to civil strife, this area has long been deprived from new research and development initiatives (Pypers et al., 2011) and recent scientific output is extremely scarce. We analyze farmers adoption behavior after the Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA) has introduced mineral fertilizer, among other technologies, in the area. We disentangle the adoption process of farmers by distinguishing three steps: 1/ awareness about the technology, 2/ tryout of the technology, and 3/ continued adoption. With this approach we combine elements of previous studies that have distinguished either between awareness and adoption, or between tryout and continued adoption.

The focus on mineral fertilizer adoption is very relevant for our research area, and for SSA in general. It is well-recognized that fertilizer use is essential for sustaining soil fertility in the long run and for ensuring an adequate food supply for growing populations (Dawson & Hilton, 2011; Crawford, Jayne, & Kelly, 2006). It is generally believed that interventions that increase fertilizer use among poor farmers can improve food security and empower them to escape from poverty (Liverpool & Winter-Nelson, 2010). However, current mineral fertilizer use is especially low in Africa. The entire African continent is using only 2–3% of total world mineral fertilizer consumption and SSA applies less than 1% (Kelly, 2006). Before its introduction by the project, the farmers in our research area were nearly completely unaware of mineral fertilizer (Ouma et al., 2011). In such a context of low awareness it is especially important to unravel the adoption decision process of farmers in order to more correctly estimate effects of program interventions and adoption potentials.

2. Research background

a. The case-study

Our research area comprises two territories, Walungu and Kabare, in the highlands of South Kivu, in Eastern D.R. Congo (Figure 1). This is an extremely poor region in an extremely poor country – currently at the very bottom in the human development index ranking (United Nations Development Programme, 2013) and in the GDP per capita ranking (The World Bank, 2013b). An estimated 71% of the population in the country, and 85% in South Kivu, live below the national poverty line (The World Bank, 2013a; Ansoms & Marivoet, 2010).

Agriculture is the main income-generating activity for the rural population in South Kivu. Farmers usually have mixed cropping systems with cassava, common beans, banana, sweet potatoes, maize and sorghum as main food crops (Ouma et al., 2011). Population density is high – more than 250 inhabitants per km² in Kabare and Walungu territories (Unité de Pilotage du Processus DRSP, 2005) – resulting in high land pressure. Agricultural intensification and investment in land productivity are urgently needed in the region (Pypers et al., 2011). For more than a decade, persisting conflict and violence in the region has inhibited research and development initiatives other than emergency relief (Rossi, Hoerz, Thouvenot, Pastore, & Michael, 2006). Most farmers have no access to information about improved agricultural technologies and to agricultural inputs such as mineral fertilizer and improved seeds (Pypers et al., 2011). Private agro-dealers sell fertilizers and other agro-inputs in the provincial capital Bukavu but not in rural areas (Pypers et al., 2011). Mineral fertilizers were virtually unknown in the research area before the start of the CIALCA agricultural technology and extension program (Ouma et al., 2011).

In 2006 the CIALCA-consortium started a program on integrated soil fertility management (ISFM) in South Kivu[1]. ISFM is a composite technology aiming at improving soil fertility and crop productivity (Vanlauwe et al., 2010). Mineral fertilizer is a main component of ISFM, next to improved germplasm and improved organic matter management (e.g. through crop rotation) (Vanlauwe et al., 2010). The program started to work in selected program villages along four action sites. In the selection of program villages attention was paid to include villages that were not targeted by other development programs, and nearby as well as remote villages. Within the villages, farmers' associations were selected based on their willingness to collaborate with the program in trying out new agricultural technologies (Ouma et al., 2011).

Within the program villages and associations, a wide range of extension activities are carried out to distribute information on ISFM practices in general and on mineral fertilizer in particular. First, in collaboration with rural radio stations, radio programs giving varied information on ISFM techniques were broadcasted in the local language in the entire program intervention area. As most farmers in South Kivu have access to radios, either in their homes or in the village, a large group of farmers can be reached with the radio programs.

Second, in program villages, small input kiosks were established to sell mineral fertilizer and improved seeds and planting material to farmers. The program also established links between agro-dealers and program associations to provide the village kiosks but the supply of inputs is not always guaranteed. Buying inputs from the kiosks is not limited to members of program associations and open for everybody. In addition, the program set up a system for seed multiplication of improved varieties in program villages.

Third, ISFM technologies and mineral fertilizer use were discussed during program association meetings and with agronomists from the program who regularly visit the program villages. Farmers who are member of program associations can attend these meetings and get in direct contact with program agronomists.

Fourth, different ISFM demonstration trials were installed. These were designed by program researchers and agronomists, installed in the fields of the program associations (or in the fields of individual association members in case associations have no common fields), and jointly managed by association members and program agronomists. Demonstration trials were installed in all program villages where program associations could place a field at disposal for the trial. Association members could decide how intensively they participate in the trial. Through these demonstration trials, technical knowledge about the new technologies is distributed to participating farmers. But also farmers who are not directly targeted by the program might learn from the presence of these demonstration trials in their village.

Fifth, a second type of trials, on-farm trials, were installed in the fields of individual program association members. These trials were designed by program researchers and agronomists, but were installed and managed by the farmers themselves. Training and assistance in trial installation and management was provided by local agents and facilitators, who were trained by the program (Paul, 2011). Farmers participating in an on-farm trial received a complementary input package (seeds and/or mineral fertilizer), a technical brochure, and a farm booklet for monitoring of the field trial, provided that the program could collect information, and soil and plant samples from the trial plots. The selection of on-farm trial farmers was a joint decision of the steering committee of the association, the program agronomist, and the applying farmers.

b. Data collection

We use data from a quantitative household survey, a village survey and complementary focus group discussions and stakeholder interviews. Household survey data were collected in the period February - June 2011 in the northern Walungu territory and the southern Kabare territory in South Kivu. A two-stage stratified random sampling strategy was used. We purposively selected the groupings[2] (*groupements*) of Burhale and Lurhala in Walungu territory, and Kabamba and Luhihi in Kabare territory because these groupings were most intensively involved in the CIALCA program. In the first sampling stage, we constructed a list of villages for each grouping and did a stratified random selection of program villages (villages which are home to a program association), neighboring villages (villages neighbouring program villages), and other villages. In each territory, six program villages, five or six neighboring villages and three or four other villages were selected (table 1).

[Table 1]

In the second sampling stage, we constructed a list of households for each selected village with the help of the village head and program agronomists, and did a stratified random selection of program households (a household in which at least one adult is member of one of the program associations) and non-program households. Farmers' associations sometimes cross village borders and hence our sample includes several program households in neighbouring villages. To ensure a sufficiently high number of households adopting new technologies, program households were oversampled. To correct for this oversampling, we use sampling weights, calculated as the inverse of the probability of the household to be in the sample. The total sample includes 420 farm-households but only 412 observations are used for the analysis in this paper due to missing information.

A structured quantitative questionnaire was used with different modules on different topics, including agronomic and socio-economic issues. Recall data were collected for key variables such as land and asset ownership for the year 2006, the year the program initiated. Respondents were asked about the history of association membership and mineral fertilizer application. Complementary to the household survey, we conducted a village survey to collect data on village demographics, infrastructure and institutions. In addition, a comprehensive qualitative study was undertaken in July- August 2010 through in-depth semi-structured interviews with program staff and program association members, and focus-group discussions in program villages.

3. The adoption process

a. Conceptual discussion

Information plays a key role in the process of adopting a new technology such as mineral fertilizer. The final decision of sustained adoption is preceded and accompanied by a learning period (Saha, Love, & Schwart 1994; Marra, Pannell, & Abadi Ghadim, 2002). A first prerequisite for a farmer to apply a new technology is to be aware about the existence of the technology. The awareness about a technology likely varies with the type of technology, the specific context, and the characteristics of farmers. More recently introduced technologies might be less well known than technologies that have been spreading for a longer period of time. The awareness about a specific technology might be virtually complete in certain areas – like mineral fertilizer in Asian agro-industrialized countries – but very low or virtually zero in other areas – like in South Kivu. The supply and diffusion of information about a technology – and hence the type and intensity of information campaigns and extension activities – are crucial for increasing awareness rates, but also the demand for information matters. Certain farmers might be more eager to learn than others and more actively engage in the search for information about farming. The cost of searching for information might be lower for better educated and more experienced farmers, and farmers with a larger network and more social capital.

It is especially for technologies and in contexts where awareness is limited and varies across the population, that awareness is an important first step in the analysis of technology adoption. Disregarding this step, may result in non-exposure bias in estimates of adoption rates, program impact and determinants of adoption (Diagne & Demont, 2007). Especially when farmers with a higher likelihood of adopting a new technology are more intensively targeted by extension programs or do more actively search for information themselves, adoption rates and effects may be overestimated and lead to misguided conclusions. In studies on the adoption of new rice varieties in Cote d'Ivoire and Ghana, Diagne and Demont (2007), and Asuming-Brempong et al. (2011) show that adoption rates would increase strongly if awareness would be complete and that estimated effects of adoption determinants differ strongly whether or not non-exposure bias is corrected for. In a study on banana tissue culture, which has been introduced already 10 years in Uganda, Kabunga et al. (2012) do not find significant differences between current and potential adoption rates and between determinants of awareness and adaption. In our case-study area, where mineral fertilizer was introduced only recently, we expect the awareness step to matter in the adoption decision process.

Once farmers are aware about the existence of a new technology, they will consider using it or not. The decision to tryout a new technology might differ from subsequent decisions to continue to apply the technology. Some studies have explicitly disentangled tryout and continued adoption and find that adoption determinants affect the first adoption decision differently than subsequent decisions to continue with or abandon the technology (Kijima et al., 2011; Moser & Barrett, 2006; Neill & Lee, 2001). Tryout of a new technology requires farmers to be able to use the technology and to positively judge the returns in terms of expected utility. Information again plays a very important role. Farmers will only be able to apply the technology if they have more in-depth and practical knowledge about the technical specifications and the application modalities, which goes beyond mere awareness of the technology. To judge expected returns, farmers need information on technology attributes, such as yield effects, and labour and capital intensity, and on market prices and input costs. Besides access to information, farmers might be additionally constrained in their ability to apply a new technology due to cash constraints, land and labour constraints or access to input markets. For adoption of mineral fertilizer, cash and labour constraints and access to input markets might be important as it concerns an input- and labour-intensive technology. Land constraints are likely less important. Uncertainty and risk related to technology attributes and market prices may lower farmers' expected utility, especially for risk averse farmers. As risk aversion is correlated with income and wealth, poorer farmers might be less likely to try a new technology (Marra et al., 2002).

After tryout, subsequent decisions to continue to use the technology will strongly depend on the farmers' own experience with the technology. Before farmers apply a new technology for the first time, they mostly learn from others (e.g. extension agents, neighboring farmers) while the tryout stage involves learning-by-doing. Through own experience with applying the technology and by observing the outcomes on their own fields, farmers' perception about technology attributes and returns may change. An important element in the decision about continued use of a technology is whether farmers' expectations were met or not. Even if realized returns are positive, if they are far below expected returns, farmers might be disappointed and abandon the technology. Also if labor and input requirements are higher than expected, farmers may stop using the technology. For example, Kijima et al. (2011)

conclude that high dropout rates in the adoption of new rice varieties in Uganda can be explained by unrealistic expectations about returns and high labor intensity of the technology. The better informed farmers are, the better they can assess technology attributes and the more realistic their expectations about returns might be. Therefore, access to information during the learning period may importantly determine the decision to adopt a technology after tryout.

Returns to a technology may also depend on biophysical and agro-ecological conditions – e.g. soils may vary in their responsiveness to mineral fertilizer – and favorable conditions are expected to positively affect adoption. If farmers are well informed about technology attributes under different conditions, biophysical and agro-ecological conditions may matter more in the tryout decision than in the continued adoption decision. Through applying the technology themselves, farmers may increase their skills for more successful application and risk and uncertainty may be partially reduced, which increases expected returns and the likelihood to continue with the technology. Yet, cash constraints, labor constraints and market access constraints continue to play a role in the adoption decisions after tryout.

In line with this discussion, we expect the program interventions in our research area to be important in the different steps of the adoption process of farmers. The intensity and type of information that is disseminated varies over different program activities, resulting in different degrees of exposure to new technologies and learning. While radio programs likely reach a large group of farmers, the type and intensity of disseminated information is rather limited. Such an intervention might have the largest impact on awareness about mineral fertilizer. Discussions in association meetings and direct interactions with agronomists allow to distribute more in-depth and more technical information about new technologies, which likely increase awareness and farmers' ability to try the technology. Only farmers from program associations can directly benefit from these interventions but information might spread from program to non-program associations and in the networks of program farmers. Input kiosks remove farmers' constraints in accessing inputs in program villages and likely reduce transactions costs for buying inputs for farmers in neighboring, and even in more distant, villages as well. Demonstration trials further improve farmers' ability to apply the technology themselves, reduce uncertainty about technology attributes and likely have a large impact on farmers' perception about expected returns. Depending on farmers' own level of participation in the demonstration trial, this intervention entails an element of learning-by-doing – in contrast to radio programs, meetings and discussions, which are purely learning-from-others. On-farm trials with free input packages and extension assistance, lift most existing constraints for application of the technology, and directly lead to tryout and learning-by-doing. While only program association members are directly involved in field trials, certain technology attributes – most importantly yield potential – can be observed in the field by other farmers as well.

b. Awareness, tryout and adoption

We use the terms awareness, tryout and adoption to indicate the different stages in the decision-making process. We categorize households according to whether the farmer and/or his wife have heard about mineral fertilizer or not (aware and non-aware households); whether they have used mineral fertilizer at least once on their own fields since the start of the program, or not (tryout and non-tryout households); and whether they continued using mineral fertilizer to the time of the survey and at least for two seasons, or not (adopter and non-adopter households). We need to note that farmers who participated in on-farm trials are logically all classified as tryout farmers and that the adoption of households who started using fertilizer the last season is unobserved.

The total awareness, tryout and adoption rates of mineral fertilizer in the research area are respectively 57%, 8% and 4% (table 2). There is a relatively large discrepancy between conditional and unconditional tryout and adoption rates due to incomplete awareness and tryout (table 2). Conditional on awareness, tryout increases to 13% and adoption to 7%. Conditional on tryout, the adoption rate is 70%. We find much higher awareness, tryout and adoption rates in program and neighboring villages than in distant villages. Despite a considerable rate of awareness (48%), tryout and adoption rates are virtually zero in distant villages. We observe slightly lower awareness rates but slightly higher tryout and adoption rates in neighbouring villages than in program villages. These differences across villages are likely related to the dissemination of information about mineral fertilizer and the access to inputs in the villages. In distant villages, there is limited access to information and inputs as there are no program associations, no program farmers, no input kiosks and no field trials (table 2). As these villages are not bordering any program villages, technical information beyond the information provided in radio programs, less easily spreads to these villages. The relatively high tryout and adoption rates in neighboring villages are likely explained by easier communication and exchange between program and neighboring villages and by the quite high share of households who are member of program associations in neighboring villages (10% compared to 17% in program villages). Yet, the intensity of interventions is much lower in neighboring villages.

[Table 2]

Figure 2 shows that the application of mineral fertilizer was practically absent until 2006 and gradually increased after the start of the program in 2006. Interestingly, neighbouring villages had a higher adoption rate (2.8%) before the start of the program. The graph shows a fast increase in fertilizer use in program villages immediately after the start of the program and a delayed and smoother increase in fertilizer use in neighboring villages. By 2010 mineral fertilizer use is again higher in neighboring than in program villages. In villages more distant from program villages, mineral fertilizer application is practically absent.

[Figure 2]

In table 3 we compare households who are member of program associations (program households) with households who are member of other agricultural associations that are not directly linked to the program, and with households who are not a member of any agricultural association. The figures show that awareness, tryout and adoption rates are highest among program households. Yet, also among non-program households who are member of an agricultural association (a non-program association) and even among households who are not member of any agricultural association, awareness is quite high (80% and 47%). An important difference between these two groups of households is that conditional tryout and adoption are a lot higher among the former households (20% compared to 6%, and 78% compared to 9%).

[Table 3]

c. Aware, tryout and adopter households

In table 4 we compare the access to information and program interventions of (non-)aware, (non-)tryout and (non-)adopter households. In the survey, we specifically asked aware farmers about the main source from which they obtained information about mineral fertilizer. The majority of aware households obtained information from peer farmers (family, friends and neighbours) (54%) and from radio programs (20%). Only a minor share of the aware households mainly obtained information from agricultural associations, either program or non-program associations (respectively 6% and 7%). Yet, for tryout and adopter households, program associations are an important source of information (36% and 38%) while radio programs are not important at all. It is remarkable that for non-adopters, information from peer farmers if the most important sources of information while this is not an important source of information for adopter farmers. This might entail that there is an important difference in the type of information that is obtained directly from the program and that obtained through social networks, or that social networks work slower in disseminating information.

[Table 4]

Participation in program interventions differs substantially across households. Not surprisingly, participation in program associations, in attending program meetings, in contacts with program agronomists and in field trials is higher for aware households than for non-aware households, and higher for tryout household than for non-tryout households (table 4). In addition, aware households listen to agricultural radio programs more frequently than non-aware households, and tryout households more frequently than non-tryout households. We find no significant difference between adopter and non-adopter households in terms of participation in program interventions.

As can be revealed from table 2, 30% of farmers do not continue applying mineral fertilizer after tryout. We asked these disadopters about the reasons to not continue the use of mineral fertilizer. The main reasons cited include the high cost of mineral fertilizer (40%) and the limited availability (22%). Only one farmer quoted bad yields under fertilizer application as the main reason for disadoption.

In table 5, we compare farm and household characteristics of (non-)aware, (non-)tryout and (non-) adopter households. There is not much difference between households in terms of social capital. Membership in an agricultural association (including program and non-program associations) is significantly higher for aware and tryout households compared to respectively non-aware and non-tryout households. In terms of farm characteristics, we observe that aware and tryout households have significantly more fields and more livestock than non-ware and non-tryout households. In addition, aware households, in comparison with non-aware households, have higher asset holdings, more access to off-farm income, a higher education and are located closer to the market. Tryout households, in comparison with non-tryout households, have more assets, more access to off-farm income and more labour available in the family. There are hardly any significant differences between adopter and non-adopter households; only the access to off-farm income is higher for adopter households. To reveal whether these household characteristics and the access to information through different program interventions are important in determining the different steps in the adoption process, we need a more detailed analysis.

[table 5]

4. Econometric approach

We analyze farmers' adoption process by disentangling three steps, awareness, tryout and continued adoption, as specified in the following equations:

Awareness: $$Y_{iAwa} = 1 \; [\beta'_{Awa} X_{ij} + \gamma'_{Awa} PP_i + \varepsilon_{iAwa} > 0] \quad (1)$$

$$= 0 \text{ , otherwise}$$

Tryout: $$Y_{iTry} = 1 \; [\beta'_{Try} X_{ij} + \gamma'_{Try} PP_i + \varepsilon_{i\,Try} > 0] \quad \text{if } Y_{i\,Awa} = 1 \quad (2)$$

$$= 0 \text{ , otherwise}$$

Adoption: $$Y_{iAdo} = 1 \; [\beta'_{Ado} X_{ij} + \gamma'_{Ado} PP_i + \varepsilon_{iAdo} > 0] \quad \text{if } Y_{i\,Try} = 1 \quad (3)$$

$$= 0 \text{ , otherwise}$$

We use binary outcome variables[3]: Y_{iAwa} for awareness, Y_{iTry} for tryout, and Y_{iAdo} for continued adoption. Our main interest lies in understanding which factors explain the adoption process, and how their effects differ in the different adoption steps. Program participation and different program interventions are important factors explaining awareness, tryout and adoption. These effects are captured by the variable PP_i. In a first set of estimations, we estimate the equations for awareness, tryout and adoption with PP_i being a binary variable for whether the household is member of a program association or not. In a second set of estimations, PP_i is a vector of variables measuring participation in different program interventions, including membership in a program association, attendance at program meetings, contacts with program agronomists, participation in demonstration trials, and participation in on-farm trials. We expect these variables to positively affect awareness, tryout and adoption but effects may vary since the intensity and type of information that is disseminated varies over different program activities.

We include a large set of other explanatory variables X_{ij}. This includes variables that are related to dissemination of information: membership in an agricultural association (that is not necessarily a program association), the frequency of listening to agricultural radio programs, and dummy variables for being in a program village or a neighboring village. These latter two dummy variables cannot be included in the adoption equation because in villages other than program or neighbouring villages, adoption is either zero or missing (if the first tryout only happened during the last seasons observed). The vector X further includes measures of wealth and financial capital (livestock holdings, an index of household assets[4], access to off-farm income), physical land capital (total number of fields, number of sloped fields, and having at least one field with a good soil), human capital (education of the household head, age of the household head and its square, the number of laborers in the household), social capital (membership of a non-agricultural organization, participation in community collective action, number of people one could borrow money from) and location (distance to the market in minutes, territory dummy). These variables are explained and summarized for (non-)aware, (non-)tryout and (non-)adopter households in table 5 and have been discussed in the previous section.

We use different methods to estimate the equations in order to reduce and understand problems of non-exposure bias, selection bias, and endogeneity bias. Incomplete awareness and tryout of mineral fertilizer may cause non-exposure and selection bias in our estimates (Diagne & Demont, 2007; Heckman, 1979; Kabunga et al., 2012) while non-random program placement and participation in program interventions may lead to endogeneity bias. In a first method, we use univariate probit models to estimate the equations on awareness, tryout and adoption using the full sample of observations for each adoption step. With this method, we likely have a problem of non-exposure and selection bias in equation (2) and (3) because tryout is only possible for aware farmers, and adoption only for tryout farmers. Due to non-awareness, or non-tryout, some farmers cannot decide to tryout or adopt mineral fertilizer. If these farmers are coded as non-tryout, and/or non-adopting farmers in our analysis, there is a possible underestimation of the marginal effects of the explaining variables on the one hand, and a confounding effect with factors explaining awareness or tryout on the other hand. Moreover, there is possible bias due to correlation between the error terms.

In a second method we estimate equations (2) and (3) using univariate probit models on a sub-sample that is restricted to the aware households in the tryout equation (2) and to the tryout households in the adoption equation (3). This comes down to treating tryout and adoption as unobserved for respectively non-aware and non-tryout households. Restricting the sample to aware or tryout households is especially useful if we suspect effects to be significantly underestimated when taking into account the full sample (non-exposure bias), and if some observed effects can be confounded with factors affecting the preceding awareness or tryout step.

Univariate probit models on the aware and tryout sub-samples will still result in biased estimates of tryout and adoption determinants respectively. Most commonly in the literature a positive selection bias is found, explained e.g. by a higher motivation and ability, resulting in a higher likelihood of adoption, among aware farmers or by research and extension agents targeting farmers who are more likely to try and adopt a technology (Diagne & Demont, 2007). Yet, selection or non-exposure bias might also be negative if aware households have a lower probability of tryout and adoption.

In a third method, we model the consecutive adoption steps as a selection model in which the outcome is conditional on having achieved the previous step in the adoption process. We use Heckman selection probit (Heckprobit) models to estimate the tryout equation (2) with the awareness equation (1) as selection equation, and the adoption equation (3) with the tryout equation (2) as selection equation. We need to identify selection variables that determine awareness (tryout) in the selection equation on the full sample but not tryout (adoption) in the outcome equation on the aware (tryout) sub-sample (Wooldridge, 2010; Bushway, Johnson, & Slocum, 2007). We use the percentage of households in the village that are aware of mineral fertilizer as a selection variable. Literature has shown that information often spreads through peers, neighbours, and friends (Foster & Rosenzweig, 1995), and that technology diffusion can be spatially correlated (Abdulai & Huffman, 2005). The constructed village awareness rate is significantly and positively correlated with respondent awareness (R^2=0.37, p=0.00). Because respondents' awareness and tryout are highly correlated in the full sample of aware and non-aware households, village awareness is also highly correlated with respondent tryout in the full sample (R^2=0.21, p=0.00) (but not with respondent tryout in the aware subsample). We expect village awareness to affect respondent tryout and adoption only through respondent awareness. When adding village awareness in the outcome equations, it has no significant effect. We expect the heckprobit model to perform best in reducing selection bias, resulting in effects on tryout and adoption that are in between the results of the simple probit models on the full sample and on the restricted samples [5].

Using a fourth method, we deal with the remaining problem of endogeneity bias. Participation in program associations and in program interventions is likely not randomly distributed in the population and might depend on unobserved factors, such as motivation, ability and risk aversion, that we cannot control for. As program associations where purposively selected by the program, so are the member farmers. Additionally, farmers might self-select into a program association, if they join after the start of the program, or might self-select into specific program interventions. This endogeneity might lead to PP_i being correlated with the error term, and result in biased estimates. To reduce endogeneity bias, we use a bivariate probit model[6] to jointly estimate program membership (equation 4) and awareness (equation 1) – and similar for tryout (2) and adoption (3). The determinants of program association membership are estimated as follows:

$$\text{Program membership:} \qquad PP_i = 1 \qquad [\mu'_{PP}\, Z_{i\,PP} + v_{i\,PP} > 0] \qquad (4)$$

The variable Z_{iPP} is an additional identification variable for program membership. This is specified as a dummy variable indicating whether 5 years ago (before the start of the program) the household was member of an agricultural association that was not selected as program association. This variable is considered to be exogenous since it concerns a pre-treatment variable. It is also relevant since it is strongly and negatively correlated with program association membership (R^2= -0.09, p=0.06). Because correcting for selection bias and endogenous explanatory variables at the same time is difficult when outcome variables are binary (Wooldridge, 2002), we perform the bivariate probit analysis with the restricted samples for the tryout and adoption equations (and with the full sample for the awareness equation). Due to a lack of selection variables for different program interventions, we can only estimate the bivariate probit models for program membership as main dependent variable.

5. Results and discussion

In table 6, we present the average marginal effects of the different probit regression models in which membership in a program association is the main explanatory variable. For the awareness equation, we report the results of two different models: a probit model on the full sample, and a bivariate probit model correcting for endogeneity of program membership. For the tryout and adoption equations, we report the results of four different models: a probit model on the full sample, a Heckman selection probit model, a probit model on the restricted sample, and a bivariate probit model correcting for endogeneity of program membership.

[Table 6]

Comparing the estimated effects over the different models, we find that results are quite consistent for awareness and tryout, but not for adoption. For the tryout equation, the magnitude of the effects (in absolute value) are somewhat smaller respectively larger in the probit model on the full and the aware sub-sample, and effects estimated by the Heckman selection model are in between. This is consistent with the selection model giving the best estimates and the univariate probit models resulting in small under- and overestimations. For the adoption equation, we find large differences in the magnitude, and for some covariates also in the significance level and sign, of the effects between the probit model on the full sample and the probit model on the tryout sub-sample. This is due to relatively low tryout rates. Estimated effects of the Heckman selection model are quite similar – in most cases somewhat smaller in magnitude – than the estimated effects of the probit model on the tryout sub-sample. For both tryout and adoption, we find no evidence of sample selection bias from the likelihood ratio test – with p-values of 0.94 and 0.83, we cannot reject the null hypothesis of no correlation between the error terms of the awareness and tryout equations respectively the tryout and adoption equations. This means that the probit models on the restricted sub-samples perform as well as the Heckman selection models.

For all three equations, the bivariate probit models give results that are very similar to those of the respective (sub-sample) probit models, except for the endogenous explanatory variable 'program association membership'. We find evidence for endogeneity of program association membership in the tryout model but not in the other models – the likelihood ratio test gives a negative and significant error correlation (rho) in the case of tryout. This indicates that unobserved factors influence both membership in program associations and tryout of mineral fertilizer, resulting in an underestimation of the effect of program association membership in the univariate probit model. The estimated marginal effect in the bivariate probit model is more than twice as large as the effect in the univariate probit models. Contrary to most other studies, we find negative selection and endogeneity bias. Possible explanations for this relate to program targeting and self-selection of farmers in the program. On the one hand, the program may have targeted farmers who are less motivated/able to use new technologies by specifically selecting associations (and their members) that did not receive assistance of NGO or donor programs before. On the other hand, there might be some adverse selection of farmers who are less motivated/able to apply new technologies but who are attracted to program associations because of expectations towards complementary program services such as the provision of free meals during program meetings, or because they hope to receive direct income support. In an extremely poor and insecure environment, small benefits may attract people and result in adverse selection.

We discuss the estimated effects based on the results from the probit model on the full sample for awareness, from the bivariate probit model for tryout, and from the probit model on the tryout sub-sample for adoption.

(a) Association membership and access to information

We find that membership in a program association has no effect on awareness about mineral fertilizer, a significant positive impact on tryout, and a significant negative effect on adoption. The lack of an effect on awareness should be interpreted with care. We find that living in program villages and being member of an agricultural association (that is not necessarily a program association) significantly increases the likelihood of being aware about mineral fertilizer. This indicates that awareness about mineral fertilizer has spread beyond program associations, through village and association networks. For tryout, the results indicate that membership of a program association increases the likelihood of tryout with 7.5 to 22 percent. This is a large effect, which demonstrates the success of the program in convincing farmers to apply mineral fertilizer. Also being in a program or neighboring village, being member of an agricultural association and listening to agricultural radio programs, increases the likelihood of tryout. This again points to the importance of village and organizational networks for spreading information on technology characteristics and market conditions that can convince farmers to try a new technology.

The significant negative effect of program association membership on continued adoption (conditional on tryout) is in sharp contrast with its positive impact on tryout. The effect is also in contrast with the significant positive effect of association membership on continued adoption. This means that program members are more likely to try mineral fertilizer but less likely to keep applying it after first trial, while members of other agricultural associations are more likely to try and to continue using the technology. As pointed out before, program members might have been adversely selected and be less motivated or able to use new technologies. Convincing such farmers to try mineral fertilizer does not lead to sustained adoption. In addition, program members might have too high expectations about the return and disadopt after first tryout because they are disappointed when they find that the benefit is lower than previously expected. Disentangling different program interventions, as we do in the next paragraphs, can shed more light on these finding.

The discussed results are consistent with previous findings and arguments that associations are important in the adoption process because they reduce the cost of information (Kabunga, Dubois & Qaim, 2012; Fisher & Qaim, 2012) and with the conceptual discussion that program participation affects different steps in the adoption process differently.

(b) Program interventions

In table 7, we report the estimated marginal effects for different program interventions from univariate probit models (on full and restricted samples) and Heckman selection models. These results show that there are differences in how different interventions affect tryout and adoption of mineral fertilizer. We find that higher attendance at program meetings results in a higher likelihood of adoption (conditional on tryout) but does not affect tryout. Contact with program agronomists significantly increases the likelihood of both tryout and continued adoption. This intervention allows to distribute in-depth and technical information about the technology, which increases farmers' ability to try the technology and results in good practices during tryout. This increases the likelihood of a positive return during tryout and of continued adoption.

Participation in demonstration trials on association fields, increases the likelihood of tryout but decreases the likelihood of continued adoption. Demonstration trials include an element of learning-by-doing, which improves farmers' ability to apply the technology themselves, leading to a positive impact on tryout. Demonstration trials also give farmers a better idea about technology attributes and potential returns. This further increases the likelihood of tryout but negatively affects adoption, likely because of unrealistic expectations. On-farm trials with free input packages and extension assistance, directly result in tryout, but also increase the probability of continued adoption after tryout. It seems that on-farm trials are more successful than demonstration trials for achieving sustained adoption of mineral fertilizer in the research area.

The different program interventions have a positive effect on tryout, continued adoption or both. When including these interventions as explanatory variables in the models, the effect of program association membership on tryout becomes insignificant and the effect on adoption remains significantly negative. This indicates that program membership as such is no guarantee for adoption, but participation in specific program interventions is important. Adverse selection of farmers who are less motivated/able to apply new technologies in program associations is an issue of concern as it jeopardizes sustained adoption, and therefore reduce the program outcome.

[Table 7]

(c) Wealth and financial capital

Other factors are found to be significant in explaining one or several adoption steps as well. The estimated marginal effects of other explanatory variables are qualitatively equal and quantitatively very similar whether only program association membership is included as main variable or whether specific program interventions are included as well, but are only reported in the former case (table 6). We find that our indicators for wealth and access to financial capital have no impact on awareness and tryout but positively affect adoption (conditional on tryout). The significant positive effects of the asset index and of access to off-farm income on adoption, indicate that capital and credit constraints matter for the continued adoption of mineral fertilizer. This is not surprising, given the context of widespread poverty, and is consistent with previous studies that indicate household income and access to credit are key determinants of fertilizer adoption in poor countries (Liverpool & Winter-Nelson, 2010; Feder & Umali, 1993; Dercon & Christaensen, 2011). Access to off-farm income has been pointed out to be particularly important for technology adoption as it can help to smooth consumption and alleviate credit problems (Liverpool & Winter-Nelson, 2010), which is consistent with our findings. Despite the fact that livestock is an important current asset for farmers in SSA – associated with wealth, status and access to cash, (Wubeneh & Sanders, 2006) – we do not find a significant effect of livestock ownership on mineral fertilizer adoption. A possible explanation is that livestock provides manure to fertilize fields, and thereby reduces the interest of farmers for chemical fertilizer application.

The fact that wealth and financial capital are not important in explaining awareness is in line with the expectations as credit and cash constraints are likely less important for being exposed to new technologies than for applying them. The lack of significant effects of wealth and financial capital indicators on tryout might be related to the fact that a substantial share of the tryout households receiving inputs for free as part of farm trials (table 4).

(d) Land capital

We find that land ownership has no impact on awareness, tryout and adoption. Some previous studies found that adoption of agricultural technologies is more likely for farmers with larger landholdings (Wakeyo & Gardebroek, 2013). Our results indicate that land constraints are not important for the adoption of a capital-intensive technology that increases the returns to land, like mineral fertilizer. Yet, the quality of the land is found to matter somehow. We find that sloped fields decrease the likelihood of farmers trying out mineral fertilizer but we find no effect on continued adoption. Also, the soil quality indicator does not affect any of the adoption steps. This is against the expectations because several studies (Marenya & Barrett, 2009; Duflo, Kremer, & Robinson, 2009; Vanlauwe et al., 2010; Dercon & Christiaensen, 2011) point out that the profitability of mineral fertilizer is highly dependent on the local biophysical conditions. Specifically for the research area, it has been demonstrated that mineral fertilizer is only profitable on moderate to good soils and that profits diminish on sloped fields (Pypers et al., 2011). One would therefore expect to find an effect of these indicators, especially in the adoption step, but we are unable to show these effects with the very rough soil and land quality indicators from our survey data.

(e) Human and social capital

We find that more educated farmers and farmers who participate more often in collective action, are more likely to be aware of mineral fertilizer. This is in line with the expectations and likely explained by a lower cost of searching for information for better educated farmers and farmers with more social capital. While more educated farmers are also expected to be better informed about technology characteristics and to more accurately assess expected returns to a new technology (Huffman, 2001), we do not find an effect of education on tryout (conditional on awareness) and adoption of mineral fertilizer. This might be related to the general very low level of education in the research area (on average only 2.3 years) and a higher opportunity cost of labor for more educated people.

The availability of family labor positively influences the probability of tryout but has no effect on continued adoption. Farmers' age has no effect on awareness, a negative (and increasing) effect on tryout, and a positive effect on continued adoption. Younger farmers, while having less experience, are often observed to be less risk averse (Wakeyo & Gardebroek, 2013), and therefore more easily try a new technology. Yet, older and more experienced farmers are probably more efficient and can judge expected returns more accurately, which leads to higher adoption rates after first tryout.

Social capital indicators do not only affect awareness, but also tryout and adoption. Farmers who engage more frequently in collective action are more likely to tryout mineral fertilizer while farmers who engage in non-agricultural association and farmers with a larger network of people they could borrow from, are more likely to continue to use mineral fertilizer once tried out. The impact of these variables documents the importance of social capital to diffuse new technologies and facilitate technology adoption.

(f) Location

Finally, we find that living in villages further away from the market reduces the likelihood of tryout. These farmers have higher transaction costs for both buying inputs as well as selling outputs, which reduces the return of mineral fertilizer application. They might also lack market information to make a judgment about the expected return of the technology.

6. Conclusion

In this paper we analyzed farmers' technology adoption process after the introduction of mineral fertilizer in South-Kivu, eastern D.R. Congo –an area that has long been deprived of research and extension programs. We specifically disentangled the adoption process into an awareness step, a tryout decision and a continued adoption decision. We argue that in an area where exposure to new technologies is low and diffusion incomplete, looking beyond a single adoption decision is important to understand farmers' adoption process and improve the chances for sustained adoption of improved technologies. We find that different constraints exists in different adoption steps and that extension interventions have diverging effects each steps.

Labor and land constraints are found to be of little importance in the adoption process while social capital is an important factor in all the adoption steps. Capital and credit constraints are specifically important in the decision to continue adoption after first tryout. Younger and less experienced farmers are more likely to tryout a new technology while older and more experienced farmers are more likely to continue using mineral fertilizer after tryout. Specific efforts might be needed to convince older farmers to change their farming practices while technical assistance during tryout might be more beneficial for younger and less experienced farmers. Different extension interventions affect the adoption process differently. Personal contacts with agronomists work better than program meetings to increase tryout and adoption of mineral fertilizer. In addition, on-farm trials are more successful for sustained adoption than demonstration trials. The latter perform well to convince farmers about tryout but do not lead to sustained adoption.

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8. Figures

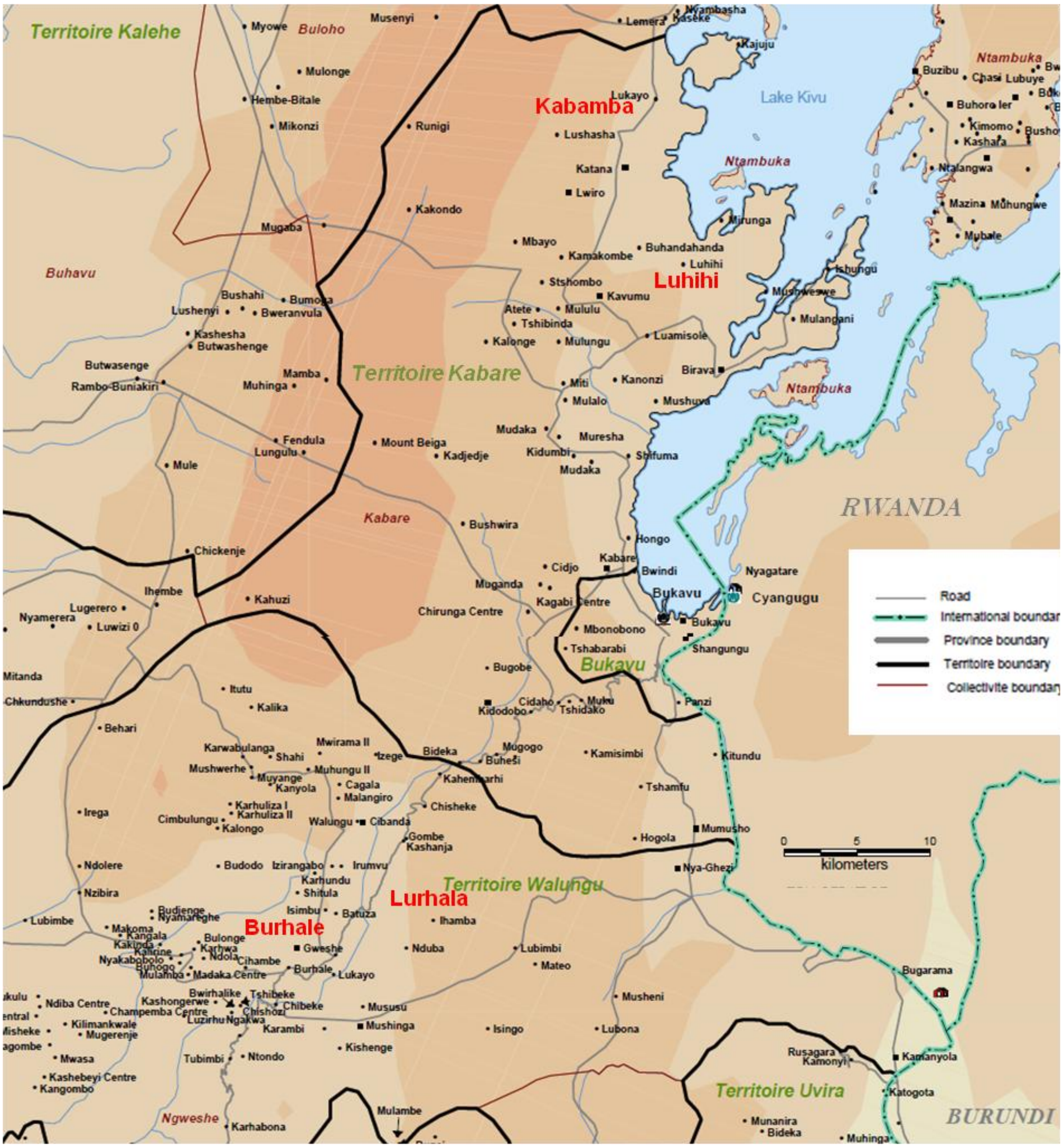

Fig. 1: Map of research area (Source: UNHCR, Global Insight digital mapping 1998)

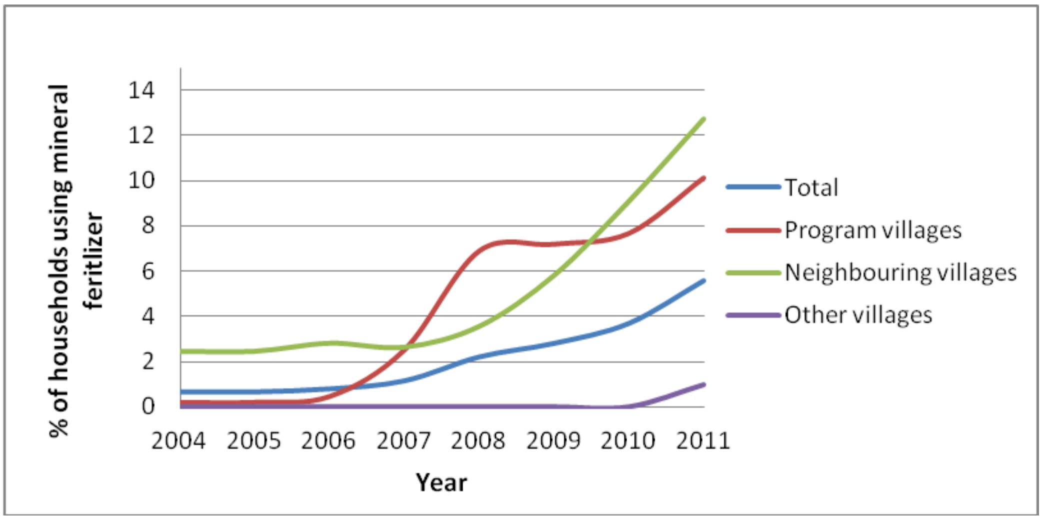

Fig. 2: Percentage of households applying mineral fertilizer, 2004 -2011 (Source: authors' estimation based on household survey data)

9. Tables

Table 1: Overview of selected territories, groupings and villages in the sample

	Program village		**Neighbouring village**		**Other village**	
	Total	Selected	Total	Selected	Total	Selected
Groupings in Kabare territory						
Luhihi	6	1	4	2	7	1
Kabamba	29	5	26	4	43	2
Groupings in Walungu territory						
Burhale	10	3	8	3	32	3
Lurhala	8	3	17	3	40	1

Table 2: Awareness, tryout, and adoption rates, and associations across villages (Source: authors' estimation based on household survey data)

	Total		Program villages		Neighbouring program villages		Other villages	
	Mean	*(Se)*	Mean	*(Se)*	Mean	*(Se)*	Mean	*(Se)*
Awareness, tryout and adoption rates								
Number of observations	412		200		131		81	
Awareness	0.57	*(0.03)*	0.74	*(0.05)*	0.65	*(0.52)*	0.48	*(0.05)*
Tryout, unconditional	0.08	*(0.03)*	0.15	*(0.04)*	0.18	*(0.04)*	0.01	*(0.01)*
Tryout, conditional on awareness	0.13	*(0.05)*	0.20	*(0.05)*	0.27	*(0.14)*	0.02	*(0.02)*
Adoption, unconditional	0.04	*(0.02)*	0.07	*(0.04)*	0.10	*(0.07)*	0.0	*(.)*
Adoption, conditional on awareness	0.07	*(0.03)*	0.10	*(0.05)*	0.16	*(0.11)*	0.0	*(.)*
Adoption, conditional on tryout	0.70	*(0.08)*	0.62	*(0.14)*	0.75	*(0.10)*	0.0	*(.)*
Program participation rates								
Program association member	0.06	*(0.01)*	0.17	*(0.03)*	0.10	*(0.03)*	0.00	*(.)*
High attendance at program meetings[a]	0.02	*(0.00)*	0.06	*(0.02)*	0.02	*(0.01)*	0.00	*(.)*
Number of contacts with program agronomist	0.25	*(0.08)*	0.93	*(0.32)*	0.30	*(0.08)*	0.00	*(.)*
Demonstration trial	0.03	*(0.01)*	0.11	*(0.03)*	0.02	*(0.01)*	0.00	*(.)*
On-farm trial	0.01	*(0.01)*	0.06	*(0.02)*	0.01	*(0.01)*	0.00	*(.)*
Associations at village level								
Number of observations	30		12		12		6	
Number of agricultural associations	3.17	*(2.10)*	3.75	*(2.34)*	2.91	*(1.76)*	2.57	*(2.23)*
Number of agricultural associations before start of program	1.40	*(1.52)*	1.83	*(1.80)*	1.64	*(1.36)*	0.29	*(0.49)*
Number of program associations	0.87	*(1.04)*	1.75	*(1.06)*	0.45	*(0.52)*	0.00	*(0.00)*

[a] Dummy indicating that the household members are attending more program meetings than the mean number of meetings that are attended by the program households.

Table 3: Awareness, tryout and adoption rates across association membership (Source: authors' estimation based on household survey data)

	Non- agricultural association member	Agricultural association member	
		Non-program member[a]	Program member[b]
Number of observations	206	118	88
Awareness	47.4	79.6 ***	93.4
Tryout, unconditional	2.6	15.5	41.0 *
Tryout, conditional on awareness	5.5	19.5	43.9
Adoption, unconditional	0.0	10.1	24.4
Adoption, conditional on awareness	0.1	12.8	26.3
Adoption, conditional on tryout	8.6	78.2 *	64.8

[a.] Not member of an association compared to households who are member of a non-program association,
[b.] Members of non-program associations compared to program households
Pairwise comparisons significantly different on *** $p < 0.01$; **$p < 0.05$; *$p < 0.10$

Table 4: Access to information and program interventions for aware, tryout and adopter households (Source: authors' estimation based on household survey data)

			Aware		Tryout	
	Non-aware	Aware	Non-tryout	Tryout	Non-adopter	Adopter
	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)
Number of observations	139	272	199	73	24	32
Main source of information on mineral fertilizer						
Program association	n.a.	0.06	0.02	0.36*	0.40	0.38
		(0.02)	*(0.01)*	*(0.18)*	*(0.22)*	*(0.25)*
Other association	n.a.	0.07	0.06	0.13	0.04	0.21
		(0.02)	*(0.02)*	*(0.04)*	*(0.03)*	*(0.13)*
Family, neighbours, friends	n.a.	0.54	0.57	0.27**	0.53	0.02*
		(0.05)	*(0.06)*	*(0.10)*	*(0.26)*	*(0.01)*
Radio	n.a.	0.20	0.22	0.00***	0.00	0.01
		(0.05)	*(0.05)*	*(0.00)*	*(.)*	*(0.01)*
Participation in program interventions						
Program association member	0.01 *(0.00)*	0.09*** *(0.02)*	0.06 *(0.02)*	0.30* *(0.11)*	0.48 *(0.20)*	0.36 *(0.18)*
On-farm trial	0.00 *(.)*	0.02** *(0.01)*	0.00 *(0.00)*	0.18** *(0.08)*	0.16 *(0.09)*	0.28 *(0.14)*
Demonstration trial	0.00 *(0.00)*	0.04*** *(0.01)*	0.01 *(0.00)*	0.25** *(0.09)*	0.34 *(0.15)*	0.31 *(0.15)*
High attendance at program meetings	0.00 *(0.00)*	0.03*** *(0.01)*	0.01 *(0.00)*	0.12* *(0.06)*	0.18 *(0.10)*	0.19 *(0.11)*
Number of contacts with program agronomist	0.02 *(0.01)*	0.43*** *(0.14)*	0.17 *(0.06)*	2.09* *(1.02)*	1.99 *(1.21)*	3.37 *(1.94)*
Times listened to agricultural radio programs during the past month	1.78 *(0.25)*	3.09** *(0.50)*	2.78 *(0.43)*	5.10*** *(0.67)*	5.54 *(1.06)*	5.00 *(0.78)*

T-test of pairwise differences, significant at p-value of: *** < 0.01; ** <0.05; * <0.10

Table 5: Farm and household characteristics for aware, tryout, and/or adopter households (Source: authors' estimation based on household survey data)

			Aware		Tried	
	Not Aware	**Aware**	**Not Tried**	**Tried**	**Not adopt**	**Adopt**
	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)
Number of observations	139	272	199	73	24	32
Social capital						
Agricultural association member	0.12	0.41***	0.35	0.76***	0.90	0.99
	(0.04)	*(0.06)*	*(0.06)*	*(0.08)*	*(0.07)*	*(0.01)*
Member of non-agricultural association	0.07	0.11	0.10	0.14	0.00	0.06
	(0.04)	*(0.03)*	*(0.04)*	*(0.05)*	*(0.00)*	*(0.05)*
Times participated in collective action during the past year[a]	36.95	41.74	40.17	51.82	41.14	57.25
	(12.35)	*(4.23)*	*(4.94)*	*(5.36)*	*(9.27)*	*(10.07)*
Number of persons to borrow money from	2.66	3.17	3.12	3.51	3.73	4.15
	(0.35)	*(0.24)*	*(0.27)*	*(0.45)*	*(0.98)*	*(0.42)*
Physical and financial capital						
Fields on slope[b]	0.19	0.25	0.25	0.22	0.40	0.25
	(0.06)	*(0.11)*	*(0.12)*	*(0.09)*	*(0.22)*	*(0.14)*
At least one field with good soil[c]	0.8	0.74	0.72	0.80	0.84	0.81
	(0.07)	*(0.06)*	*(0.06)*	*(0.11)*	*(0.09)*	*(0.11)*
Total number of fields cultivated	2.89	3.87***	3.72	4.82**	5.37	5.22
	(0.18)	*(0.24)*	*(0.26)*	*(0.37)*	*(0.87)*	*(0.68)*
Tropical livestock units[d]	0.49	0.85**	0.74	1.59***	2.21	1.74
	(0.12)	*(0.16)*	*(0.14)*	*(0.20)*	*(0.41)*	*(0.31)*
Asset index	2.05	2.83***	2.73	3.53***	3.37	3.86
	(0.16)	*(0.17)*	*(0.17)*	*(0.20)*	*(0.24)*	*(0.25)*
Off-farm income[e]	0.51	0.67**	0.64	0.83***	0.45	0.94*
	(0.06)	*(0.04)*	*(0.04)*	*(0.05)*	*(0.19)*	*(0.05)*
Human capital						
Female headed household	0.17	0.05	0.05	0.05	0.00	0.11
	(0.05)	*(0.03)*	*(0.03)*	*(0.05)*	*(.)*	*(0.09)*
Education of household head[f]	2.33	4.59***	4.22	6.92	5.59	8.02
	(0.32)	*(0.53)*	*(0.45)*	*(1.73)*	*(0.76)*	*(2.50)*
Age of household head	45.54	46.83	47.39	43.21	40.66	44.74
	(1.67)	*(1.91)*	*(1.85)*	*(4.13)*	*(5.63)*	*(3.52)*
Household labour[g]	3.02	3.34	3.24	3.95**	4.12	3.95
	(0.15)	*(0.16)*	*(0.16)*	*(0.31)*	*(0.25)*	*(0.32)*
Location						
Distance to the market[h]	57.35	42.35**	44.61	27.73	36.13	26.86
	(10.33)	*(8.01)*	*(9.17)*	*(6.32)*	*(10.77)*	*(8.95)*
Kabare territory	0.35	0.23	0.22	0.29	0.30	0.31
	(0.11)	*(0.07)*	*(0.07)*	*(0.12)*	*(0.14)*	*(0.20)*

T-test of pairwise differences, significant at p-value of: *** < 0.01; ** <0.05; * <0.10

a. Collective action was explained to the respondents as tasks in which they participated freely and voluntarily, to the benefit of the community

b. Number of fields cultivated by the farmer that are positioned on a slope
c. Local farmers' classification of soil quality (CIALCA, 2009)
d. One cow equals 1 livestock unit, pig is 0.40, goat/sheep 0.20, chicken/rabbit 0.05, guinea pig 0.005
e. Dummy variable if during the past 12 months at least 1 household member had a permanent off-farm job or an off-farm business
f. Years of education successfully finished by household head
g. Total labour units in the household. Adults (19 – 65 years) have value 1, youngsters (12-18 years) and elderly (> 65 years) equal 0.5
h. Time (in minutes) walking without heavy weight and for a normal healthy person

Table 6: Average marginal effects for univariate probit and Heckman corrected probit regressions (Source: authors' estimation based on household survey data)

Outcome	**Aware**		**Tryout**				**Adopt**			
Sample	**full**	**full**	**full**	**full**	**aware**	**aware**	**full**	**full**	**tryout**	**tryout**
Estimation method	**probit**	**iv**	**probit**	**HM**	**probit**	**iv**	**probit**	**HM**	**probit**	**iv**
	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)
Program association member	0.0937	-0.0159	0.0562**	0.0759**	0.0964**	0.2252***	0.0272	-0.2520***	-0.2689***	-0.4410*
	(0.1228)	*(0.2687)*	*(0.0232)*	*(0.0379)*	*(0.0404)*	*(0.0442)*	*(0.0170)*	*(0.0611)*	*(0.0623)*	*(0.2680)*
Agricultural association member	0.1860**	0.1851**	0.0665***	0.0590**	0.0778**	0.0772**	0.0986***	0.2803***	0.2633***	0.2743**
	(0.0884)	*(0.0890)*	*(0.0243)*	*(0.0288)*	*(0.0369)*	*(0.0338)*	*(0.0352)*	*(0.1051)*	*(0.0923)*	*(0.1111)*
Program village	0.1342*	0.1478*	0.1085***	0.1519***	0.1925***	0.1578***				
	(0.0768)	*(0.0804)*	*(0.0294)*	*(0.0548)*	*(0.0507)*	*(0.0479)*				
Neighbouring program village	-0.0030	-0.0018	0.0918***	0.1365**	0.1716***	0.1648***				
	(0.0874)	*(0.0873)*	*(0.0336)*	*(0.0612)*	*(0.0553)*	*(0.0501)*				
Radio	0.0014	0.0018	0.0032*	0.0085**	0.0106***	0.0083**	0.0011	0.0065*	0.0063	0.0084
	(0.0076)	*(0.0079)*	*(0.0017)*	*(0.0040)*	*(0.0034)*	*(0.0033)*	*(0.0008)*	*(0.0036)*	*(0.0040)*	*(0.0066)*
Tropical livestock units	-0.0172	-0.0131	0.0043	0.0073	0.0089	-0.0017	0.0088	0.0002	-0.0016	0.0003
	(0.0403)	*(0.0430)*	*(0.0093)*	*(0.0129)*	*(0.0154)*	*(0.0153)*	*(0.0060)*	*(0.0184)*	*(0.0188)*	*(0.0233)*
Asset index	0.0305	0.0305	-0.0069	-0.0182	-0.0223	-0.0222*	-0.0035	0.0545***	0.0571***	0.0738***
	(0.0309)	*(0.0309)*	*(0.0074)*	*(0.0146)*	*(0.0136)*	*(0.0122)*	*(0.0062)*	*(0.0168)*	*(0.0198)*	*(0.0284)*
Off-farm income	0.0806	0.0841	0.0194	0.0217	0.0296	0.0216	0.0474**	0.4316***	0.4433***	0.5110***
	(0.0746)	*(0.0754)*	*(0.0220)*	*(0.0303)*	*(0.0382)*	*(0.0378)*	*(0.0211)*	*(0.0809)*	*(0.0665)*	*(0.1143)*
Fields on slope	-0.0577	-0.0549	-0.0224**	-0.0251*	-0.0323*	-0.0319*	-0.0057	-0.0216	-0.0219	-0.0269
	(0.0472)	*(0.0477)*	*(0.0111)*	*(0.0148)*	*(0.0172)*	*(0.0175)*	*(0.0088)*	*(0.0200)*	*(0.0211)*	*(0.0355)*
At least one field with good soil	-0.0782	-0.0774	0.0139	0.0225	0.0261	0.0237	-0.0005	0.0695	0.0709	0.0589
	(0.0779)	*(0.0779)*	*(0.0238)*	*(0.0353)*	*(0.0392)*	*(0.0354)*	*(0.0176)*	*(0.0524)*	*(0.0554)*	*(0.0679)*
Total number of fields	0.0477	0.0487*	0.0052	0.0047	0.0064	0.0046	0.0019	-0.0115	-0.0122	-0.0120

	(0.0292)	*(0.0293)*	*(0.0055)*	*(0.0069)*	*(0.0085)*	*(0.0078)*	*(0.0031)*	*(0.0096)*	*(0.0093)*	*(0.0121)*
Education	0.0247**	0.0246**	0.0060**	0.0051	0.0069	0.0065	0.0040	-0.0057	-0.0063	-0.0098
	(0.0101)	*(0.0101)*	*(0.0026)*	*(0.0038)*	*(0.0046)*	*(0.0041)*	*(0.0027)*	*(0.0087)*	*(0.0089)*	*(0.0119)*
Age	0.0012	0.0013	-0.0024***	-0.0033*	-0.0041***	-0.0042***	-0.0002	0.0090***	0.0096***	0.0115***
	(0.0030)	*(0.0031)*	*(0.0007)*	*(0.0018)*	*(0.0014)*	*(0.0013)*	*(0.0005)*	*(0.0023)*	*(0.0022)*	*(0.0039)*
Age squared	0.0000	0.0000	0.0001**	0.0001	0.0001	0.0001*	0.0000	0.0000	0.0000	0.0000
	(0.0001)	*(0.0001)*	*(0.0000)*	*(0.0001)*	*(0.0001)*	*(0.0001)*	*(0.0000)*	*(0.0001)*	*(0.0001)*	*(0.0002)*
Labour	-0.0161	-0.0165	0.0173***	0.0252*	0.0314***	0.0304***	0.0044	0.0015	-0.0004	0.0043
	(0.0248)	*(0.0249)*	*(0.0066)*	*(0.0130)*	*(0.0108)*	*(0.0102)*	*(0.0056)*	*(0.0203)*	*(0.0209)*	*(0.0279)*
Member of non-agricultural association	0.1007	0.0995	-0.0075	-0.0411	-0.0497	-0.0408	-0.0177	0.3756**	0.4055***	0.4055**
	(0.1014)	*(0.1016)*	*(0.0372)*	*(0.0609)*	*(0.0673)*	*(0.0618)*	*(0.0271)*	*(0.1705)*	*(0.1334)*	*(0.1807)*
Log of persons to borrow money from	-0.0494	-0.0494	-0.0121	-0.0159	-0.0211	-0.0237	0.0039	0.1691***	0.1746***	0.1823***
	(0.0511)	*(0.0512)*	*(0.0126)*	*(0.0181)*	*(0.0223)*	*(0.0195)*	*(0.0077)*	*(0.0366)*	*(0.0374)*	*(0.0510)*
Collective action	0.0435**	0.0431**	0.0275***	0.0365***	0.0467***	0.0371**	0.0151*	-0.0116	-0.0147	-0.0129
	(0.0200)	*(0.0200)*	*(0.0075)*	*(0.0139)*	*(0.0133)*	*(0.0152)*	*(0.0078)*	*(0.0217)*	*(0.0212)*	*(0.0304)*
Distance to the market	-0.0002	-0.0002	-0.0007**	-0.0011*	-0.0014***	-0.0013**	-0.0003	-0.0002	-0.0001	0.0005
	(0.0010)	*(0.0010)*	*(0.0003)*	*(0.0006)*	*(0.0005)*	*(0.0005)*	*(0.0002)*	*(0.0008)*	*(0.0008)*	*(0.0014)*
Kabare territory	-0.0914	-0.0932	0.0295	0.0264	0.0318	0.0368	0.0334*	-0.0270	-0.0321	-0.0396
	(0.0761)	*(0.0762)*	*(0.0196)*	*(0.0327)*	*(0.0368)*	*(0.0308)*	*(0.0191)*	*(0.0665)*	*(0.0641)*	*(0.0709)*
Pseudo R2 (Mc Fadden)	0.2200		0.4881		0.4678		0.5218		0.7014	
p	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Rho		0.1998		-0.1486		-0.7567		-0.1341		0.6632
P (rho=0)		0.5998		0.9496		0.0895		0.8304		0.5027
Number of observations	405	405	405	405	267	267	389	389	55	55

Average marginal effects significantly different from 0 for * p<.10, ** p<.05, *** p<.01

HM: Heckman probit model on full sample, corrected for selection bias (only final stage reported)

Table 7: Average marginal effects for regressions controlling for multiple program activities (Source: authors' estimation based on household survey data)

Outcome	**Aware**	**Tryout**			**Adopt**		
Sample	**full**	**full**	**full**	**aware**	**full**	**full**	**tryout**
Estimation method	**probit**	**probit**	**HP**	**probit**	**probit**	**HP**	**probit**
	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)	Mean (*se*)
Program association member	0.1072	-0.0514	-0.0681	-0.0818	-0.0611**	-0.1425***	-0.1774*
	(0.1576)	*(0.0419)*	*(0.0679)*	*(0.0658)*	*(0.0309)*	*(0.0530)*	*(0.0976)*
High attendance at program meetings	-0.4153	0.0267	0.0380	0.04360	0.0549***	0.1933***	0.1843***
	(0.3030)	*(0.0301)*	*(0.0518)*	*(0.0462)*	*(0.0185)*	*(0.0368)*	*(0.0624)*
Contacts with program agronomist	0.0846	0.0078***	0.0086**	0.0109***	0.0051***	0.0104***	0.0084***
	(0.0569)	*(0.0029)*	*(0.0036)*	*(0.0042)*	*(0.0016)*	*(0.0030)*	*(0.0032)*
Demonstration trial	0.0082	0.1157***	0.1738*	0.2108***	-0.0022	-0.3560***	-0.4993***
	(0.3374)	*(0.0352)*	*(0.0899)*	*(0.0549)*	*(0.0215)*	*(0.1164)*	*(0.1438)*
On-farm trial					0.0761***	0.2509***	0.2950***
					(0.0226)	*(0.0561)*	*(0.0668)*
Pseudo R2 (Mc Fadden)	0.2266	0.5345		0.5312	0.6432		0.8092
p	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Rho			-0.11784			0.9017	
p (rho=0)			0.9157			0.2083	
Number of observations	405	405	405	267	389	389	55

Average marginal effects significantly different from 0 at * p<.10, ** p<.05, *** p<.01

Note: only final stage reported.

ENDNOTES

[1] The CIALCA consortium coordinates projects by Bioversity International, TSBF-CIAT and IITA and focuses on Central Africa, including different regions in Congo D.R., Burundi and Rwanda. The program in South Kivu is part of this broader initiative.

[2] The *groupement* (grouping) is the administrative unit above the village in Congo D.R. A territory comprises sectors, groupings within the sectors, and villages within the groupings.

[3] Several overview studies propose to study not only the binary adoption decision but also the intensity of adoption (Feder et al., 1985; Doss, 2006). For our case-study, we choose to focus on binary decisions because the diffusion process started only recently and is not yet completed and we therefore have too few observations to study fertilizer use intensity.

[4] We use a household asset index that aggregates various asset ownership indicators as a proxy for long-run household welfare (Filmer & Pritchett, 2001). The index is the first principal component of a polychoric principal component analysis on indicators of housing quality and non-productive assets.

[5] Recently, Diagne and Demont (2007) proposed the ATE methodology to improve parameter estimates of agricultural technology adoption in the case of considerable non-exposure. In our case, applying their method did not result in significantly different parameter estimates. To reduce the length of the paper, we chose not to report these results.

[6] The two most cited method for estimating probit models with binary endogenous regressors are linear instrumental variable (IV) estimation, and multivariate probit model (Chiburis, Das, & Lokshin, 2012). As linear IV estimates perform badly when treatment probabilities are low (Chiburis et al., 2012), we chose to use multivariate probit models. Greene has shown that in a full information maximum likelihood estimation of a bivariate probit model with an endogenous binary regressor, the outcome will not be affected by self-selection bias (Greene, 2008).