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Tryout and (Dis)adoption of conservation agriculture. Evidence from Western Madagascar

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ABSTRACT

Conservation agriculture has been promoted in sub-Saharan Africa to address land degradation, which jeopardizes farmers' livelihoods. However, the low adoption rate of this technology raises the question of its suitability for smallholders. The aim of this study is to assess the factors influencing the tryout and disadoption of conservation agriculture thanks to a qualitative and econometric analysis. The Sustainable Rural Livelihoods framework is used to structure the analysis. Drawing on primary data collected from farmers in Western Madagascar, our model shows the adoption of the technology as a two-step process encompassing the tryout and disadoption. Our findings show a high tryout rate of CA - 56 % of the whole sample tried out CA - and also a high disadoption rate thereafter - 80 % of farmers who tried out CA later disadopted. We conclude that monetary poverty (financial capital) and agricultural work (social capital) decrease the likelihood a farmer will try out CA. The results also highlight that the longer the farmers receive CA technical support (human/social capital), the less likely they disadopt CA. The availability of upland areas (natural capital) influences farmers' decisions both to try out CA and to adopt the technology thereafter. To tackle the problem of land degradation in this area, it is important to tailor conservation agriculture technology and its accompanying measures to the diversity of farm characteristics. Moreover, technical changes and farmers' innovations need to be supported for a longer period.

1. Introduction

Land degradation has been defined as "a process that diminishes or destroys the agricultural and forest production capacity of land. It is induced by human activities or can be a natural phenomenon aggravated by the effects of human activities" (Brabant, 2010). Sheet erosion and nutrient depletion are two types of degradation which contribute to the risk of desertification (Brabant, 2010), an issue that seriously jeopardizes agricultural sustainability in sub-Saharan Africa (Drechsel et al., 2001). Conservation agriculture (hereafter, CA) is a potentially efficient technology for addressing these land degradation issues (Husson et al., 2008). It entails minimal soil disturbance as well as permanent soil cover using cover crops and crop rotations or associations (FAO, 2017).

After the success of CA in mechanized agriculture systems like in Brazil or in Australia, it has been put to the test in the resource-limited context of small family farming in sub-Saharan Africa. CA technology has been disseminated at a large scale among farmers after an on-station experimentation phase (Husson et al., 2008).

Each component of CA has specific agronomic functions (Seguy et al., 2009). No-tillage, for example, reduces erosion and maintains fertility at the surface of the soil. Cover crops help the soil to retain water, which is useful in areas facing severe drought or exposure to high temperatures with low or erratic rainfall as is the case in sub-Saharan Africa. They also increase the physical, the biological (microbiological activity), and the chemical structure (nutrients) of the soil, which all progressively enhance soil fertility and agricultural production. Crop rotation contributes by limiting pests and diseases and thus reduces operational costs related to the use of phytosanitary measures.

Despite the diverse agronomic strengths of CA, its potential efficiency in addressing soil degradation issues and the dissemination efforts made by development institutions, its adoption rate is low in sub-Saharan Africa. Farmers appear reluctant to try out such a technology and to adopt it over time (Serpantié, 2009; Hove et al., 2011). FAO-

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REOSA (2010) estimates that the land run according to the principles of CA in 2010 corresponded to less than one percent of the cultivated land area in sub-Saharan Africa. In 2012, nearly 1 000 000 ha run using CA were cultivated by 400 000 farmers (Friedrich et al., 2012).

In this paper, we provide elements of answers of why the CA adoption level remains low in sub-Saharan Africa. We focus on factors underlying the farmers' tryout and disadoption of CA in Madagascar. We provide further analysis of the disadoption behavior, which is little documented in the relevant literature. This paper contributes to the existing empirical studies in the related area in sub-Saharan Africa and aims to enhance the efficiency of the design and the implementation of CA programs in Madagascar. Several papers have already analysed factors which influence farmers' decisions to adopt CA in sub-Saharan Africa (Feder et al., 1985; Knowler and Bradshaw, 2007; Knowler, 2015). However, it is still relevant to duplicate similar studies in other countries such as Madagascar for the two following reasons:

(i) Existing empirical evidence has produced a set of heterogeneous and inconclusive results about the determining factors behind CA adoption in sub-Saharan Africa. For example, some empirical results have shown farm size to have a significant positive influence on the decision to adopt CA, while others have shown the same factor to have an insignificant and negative correlation (Knowler and Bradshaw, 2007). Factors that influence the adoption of CA in fact appear to be highly context-specific. In our study, we have refined the analysis of factors that influence CA adoption within the specific context of Madagascar;

(ii) There are different kinds of CA systems. CA is known as a technological package with three main components: minimal soil disturbance, permanent soil cover and crop rotation or association (FAO, 2017). However, each of the three components can be emphasized to varying degrees (Derpsch et al., 2010). For example, in Zambia, planting basins - which are one type of CA - only call on the no-tillage component. Conservation farming - another type of CA - takes into account all three components. Conservation farming used in conjunction with planting basins involves a cereal-legume based rotation and the retention (no burning) of crop residue (Andersson and D'Souza, 2014). Farmers make different decisions about adopting CA depending on the CA technology used. To avoid any misunderstanding, it is thus important to specify what type of CA is under study and to what extent the three components are at play. In our study, all three components are involved. The CA system at the core of our analysis is a cereal-legume based rotation specifically using stylosanthes as a cover crop.

The rest of the paper is organized as follows. The first section provides an overview of the dissemination of CA in Western Madagascar and a brief description of the Sustainable Rural Livelihoods (hereafter SRL) framework which structures the analysis. Section 2 presents the method used to collect and to analyse data. Section 3 presents and discusses the results of our study. The final section draws some conclusions and points to their policy implications.

1.1. CA dissemination in Western Madagascar

Land degradation threatens the agricultural production in the Western Madagascar. The diagnosis of the level of soil fertility can be related to bio-indicator plant (Ducerf, 2014). A weed named *Striga asiatica* is for example a good indicator of the low level of the soil fertility because it thrives on nutrient-poor soil (more specifically lacking nitrogen and organic matter) by attacking cereal crops (Husson et al., 2008). This type of weed is difficult to manage and in case of heavy infestation, cereal production may be reduced by 35%–80% (Rodenburg et al., 2016). Randrianjafizanaka et al., 2018 highlighted the importance of its infestation in the Western of Madagascar.

To address land degradation, CA has been promoted as part of various and successive donor-funded projects and programs since 1996 in Madagascar, as in most of the countries in sub-Saharan Africa (Corbeels et al., 2014). The NGO named TAFA with the technical support of the Centre de coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) and the financial support of different donors including the Agence Française de Développement (AFD) has developed the core of experimentation of CA in Madagascar from 1998 to 2006.

Specifically, the dissemination of CA was one of the components of the *Bassins-Versants et Périmètres Irrigués* (hereafter BVPI[1]) which was a large-scale national program to improve agricultural production by protecting soil in upland areas and enhancing agricultural techniques in lowland areas. International donors funded the program, and the Malagasy government implemented it in different regions including the Western of Madagascar. One of the targeted areas of the program was the district of *Mandoto* in the Western part of the region of *Vakinankaratra* (see Fig. 1) where the BVPI project took place from October 2006 to January 2013. From 2006–2011, BVPI selected six municipalities out of the eight in the district, according to the presence of watershed and irrigated areas: *Ankazomiriotra, Vinany, Inanantonana, Fidirana, Mandoto* and *Ambohimanambola*. From 2011–2013, the project reduced the intervention areas and concentrated its actions in *Ankazomiriotra, Vinany, Inanantonana* and *Fidirana*. *Fidirana* is landlocked compared to the other three municipalities.

The dissemination agents working for the project raised awareness about CA among local communities on weekly market days (Cellule de projet BVPI SE/HP, 2013). We must note that in rural areas in Madagascar, the weekly market serves not only to trade goods but is also essential for human interplay, mingling and other social interactions (Raison, 1972; Hébert, 1989; Rakoto Ramiarantsoa, 1995). Interested farmers contacted the dissemination agents directly. They were then invited to join existing farmer groups or to set up new ones to facilitate the organizational, technical and financial supports provided by the dissemination agents. Farmer participation in BVPI interventions was thus voluntary and the project imposed no selection criteria.

During the first three years of the project, the dissemination of CA was associated with the intensive use of chemical fertilizer to obtain a significant increase in crop yield. The project facilitated access to credit to help farmers acquire inputs (fertilizer, seeds and phytosanitary products). This was a form of revolving credit. Seeds and fertilizers (an interest-free credit) were reimbursed in kind (rice) and/or in cash; phytosanitary products in cash with an interest rate of 1% per month. Repayment was to be made to the account of a farmer group opened in a microfinance institution. The project also added value to the cover crop by purchasing stylosanthes seeds from CA adopters. However, due to implementation difficulties such as the geographic dispersion of beneficiaries, a low rate of credit repayment, a lack of organization among seed producers, high fertilizer prices etc. all the incentives stopped after these first three years. A low-input CA cropping system gained importance and leader farmers were trained for seed production.

Research has proposed an array of CA systems adapted to the different agroecological zones of Madagascar. However, the predominant system disseminated by the BVPI was based on *Stylosanthes guianensis* including all three basic components of CA. The rationale behind choosing this type of CA technology is linked to the high agronomic value of the stylosanthes. Husson et al. (2008) outlined the different advantages of stylosanthes, and considered it an excellent cover crop. It fixes nitrogen from the atmosphere, recycles nutrients buried deep in the soil and spreads spontaneously. It also produces a biomass that can reach 20 tons per hectare of dried matter on rich soil. On poor soil, the same amount of biomass can be attained after two or three crop seasons. Stylosanthes significantly reduces the effect of weeds such as

[1] The other development topics of BVPI-SE/HP were farmer organizations, support for the milk sector, rehabilitation of irrigated perimeters and drainage.

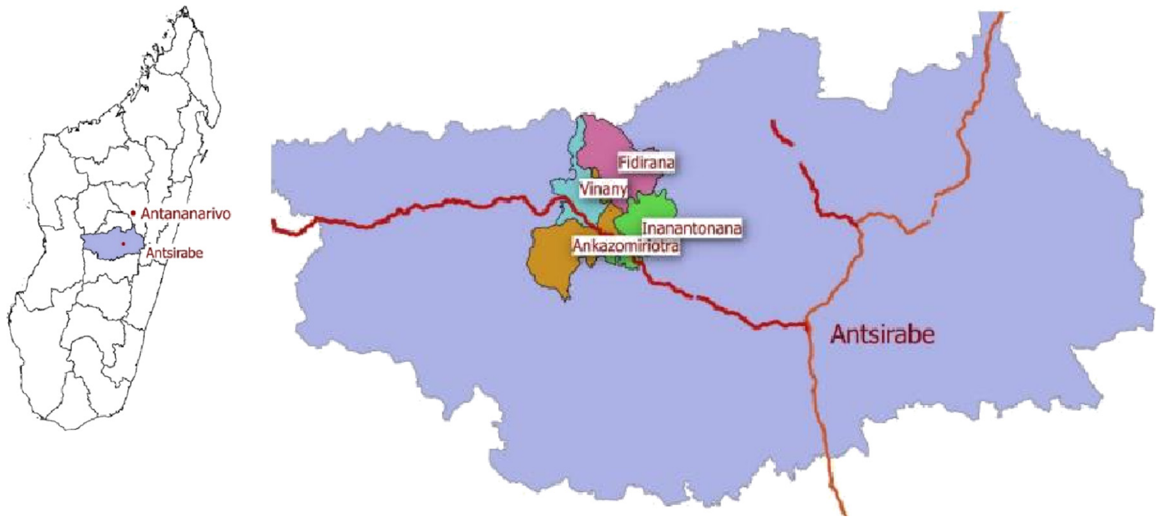

Fig. 1. Study area in Western of the region of *Vakinankaratra* in Madagascar.

Striga asiatica if they cover the soil uniformly (Ranaivoson et al., 2018). Good soil coverage requires about 10 tons per hectare of dried matter produced by stylosanthes (Naudin et al., 2015; Ranaivoson et al., 2018). Stylosanthes can also be used as animal fodder.

Husson et al. (2013) described CA based on stylosanthes in upland areas as follows: (i) for the first year of cultivation, stylosanthes (the cover crop) are intercropped with a subsistence crop (rice, maize or cassava); (ii) in the second and the third years, the plot of stylosanthes is fallowed. No subsistence crops are added; (iii) for the fourth year, stylosanthes are initially controlled manually, chemically or mechanically to cover the soil. Thereafter, a subsistence crop is cultivated under a layer of mulch with no tillage. Managing stylosanthes manually requires 80–90 man.days per ha (Cellule de projet BVPI SE/HP, 2013). It represents, for example, 50–56% of the total labor requirement for a rice and stylosanthes based system. The mechanical treatment requires the use of a specific equipment named a roller. The chemical treatment uses herbicides but was not a possibility for most of the farmers in the study area.

1.2. The sustainable rural livelihoods framework

Since the seminal works of Chambers and Conway (1992); Ellis (1998); Scoones (1998); Bebbington (1999), the SRL framework has been widely used by different international organizations and NGOs to understand the structure and functioning of farms, households, as well as other categories. The SRL framework identifies five categories of assets or capitals to ensure livelihoods: physical, natural, financial, social and human capitals. The individual livelihood capitals (here at farmers' level) are influenced by the context and the environment in which they operate. Available livelihood capitals enable farmers to implement livelihood activities and strategies, resulting in livelihood outcomes.

The SRL framework intends to provide a better understanding of poverty as the basis for development actions. The scope of this framework is not limited to interventions targeting poverty alleviation but to all actions that enhance the livelihood of farmers such as research and development related to innovation. However, the limit of the framework to analyse innovation processes is on debate. DFID (1999) assumed that '*this framework is 'dynamic' in that it attempts to understand change, complex cause-and-effect relationships and iterative chains of events*". The framework seems thus to be relevant to analyse the dynamic nature of the innovation process at farm level. However, Adato and Meinzen-Dick (2007) and Duncombe (2014) outlined a shortcoming in the use of such a framework to analyse technological changes for poverty reduction. Scoones (2009) added that the livelihood approach failed to handle the livelihood change in the long-run including technological change. For example, the SRL framework can have difficulties explaining how the experiences and competences acquired during this adoption process enable farmers to improve their know-how (human capital) about the use of this agricultural innovation in the long run. Or how farmers improve the performance of the innovation, when applied specifically on their farm, for a better impact on their livelihood outcomes, as delineated by the evolutionist approach as learning process. Dorward et al. (2003) also highlighted that there are missing links to the innovation analysis in the 'classical' SRL framework and that it is not easy to find a place to locate it within this framework.

In this paper, we thus use the SRL framework more as a structuring tool for the analysis of factors which determine the tryout and disadoption of CA at farm level, than as a guiding theoretical framework.

2. Data and methods

2.1. Study area

The Western areas of Madagascar comprises 12 regions out of a total of 22, between the Central Highlands and the West Coast. The average altitude is 1000 m, and the average rainfall is 1100 mm per year with a dry period from April to October. The landscape is dominated by upland areas that are potentially suitable for rainfed crops. The lowland areas are often narrow valley bottoms, which limits expansion of irrigated rice fields.

The study area is located in the Western of the region of *Vakinankaratra*. Data has been collected in four municipalities (*Ankazomiriotra, Vinany, Inanantonana* and *Fidirana)* (see Fig. 1). These municipalities have been equally covered by the project (BVPI) promoting CA in this area from 2007 to 2013. In each municipality, two *fokontany* (the smallest administrative subdivision in Madagascar, which can be considered as a village) were selected for our sample: one near the administrative center of the municipality and the other more remote. Our hypothesis is that farmers located closer to the center might be more exposed to the CA dissemination of the project than distant farmers.

2.2. Data collection

The unit of analysis used in this paper is the farm or the household. The two units fully overlap in Madagascar as smallholders are purely nuclear family-based farming systems. Both terms are thus used interchangeably throughout the article. A sample of 240 farmers was randomly selected at the *fokontany* level from two lists: (*i*) 120 former beneficiaries of the BVPI project, taken from the project database; (*ii*) 120 farmers selected from the electoral lists (not involved in BVPI activities).

Survey was done during a face-to-face interview between the interviewer and the head of household most often with his/her spouse according to his/her availability in February 2015 (three years after the end of BVPI project). Interviewers were young engineers from the graduate school of agricultural sciences at the university of Antananarivo. They were not part of the BVPI project teams and were recruited for the occasion. Interviewers were trained on the questionnaire. Scientists involved in the study oversaw the data collection.

The data collected comprised a socio-demographic description of the household, information on productive and non-productive assets, on- and off-farm activities and the income generated by each activity in the 2013/2014 cropping year. For each plot of each farmer, we also collected data on: the cropping system of the previous cropping year and those for the surveyed cropping year, the operational costs (hired labor, fertilizer, seed, phytosanitary products) and crop yields. The questionnaire was about 20 pages long and the survey lasted 4 h per farmer.

Qualitative data, including specific questions related to the CA tryout and disadoption, were collected in the survey using open questions. The reasons of CA adoption and disadoption by farmers were requested. Among 102 disadopters, 63 detailed reasons why they decided to disadopt CA. As one farmer may give multiple disadoption reasons, then 74 responses has been reported. All the 32 adopters gave reasons of adoption. Farmers ‘responses were coded and analysed using Stata 13.

2.3. Econometric analysis

Lambrecht et al. (2014) defined the technology adoption process at farm level in three phases: (i) awareness; (ii) tryout; (iii) continued adoption or disadoption. The first step is a discovery phase for farmers during which they are persuaded to adopt the technology. The second step corresponds to the experimentation phase. At the third phase, farmers are able to evaluate the profitability and the limits of the technology as experienced during the second step and can decide to continue the adoption or to disadopt it. We are interested by the second and the third phase. The decision-making process is described in the following tree decision (Fig. 2).

The determinants of CA adoption by farmers were often analysed using Logit and Probit models with a dichotomous choice question (did you adopt the technology or not), or a multinomial choice that estimates the probability of adoption according to a marginal change of an explanatory variable (e.g Nyanga, 2012; Grabowski et al., 2016; Van Hulst and Posthumus, 2016). Here, we consider the decision to disadopt CA (or not) given that the farmer initially tried out CA. Single-equation approaches then failed to capture this logical two-step decision process. We therefore model the sequential decisions of farmers to adopt CA by using a censored probit model (stata command Heckprobit) estimated in maximum likelihood (Neill and Lee, 2001; Grazzi and Vergara, 2012; Van den Broeck et al., 2013; Lambrecht et al., 2014). The determinants of the tryout decision has been modelled in the first step, and those of the disadoption in the second step.

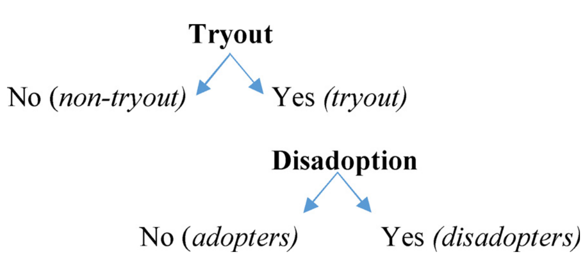

Fig. 2. Decision tree related to the tryout and disadoption of conservation agriculture.

The decision to try out CA has been considered as a dichotomous choice. The household decision is based on the utility associated with CA or non-CA technology. The utility is derived from the observable farm and household characteristics, *M* (e.g farm size, and education of household heads), and from the observable technology characteristics, *T* (e.g yield and income). The utility function is represented by U_{it} (M_i, T_i), where *i* represents household and *t* represents the technology choice (*t* equals one when any level of CA is employed, and *t* equals two when farmer uses non-CA only). We then denote U_{i1} the utility associated with CA for the *i*th observation, and U_{i2} the utility associated with non-CA. The *i*th household will choose to use non-CA if $U_{i1} < U_{i2}$ or if the unobservable latent variable $C* = U_{i2} - U_{i1} > 0$, and it will choose CA when $U_{i1} > U_{i2}$ or if the latent variable $C* = U_{i1} - U_{i2} > 0$ (Eq 1).

$$C_i = 0 \; if \; U_{i1} < U_{i2} \quad (1)$$

$$C_i = 1 \; if \; U_{i1} > U_{i2}$$

The second step of the model involved the disadoption decision which only applies to the subsample of farmers who initially tried out CA (Eq 2).

$$Y_i = X_i\beta \text{ if } i* = X_{i2}\beta_2 + \mu_i > H,$$

$$Y_i = 0 \text{ if } i* = X_{i2}\beta_2 + \mu_i \le H, \quad (2)$$

where Y_i is the probability of disadopting CA, $i*$ is the unobservable latent, *H* is unobservable threshold value, and X_{i2} are the independent variables to explain the disadoption decision.

From an analytical point of view, the heckprobit model assumes the existence of an underlying relationship and combines the two steps we described above simultaneously and is specified in Eq 3a and 3b as:

$$C_i = Z_i\varphi + \varepsilon_i \text{ (CA tryout)} \quad (3a)$$

$$Y_i = X_i\beta + \mu_i \text{ (CA disadoption)} \quad (3b)$$

where, C_i is a dummy variable for the CA tryout, Z_i is a vector of determinants of the CA tryout, Y_i is the CA disadoption, X_i is a vector of determinants of CA disadoption, φ and β are vectors of parameters to be estimated, and ε_i and μ_i are error terms. Eq 3a is the selection equation and the Eq 3b is the outcome equation.

There is potential bias such as non-exposure bias, unobserved heterogeneity bias and selection bias in our estimates (Heckman, 1979; Diagne and Demont, 2007; Kabunga et al., 2012; Lambrecht et al., 2014). However, we can argue that non-exposure bias is low because the geographical coverage of the project for the CA dissemination was effective: all the targeted areas of the project were covered, even farmers located in remote areas.

Unobserved heterogeneity bias due to particular contexts at municipality and village levels such as price of the product, access to credit, etc. may also influence the decision of farmers regarding the tryout and/or the disadoption of CA. To avoid it, the municipalities are used as an explanatory variable and captured fixed effects.

We can state that all farmers (beneficiary and non-beneficiary farmers of the project) in the sample are aware about CA (Table 3). The sample selection bias occurred in our estimates because the two error terms of the two equations (ε_i and μ_i) are likely to be correlated. Some unobservable characteristics, captured in the error terms of the tryout decision, influence the error terms of the disadoption decision. To correct for the selection bias, the heckprobit model first estimates the first stage (Eq 3a) to obtain a sample selection indicator called Inverse Mills Ratio (IMR). The predicted errors and the IMR in the first stage (Eq 3a) are then entered into the second stage (Eq 3b) together with the X_i vector of regressors.

Thus, we respecify Eq 3b as (Eq 4):

Table 1
Description of explanatory variables and hypothesized relations with adopters of CA (with respect to non-adopters).

Variable descriptions		Unit	Expected results: Tryout (1st step)	Expected results: Disadoption (2nd step)
Context	In remote areas	1 if yes	-	+
Human / Social capital	CA technical supports	Year	Not concerned	-
Natural capital	Cultivated upland areas	Hectare	+	-
	Good perception of the soil fertility	1 if yes	-	+
Selection variables	Below the national poverty line	1 if yes	-	Not concerned
	Agricultural work of the household head	man.days	-	Not concerned

$Y_i = X_i\beta + \theta\lambda_i + \eta_i$, (4)

where, Y_i, X_i, and β_i are as previously defined; λ_i and θ are IMR and its parameter estimate respectively; and η_i is a sample selection-corrected error term.

To ensure the robustness of our model, we had to find one or more selection variables which meet two conditions: (i) they significantly affected the tryout (Eq 3a) and not the disadoption (Eq 3b) (Wooldridge, 2010); (ii) they did not affect the IMR. To find out the correlation required in the second condition, we performed a regression of the selection variables on the IMR. A similar method has been used by Mujawamariya and Karimov (2014) with reference to Puhani (2000).

In our empirical model, a set of variables standing for some elements of the sustainable rural livelihood framework are used as explanatory variables.

2.4. Explanatory variables

In their literature review, Knowler and Bradshaw (2007) showed that farm and household characteristics influence CA adoption. According to the SRL framework, farm characteristics are seen as livelihood assets or capitals (*human, natural, financial, physical and social capital*). Bosc et al. (2015) outlined the practical difficulties to characterize capital in the SRL framework because one or more variables can be used as a proxy of one or more capitals. In our study, we categorize each variable in one or more capitals and make assumptions on how a variable may affect first the tryout and disadoption decision thereafter by farmer.

The number of years of technical support for CA (as provided by the dissemination agent for the BVPI project) characterized *the human capital* of farmers. As CA is a complex set of techniques (Penot et al., 2015), we put forward the hypothesis that farmers who received CA technical support over a significant period during the lifetime of the BVPI project were less likely to disadopt CA, even after the completion of the project, than those who did not receive it. This assumption also includes a *social dimension*. The relationship between farmers and dissemination agents creates a social learning arena which significantly affects whether or not said farmers adopt a given an agricultural innovation (Shaijumon, 2018).

Empirical evidence in many contexts reports that land area and soil quality influence farmer's decision regarding CA adoption (e.g. Feder et al., 1985; Feder and Umali, 1993; Srisopaporn et al., 2015). Land area is one form of *natural capital*. In relation with our field surveys, we assume a positive correlation between the cultivated upland area and the tryout of CA and a negative correlation between the cultivated upland area and the disadoption of CA. The quality of soil reflects also the *natural capital* and is proxied by the farmers' perception of the status of their soil fertility. Farmers who perceive their soil as fertile do not yet have to deal with a major constraint to agricultural production and are less likely to adopt CA than those who perceive their soil as non-fertile (Knowler and Bradshaw, 2007).

We also hypothesize that farmers located near the capital city have better access to information and services, for example, supports and advices about CA provided by the dissemination agents. In that case, farmers in the villages near the administrative capital of the municipality would try out an adopt CA more likely than farmers in distant villages.

The selection variables used in our paper are poverty *(financial capital)* and agricultural work *(social capital)* because they meet all the required statistical conditions: (i) they significantly affect the decision to try out CA but not the disadoption decision; (ii) they don't affect the IMR (see Tables 8 and 9).

We assume that poor farmers are less likely to try out CA than non-poor farmers (Arslan et al., 2014; Grabowsky et al., 2016). In our study, poverty is not expressed in terms of the absolute value of total income per capita. Instead, we use the national poverty line estimated at 600 000 Ariary (the local currency) as a threshold. We compare the income per capita of the farmer to this poverty line, which divides the population into poor and non-poor.

Regarding agricultural work, we correlated this variable more precisely to the agricultural work of the household head. This reflects the diversification in the livelihoods of farmers in sub-Saharan Africa (Alobo Loison, 2015). In our study area and in many rural areas in Madagascar, the agricultural labor market is active. As the majority of field work is done manually, farms with a shortage of labor use mainly temporary agricultural workers during peak times to perform four major crop operations: soil preparation, sowing/transplanting, weeding and harvesting. The work is paid for in cash at the end of the day. We hypothesize that the higher the number of working days (man.day) devoted by the household head to agricultural work on neighboring farms, the lower the likelihood that the farmer will try out CA on its own farm. Such a correlation is rarely documented in relevant literature, and this constitutes the originality of our paper.

The expected correlations between the explanatory variables and the tryout and disadoption of CA are summarized in Table 1. The selection variables are in grey.

Other variables potentially affect farmers' decisions relating to the use of CA. However, they are not used in our model due either to the minor influence they have on farmers' decisions or to their correlation with other variables. Cattle ownership might for example be a potential explanatory variable for CA adoption as the decision-making process is not limited to purely conservational concerns. Stylosanthes can be used as fodder for cattle and as a cover crop. Naudin et al. (2015) have even outlined the trade-off in the use of stylosanthes as a cover crop or as animal feed in the case of mixed crop-livestock farming systems in other regions of Madagascar. However, we did not examine cattle ownership in our model because in the areas under study fodder crops are not commonly cultivated. Animal feed is then less important than soil conservation.

The cultivated lowland area was also not included in the model although farmers manage and combine cultivated areas both lowland and upland in their livelihood strategies. In addition, it is known that rice yields in irrigated lowland areas are higher and more stable than those in upland areas. Farmers may thus favor crops in lowland areas as much as possible. So, it can be assumed that an increase in cultivated lowland areas negatively influences the adoption of CA in upland areas.

Table 2
Cultivation techniques of the promoted and practiced CA system based on rice and stylosanthes.
Source: practiced CA from authors 'data survey for and promoted CA from data adapted from Raharison et al. (2012) and Cellule de projet BVPI SE/HP (2013).

Inputs		Unit per ha	Practiced CA	Promoted CA		
Seeds of rice		kg	50	60	60	60
Manure		kg	3800	5000	5000	5000
Urea		kg	70	80	80	80
NPK		kg	35	80	80	80
Insector (Insecticide)		kg	0.18	0.24	0.24	0.24
Agrimethrin (Insecticide)		l		0.16	0.16	0.16
Management of stylosanthes	manually	man.day	Not documented	80 – 90		
	mechanically	man.day			7 – 10	
	chemically	man.day				5
Sowing of rice and spread of manure		man.day		30	30	30
Spread of chemical fertilizer		man.day		15	15	15
Spread of insecticide		man.day		5	5	5
Harvesting		man.day		20	20	20
Total labor		man.day	Not documented	150 – 160	75 – 80	75

Note: Labor requirement of the practiced CA was not documented because only hired labor has been surveyed.

However, our data reveals that lowland area are significantly correlated (at around 50 %) to upland area, compelling us to choose between the two in our model. We have kept upland area in our study as CA is practiced there.

3. Results and discussion

3.1. Descriptive statistics

Farmers practiced different types of CA cropping systems using stylosanthes. During the surveyed cropping year, the most practiced (24 out of 36 adopters) was the association of rice and stylosanthes. The other practiced CA systems were based on maize and stylosanthes (4 out of 36 adopters), legumes (peanut) and stylosanthes (2 out of 36 adopters) or a fallow of stylosanthes (5 out of 36 adopters). These CA cropping systems made up the rotation system of farmers. We show in the Table 2 the cultivation techniques of the CA system based on rice and stylosanthes as promoted by the BVPI project from 2006 to 2013 and as practiced by farmers three years after the end of the project.

Result confirm that farmers implement all three basics components of CA. CA as practiced by farmers do not deviate from what has been promoted by the project (Table 2). There is just a slight decrease of the quantity of inputs with the practiced CA systems compared to the promote ones.

Tables 3 and 4 respectively show the characteristics of the sampled population according to location and to the CA adoption behavior of farmers. We found that household head rarely had no schooling. The majority, at least one half, left school after their primary education. However, some household head (about 25 %), particularly in *Ankazomiriotra* and *Fidirana*, also completed junior high school. We also note that household head in *Ankazomiriotra* and *Vinany* devoted less time to agricultural work in neighboring farms than those in *Fidirana and Inanantonana* suggesting the existence of labor exchange between municipalities.

Table 3 also illustrates that Western Madagascar is a migration area because 37 % of farmers admit being immigrants. Migration flow differs from one municipality to another and can be related to the how far each municipality is from the road. It moves along the road from East to West starting with *Inanantonana*, the most Eastern municipality, then *Ankazomiriotra* and *Vinany* towards the West. *Fidirana*, the most remote municipality, is to the North of *Ankazomiriotra* and *Vinany*.

In *Ankazomiriotra*, migration was shown to be of longer standing: 70 % of immigrants moved to the area before 1991. The migration flow decreased over time thereafter: 17 % of all immigrants arrived after 2000. This result also indicates possible land saturation. However, the average land area of farmers in *Ankazomiriotra* is among the largest, suggesting then an unequal distribution. Monetary poverty is the lowest in *Ankazomiriotra* perhaps because farmers in this area take advantage of the accessibility of various markets (agricultural, labor…) and of off farm non-agricultural activities, all facilitated by their proximity to the road. However, the poverty rate is high about 54 %.

As in *Ankazomiriotra,* migration was of longer standing in *Inanantonana*: 88 % of migrants moved to this area before 1991. The migration flow also decreased thereafter, a sign of land saturation. But contrary to *Ankazomiriotra*, farmers in *Inanantonana* have the lowest average total area (1.64 ha). In addition, they had less opportunities to carry out off farm non-agricultural activities than off farm agricultural activities. 86 % of farmers are indeed below the poverty line in *Inanantonana.*

In *Vinany,* the migration flow was active until 2000: 85 % of immigrants arrived before this date, and their number decreased afterwards. It took longer for migration rates to slow down in *Vinany* than in *Inanantonana*. Currently, monetary poverty in *Vinany* is quite similar to *Inanantonana* where 82 % of farmers are below the poverty line. They have on average the lowest total income across the four municipalities under study.

In *Fidirana,* the migration flow was well distributed across all three periods (before 1991, from 1991 to 2000 and after 2000). It remained active even after 2000, a period during which 32 % of immigrants arrived. This active migration may be due to land accessibility and good fertility of soil in this area: farmers have the highest average total area with 2.43 ha each and 45 % of farmers stated their soil was fertile. Farmers in this area draw most of their income from agricultural activities as few opportunities for non-agricultural activities exist.

Table 4 presents that CA adoption and disadoption rates differ from one municipality to another. This confirms that adoption behavior is context specific even in a same region. It also shows that livelihood assets significantly differed between each category of farmers. Non-tryout farmers are poorly endowed in capital compared to the two other categories of farmers (disadopters and adopters): with younger and less educated household head. Non-tryout farmers did not receive technical supports and advices from the dissemination agents during the six years of lifetime of the BVPI project. While, disadopters and adopters worked with dissemination agents respectively during 3 years and 5 years on average. In addition, non-tryout farmers have on average less land area and sell more workforce than farmers in the two other categories. Regarding the total income per capita, adopters are significantly wealthier than farmers in the other categories, with respect to both on-farm and off-farm incomes.

To summarize, adopters were better endowed in livelihoods assets. Non-tryout farmers were the poorest. And the category of disadopters were intermediary.

Table 3
Characteristics of the sampled population according to municipalities.

Capital	Variables	Municipalities				Sample (n = 240)
		Ankazomiriotra (n = 60)	Vinany (n = 60)	Fidirana (n = 60)	Inanantonana (n = 60)	
Natural	Total land area (ha)	2.17 ^{A} (0.368)	1.73 ^{A} (0.526)	2.43 ^{A} (0.749)	1.64 ^{A} (0.414)	2.02 (0.265)
	Total upland area (ha)	1.56 ^{A} (0.002)	1.06 ^{A} (0.003)	1.79 ^{A} (0.006)	1.10 ^{A} (0.003)	1.42 (0.006)
	Total lowland area (ha)	0.57 ^{A} (0.001)	0.55 ^{A} (0.002)	0.49 ^{A} (0.001)	0.41 ^{A} (0.001)	0.50 (0.000)
	Cultivated upland area (ha)	1.38 ^{A} (0.002)	0.77 ^{A} (0.002)	1.29 ^{A} (0.003)	0.82 ^{A} (0.002)	1.12 (0.001)
	Cultivated lowland area (ha)	0.54 ^{A} (0.001)	0.54 ^{A} (0.001)	0.47 ^{A} (0.001)	0.4 ^{A} (0.000)	0.46 (0.000)
	Good perception of the soil fertility	40 %	38 %	45 %	33 %	39 %
Human/Social	Education level of the household head	7 ^{A} (0.008)	6 ^{AC} (0.013)	5 ^{A} (0.009)	5 ^{BC} (0.007)	6 (0.004)
	No schooling	0%	7%	13 %	3%	5%
	Primary school	59 %	73 %	56 %	84 %	68 %
	Junior high school	31 %	11 %	27 %	9%	21 %
	Senior high school	9%	9%	4%	4%	6%
	University	0%	0%	0%	0%	0%
	Migrant (yes)	37 %	39 %	40 %	35 %	37 %
	Year of arrival of migrant					
	before 1991	70 %	44 %	36 %	88 %	64 %
	from 1991 to 2000	13 %	41 %	32 %	10 %	20 %
	After 2000	17 %	15 %	32 %	2%	16 %
	Age of the household head (year)	49 ^{A} (0.036)	48 ^{A} (0.049)	46 ^{A} (0.035)	48 ^{A} (0.033)	48 (0.019)
	CA technical support (year)	0.24 ^{A} (0.003)	0.72 ^{A} (0. 009)	0.19 ^{A} (0.002)	0.23 ^{A} (0.002)	0.28 (0.003)
	Awareness about CA	100 %	100 %	100 %	100 %	100 %
Financial/Physical	Number of cattle (unit)	3 ^{A} (0.014)	3 ^{A} (0.017)	2 ^{A} (0.008)	1 ^{A} (0.006)	2 (0.006)
	Number of family active workers (unit)	3 ^{A} (2)	3 ^{A} (1)	2 ^{A} (2)	1 ^{A} (2)	2 (2)
Social capital	Labor sold by household head (man.day)	25 ^{A} (0.139)	12 ^{A} (0.151)	69 ^{B} (0.271)	85 ^{B} (0.215)	53 (0.115)
Financial capital	On farm income per capita in local currency (*Ariary*)	593,225 ^{A} (2502)	273,659 ^{A} (1298)	535,243 ^{B} (1696)	266,382 ^{A} (664)	443,510 (1006)
	Off income per capita in local currency (*Ariary*)	448,394 ^{A} (2033)	119,416 ^{B} (850)	192,400 ^{A} (567)	132,530 ^{A} (559)	253,711 (767)
	Total income per capita in local currency (*Ariary*)	1,053,758 ^{AB} (4222)	407,547 ^{A} (1479)	731,050 ^{B} (1976)	401,298 ^{A} (971)	704,428 (1617)
	Below the national poverty line (600 000 Ariary per capita)	54 %	82 %	58 %	86 %	68 %

Note: Kruskal–Wallis non-parametric equality of mean rank test for continuous variables, standard error of mean in bracket. Dunn test defined group at the 5% level (Dinno, 2015).

3.2. Tryout and disadoption rate of CA

The extent of the CA tryout and disadoption among farmers was measured by the number of farmers who reported trying out, adopting or disadopting CA during the 2013/2014 cropping year (Table 5).

The sample was composed of 120 beneficiaries and 120 non-beneficiaries of the BVPI project. Table 5 emphasizes a high level of tryout in the whole sample; farmers who put CA to the test (adopters and disadopters) account for 56 % of the sample (134 out of 240 farmers) including 14 non-beneficiary farmers. Farmers seem to be interested in technical change. However, among these farmers, the disadoption rate was high: about 80 % (102 out of 134 farmers). All the non-beneficiary farmers who put CA to the test abandoned the technology the following years. The level of disadoption was particularly high after the completion of the BVPI project (Table 6).

Table 7 presents the reasons why disadopter farmers disadopted CA. We must note that data related to the reasons for CA adoption was also collected from adopter farmers. However, it was not processed because the collected information appeared to be similar to the reasons put forward by the dissemination agents of the BVPI project. We thus considered at that time that reporting the reasons for CA adoption would not particularly add value to the study. Consequently, the reasons for disadoption drew our attention as the data seemed to be more relevant and interesting to process in our study.

Most disadopters reported technical, economic and financial reasons for disadoption and these are in line with the results of other studies in Madagascar and in other sub-Saharan African countries (Andersson and D’Souza, 2014; Penot et al., 2015). Reasons for disadoption reported by farmers are: (i) weed pressure due to the low quantity of biomass provided by the cover crop; (ii) liquidity constraints calling for additional input (e.g. fertilizer, seeds, labor); (iii) loss of incentives despite the low rewards provided by the technology. Some farmers had even experienced lesser yields from CA as compared to non-CA technology during the trial period. In fact, a multi-scale analysis in seven countries in sub-Saharan Africa provided by Corbeels et al. (2014) pointed out that CA is unlikely to result in a short-term increase in yields and farm incomes; (iv) lack and/or end of technical support, however CA is complex; (v) the need for two to three fallow years of stylosanthes (and with zero crop production), which requires a large upland area.

Some disadopters also underlined social reasons related to social cohesion including sociability or conflict with other farmers and/or with the dissemination agent. The project thus has a “social weight” in local communities which dissipates after the end of the project. It shows the very specific link that local farmers have with dissemination agents. There were also farmers who had a bad relationship with dissemination agents and this contributed to their decision to disadopt CA.

Table 7 shows that some farmers disadopted CA as soon as they saw that soil fertility was restored. This finding is slightly uncommon because other studies have more often shown a positive correlation between CA adoption and soil problems (e.g. Knowler and Bradshaw, 2007), rather than between CA disadoption and restoration of the soil fertility.

3.3. Factors influencing the tryout and disadoption of CA

Table 8 presents the results of the censored probit model and reports average marginal effects. In this paper, we analyse the behavior of farmers related to the CA tryout and disadoption regardless of whether farmers have benefited from the BVPI project or not. Thus, in the second model, the two subcategories of disadopters (14 non-beneficiary farmers and 88 beneficiary farmers) have been collapsed into one. In any case, the subsample of non-beneficiary farmers who disadopted CA

Table 4
Characteristics of the sampled population according to the CA adoption status.

Assets	Variables	Non tryout (n = 106)	Disadopters (n = 102)	Adopters (n = 32)	Sample (n = 240)
Municipality/ Village	Ankazomiriotra	20%	33%	18%	25%
	Vinany	26%	22%	30%	25%
	Fidirana	27%	24%	21%	25%
	Inanantonana	26%	22%	30%	25%
	In a remote area (1 = yes)	50%	49%	53%	50%
Natural capital	Total land area (ha)	1.92 ^{A}	2.11 ^{B}	4.83 ^{C}	2.02
		(0.002)	(0.005)	(0.036)	(0.002)
	Total upland area (ha)	1.33 ^{A}	1.50 ^{B}	3.70 ^{C}	1.42
		(0.002)	(0.004)	(0.030)	(0.002)
	Total lowland area (ha)	0.47 ^{A}	0.53 ^{B}	1.01 ^{B}	0.49
		(0.000)	(0.001)	(0.010)	(0.000)
	Cultivated upland area (ha)	1.05 ^{A}	1.23 ^{B}	2.42 ^{C}	1.12
		(0.001)	(0.003)	(0.018)	(0.001)
	Cultivated lowland area (ha)	0.44 ^{A}	0.49 ^{B}	0.75 ^{B}	0.45
		(0.0)	(0.0)	(0.0)	(0.000)
	Good perception of the soil fertility	42%	30%	31%	35%
Human capital	Education of the household head (year)	5 ^{A}	7 ^{B}	7 ^{B}	6
		(0,005)	(0.008)	(0.026)	(0.004)
	No schooling	7%	2%	0%	4%
	Primary school	72%	57%	52%	63%
	Junior high school	15%	28%	42%	24%
	Senior high school	7%	11%	6%	8%
	University	0%	2%	0%	1%
	Age of household head (year)	46 ^{A}	53 ^{B}	53 ^{B}	48
		(0.02)	(0.046)	(0.126)	(0.019)
	CA technical support (year)	0 ^{A}	3 ^{B}	5 ^{C}	1.9
		(0)	(0.2)	(0.3)	(1.1)
Social capital	Labor sold by household head (man.day)	64 ^{A}	11 ^{B}	0 ^{B}	53
		(0.139)	(0.151)	(0.271)	(0.215)
Physical capital	Number of cattle (unit)	2 ^{A}	3 ^{B}	4 ^{C}	2
		(0.006)	(0.013)	(0.035)	(0.006)
	Number of family active workers (unit)	2 ^{A}	3 ^{A}	3 ^{A}	3
		(0.002)	(0.004)	(0.014)	(0.002)
Financial capital	On farm income per capita in local currency (*Ariary*)	402,106 ^{A}	588,507 ^{A}	727,742 ^{B}	4,43,510
		(1,033)	(3,026)	(5,067)	(1,006)
	Off farm income per capita in local currency (*Ariary*)	226,930 ^{A}	353,851 ^{A}	383,076 ^{A}	2,53,711
		(754)	(2,511)	(4,342)	(767)
	Total income per capita in local currency (*Ariary*)	635,239 ^{A}	953,233 ^{B}	1,123,598 ^{C}	7,04,428
		(1,650)	(4,932)	(7,466)	(1,617)
	Below the national poverty line 600 000 Ariary per capita (1 = yes)	74%	62%	28%	63%

Note: Kruskal–Wallis non-parametric equality of mean rank test for continuous variables, standard error of mean in bracket. Dunn test defined group at the 5% level (Dinno, 2015).

is too small (14 farmers) to perform a correct statistical analysis.

3.3.1. *A long learning time*

The results reported in Table 8 validate our hypothesis stating that farmers who received technical support for CA during the six years of the lifetime of the BVPI project were less likely to disadopt CA than those who did not receive such long-term support, even after the completion of the project. Pedzisa et al. (2015) reported similar results. This result is in line with the qualitative analysis when farmers linked the end of CA technical supports to the disadoption decision. For farmers, combining new agricultural technology with the traditional system requires a long learning process. The technical support and advice provided improved farmers' knowledge, skills and know-how. This kind of learning process can be defined as learning by using (Rosenberg, 1982), meaning farmers learn how to use CA and are progressively able to adapt the technology to their own constraints. CA dissemination actions carried out in the *Lake Alaotra* area in Madagascar showed that the adoption process required 7–10 years' time in 3 different stages (learning/experimentation/consolidation) (Penot et al., 2017).

3.3.2. *Endowment on upland area*

Results also confirm the assumption that an increase in cultivated upland area affects positively the tryout and negatively the disadoption of CA. That's because the CA technology using the stylosanthes as cover crop, specifically practiced in upland area, requires two to three years of fallow after harvest of the subsistence crop (e.g. rice or maize). As farmers facing land scarcity reduce the length of the fallow periods on their plots (Jouve, 1991), only farmers with large upland area are able to practice the required fallow of this type of CA. These findings are in line with the qualitative analysis which report that a large upland area is required to maintain CA adoption (Table 7).

Regarding the farmers' subjective perception of soil quality, a negative correlation with the tryout and a positive correlation with the

Table 5
Tryout/ Disadoption level of CA in Western of *Vakinankaratra*, Madagascar.

Decision-making	Non-Beneficiary (120)		Beneficiary (120)	
Tryout rate	Non tryout (106)	Tryout (14)	Tryout (120)	
Disadoption rate	Non tryout (106)	Disadopters (14)	Disadopters (88)	Adopters (32)

Table 6
Disadoption level of CA in Western of *Vakinankaratra*, Madagascar during the lifetime and after the completion of the BVPI project.

Category of farmers	Sample	Non tryout	Tryout		
			Adopters	Disadopters	
				During the lifetime of the BVPI project	After completion of the BVPI project
Number of observations	240	106	32	28	74

disadoption were expected. However, both relationships are shown to be insignificant in Table 8. This is inconsistent with several studies (e.g. Feder et al., 1985; Feder and Umali, 1993; Srisopaporn et al., 2015) which pointed out that soil quality influences farmer's decisions regarding CA adoption. To better capture the relationship between soil quality and CA adoption, it would be interesting to triangulate farmers' perceptions with the results of soil analysis. An overview of the extent of land degradation and the creation of a database on soil fertility would be necessary in this case.

3.3.3. Poverty

Results demonstrate that poor farmers below the national poverty line (600 000 Ariary per capita per day) are less likely to try out CA than farmers above the poverty line. In fact, poor farmers are reluctant to adopt new technology because they are generally more risk-averse (Barrett et al., 2001; Marra et al., 2003; Ghadim et al., 2005), less tolerant of uncertainty (Grabowski et al., 2016), more cash-constrained (Haushofer and Fehr, 2014) and more impatient than non-poor farmers (Carvalho, 2010). Specifically, when CA requires the use of stylosanthes as a cover crop, poverty constrained the tryout because yield improvement was uncertain and delayed over time. Some studies have shown that the increase in soil fertility and in yield may take in the long run (Corbeels et al., 2014; Thierfelder et al., 2013a,b, 2015). On-farm experiments show that, compared to non-CA technology, CA significantly improves crop yields after three to five seasons (Thierfelder et al., 2013b) but it can also require ten years (Giller et al., 2009). In addition, managing this type of CA is labor intensive. It requires 80–90 man.days per ha (Cellule de projet BVPI SE/HP, 2013) or the purchase of equipment such as a roller (Penot et al., 2015). CA technology thus has additional cost requirements as compared to non-CA technology. Moreover, after the first three years, the BVPI project put an end to all the incentives that had initially motivated farmers to try out CA. Poor farmers are thus vulnerable to technical change since they are not able to bear the costs of switching to CA practices.

3.3.4. Agricultural work

As expected, the results show that the higher the number of working days (man.day) devoted by the household head to agricultural work on neighboring farms, the lower the likelihood that the farmer will try out CA on its own farm. That's because agricultural workers allocate part of their time to off-farm agricultural activities, as there are few opportunities for off-farm non-agricultural activities. They work initially on neighboring farms before working on their own farm. Consequently, they have less time available to devote to CA on their own farm. In addition, CA is considered as a complex technology which requires a long learning time.

Explanations of such a correlation are also linked to land endowment, availability of labor and poverty. Table 3 reports the average upland area of farm but it often hides disparities. Farms with less land regularly have more available labor that can be sold to perform off-farm agricultural work. The head of household on these farms, but also other household members, do agricultural work to supplement their income. Other explanations may relate to poverty because agricultural work has close links with poverty in Madagascar (Minten et al., 2003). The fact that the head of household combines the status of farmer and agricultural worker makes them more vulnerable to chronic and transitory poverty (Gondard Delcroix, 2009). Farms that sell agricultural labor are the poorest and, conversely, those that buy the most labor have the highest incomes (Andrianantoandro and Bélières, 2015). Referring to the System of Rice Intensification (SRI) in Madagascar, Jenn-Treyer et al. (2007) argued that poor farmers associate the opportunity costs and risks related to the practice of technology with random gain at the end of the agricultural season and those related to agricultural work with certain and immediate monetary gain. All these explanations are

Table 7
Reasons of CA disadoption reported by farmers.

Reasons for disadoption		Responses	Explanation
Financial	Liquidity constraint	16 of 74	"Lack of financial capital: CA requires a lot of expensive farm inputs " "Mowing the cover crop costs a lot"
	Lack of access to cover crop seeds	6 of 74	"The cover crop seeds are expensive"
	Lack of fertilizer	4 of 74	"After the project stopped the access to credit for the acquisition of fertilizer, I disadopted CA practices" "CA requires fertilizers, but fertilizers are expensive"
Technical	End of technical support after the project completion	6 of 74	"After project ended, technical support was no longer provided"
	Not mastered technology	3 of 74	"CA is too complicated" "Cover crop is uncontrolled"
	Problem of weed infestation not solved	2 of 74	"CA does not overcome weed pressure"
	Lack of technical supports	2 of 74	"Lack of training in CA practices"
Economic	No increase in yield	11 of 74	"Compared to non-CA, crop yields in CA are low" "I had a yield loss in the first trial year"
	Labor constraints	10 of 74	"Not enough agricultural workers since my wife died" "I'm not strong enough because I'm old" "Managing the cover crop required additional labor"
	Requirement of large upland area	6 of 74	"The cover crop fallow requires a lot of upland area, I have no fields left to cultivate"
Social	Conflict with another farmer	4 of 74	"Neighbors' cattle grazed the cover crop"
	Conflict with the dissemination agent	3 of 74	"Disappointment because the dissemination agent didn't keep his promise" "The dissemination agent did not sell cover crop seeds as expected"
Other	Good perception of the soil fertility	1 of 74	"Plot becomes fertile"

Table 8
Heckprobit model of CA disadoption with sample selection.

		WITHOUT SELECTION VARIABLES				WITH SELECTION VARIABLES			
		TRYOUT		DISADOPTION		TRYOUT		DISADOPTION	
		Tryout (Adopters and Disadopters) vs. Non-tryout		Disadopters vs. Adopters		Tryout (Adopters and Disadopters) vs. Non-tryout		Disadopters vs. Adopters	
	Unit	Marginal effect (SE)	*p value*	Marginal effect (SE)	*p value*	Marginal effect (SE)	*p value*	Marginal effect (SE)	*p value*
Municipalities *Ankazomiriotra* versus *Inanantonana*		−0.050 (0.084)		+0.330 (0.098)	***	−0.015 (0.084)		+0.337 (0.091)	***
Vinany versus *Inanantonana*		−0.073 (0.085)		+0.113 (0.085)		−0.073 (0.084)		+0.117 (0.085)	
Fidirana versus *Inanantonana*		−0.099 (0.085)		+0.206 (0.083)	***	−0.099 (0.084)		+0.207 (0.081)	***
In a remote area	1 if yes	+0.093 (0.060)		−0.063 (0.061)		+0.094 (0.060)		−0.060 (0.057)	
Cultivated upland area	ha	+0.060 (0.028)	**	−0.064 (0.019)	***	+0.059 (0.028)	***	−0.065 (0.021)	***
Good perception of the soil fertility	1 if yes	−0.057 (0.060)		−0.071 (0.053)		−0.057 (0.060)		−0.073 (0.066)	
CA technical supports	year			−0.057 (0.053)	***			−0.058 (0.010)	***
Agricultural work of the household head	Man.days	−0.007 (0.001)	***	+0.000 (0.058)		−0.007 (0.001)	***		
Below the national poverty line	1 if yes	−0.146 (0.049)	***	+0.008 (0.058)		−0.149 (0.047)	***		
Number of observations	240			134 (uncensored obs)		240		134 (uncensored obs)	
Athrho	1.058 (0.850)					1.149 (0.569)			
Rho	0.785 (0.326)					0.817 (0.188)			
LR test of independence of equations (rho = 0)	0.84					3.13			
Prob > chi2	0.35					0.06			
Wald chi2	16.77					15.97			
Prob > chi2	0.07					0.02			

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

Table 9
Regression results of selection variables on IMR (n = 240).

IMR	Coeff	Standard error	*p value*
Agricultural employment	−0.004	0.001	
Below the national poverty line	−0.031	0.040	
Constant	+0.451	0.065	***
Adjusted R^2	0.003		

Coefficient significantly different from 0 for $^*p < .10$, $^{**}p < .05$, $^{***}p < .01$.

in line and consistent with our findings which show that poverty decrease the likelihood a farmer will try out CA.

3.3.5. Adoption behavior at municipality level

Table 8 emphasizes that the geographical isolation has no effect neither on the tryout none on the disadoption. This suggests that the geographical coverage of the BVPI project for the dissemination of CA was effective: all the targeted areas of the project were covered, even farmers located in remote area. This invalidates our hypothesis that dissemination agents had difficulty accessing remote area.

But, the disadoption decision of CA significantly differed across municipalities. Farmers in *Ankazomiriotra* and *Fidirana* are more likely to disadopt CA than those in *Inanantonana*, illustrating that the CA disadoption is context specific and differs from one municipality to another. This finding also suggests a possible social learning effect within municipalities regarding the tryout and disadoption when farmers learn from others. Schlag (1996) explains that farmers assess the performance of a technology and indeed devote a necessary period to observe successes and failures of peers in the implementation of a technology. They adopt a technology once they see enough empirical evidence to convince them that the technology is worth adopting. But our study does not allow us to draw more precise conclusions on this matter.

4. Conclusion and policy implications

This paper analyses factors affecting the tryout and disadoption decisions of farmers with respect to CA using primary data collected in Madagascar. The SRL framework is mobilized to structure the analysis. From a methodological point of view, this study demonstrates that the SRL framework appears to be a relevant analytical tool for a better understanding of factors affecting the CA tryout and disadoption. The different components which make up the framework are helpful in identifying the leverage points at play in the promotion of CA among farmers.

Our results concern CA system based on the use of stylosanthes and are specific to our case-study areas in Western Madagascar. However, they entail important policy implications which can likely be extended to other countries in sub-Saharan Africa where CA has been put to the test within small family farms through donor-funded projects and programs.

Our findings show a high tryout rate of CA - 56 % of the whole sample tried out CA - and also a high disadoption rate thereafter - 80 % of farmers who tried out CA later disadopted. Farmers seem to be interested in technical change but adopting such a technology long-term proved difficult. The study reveals that CA system using stylosanthes require major investment due to the shortfall of harvests caused by the necessary fallow seasons, to the arduous nature of the managing the cover crop, to the investment in specific equipment to help manage the cover crop and to the need for large area of upland. In addition, such systems are less effective at increasing yield in the short run than non-CA technology. Some farmers even experienced a loss of yield during the trial period. As a consequence, poor farmers were excluded from the adoption dynamic of CA. They were less likely to try out CA than non-poor farmers as they could not withstand the cost of conversion to this agricultural system. Agricultural workers also behaved in the same way since agricultural work is implicitly linked to poverty.

The disadoption decision was mainly due to lack of access to capital. Farmers with labor constraints or who were unable to invest in new equipment (physical capital) disadopted because they couldn't improve the low labor productivity of the technology. Similarly, farmers with small upland area (natural capital) were less likely to try out and to maintain adoption than the better endowed farmers because they couldn't overcome the shortfall due to the need to leave upland area fallow.

This study also highlights how social capital affects farmers' disadoption decisions. For example, social cohesion including sociability or conflict with other farmers and/or the dissemination agent can cause farmers to disadopt CA. The longer the farmers are supported during the lifetime of the project (which is also a social and human capital), the less likely they are to disadopt CA even after the completion of this project. Our results do not allow us to define the necessary time for the learning process precisely. However, they suggest that technical change and innovation require support over a long period and bring into question the typical duration of development projects in sub-Saharan Africa. Our results challenge the capacity of such “project based” development actions to reach smallholders during the usual lifetime of the project which is a maximum of five years.

To tackle the problem of land degradation in this area and to accelerate ecological transition over time, our results highlight the need to tailor CA technology and/or to propose wide range of techniques to fit in with to the diversity of farm characteristics and of their asset holdings. It will be possible to mix CA (the whole or a partial package) with other agroecological practices at farm level. Moreover, technical changes and farmers' innovations need to be supported for a longer period. For this purpose, the setting up of permanent structures similar to innovation systems, involving farmers, farmer groups, market suppliers and buyers, extension workers and researchers in the promotion of CA, should be reinforced.

Authorship contributions

Category 1

H.M. Razafimahatratra, C. Bignebat, H. David-Benz, J-F. Bélières, E. Penot: Conception and design of study

H.M. Razafimahatratra, J-F. Bélières: Acquisition of data

H.M. Razafimahatratra, C. Bignebat: Analysis and/or interpretation of data:

Category 2

H.M. Razafimahatratra: Drafting the manuscript

H.M. Razafimahatratra,

J-F. Bélières, H. David-Benz: Revising the manuscript critically for important intellectual content.

Category 3

M. Razafimahatratra, C. Bignebat, H. David-Benz, J-F. Bélières, E. Penot:Approval of the version of the manuscript to be published.

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