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Integrated soil fertility management: From concept to practice in eastern DR Congo

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Abstract

Many paradigms on sustainable agricultural intensification adhere to a combination of different and complementary agricultural technologies. Whether such a paradigm survives in practice depends on how, and if, farmers combine these technologies on their fields. The main biophysical rationale for farmers to combine different technologies is the existence of reinforcing yield effects. But farmers may face constraints that lead to a socio-economic rationale for interrelationships in the application of different technologies that contradict the biophysical rationale. There is little evidence on how and under which conditions farmers combine different agricultural technologies. In this paper, we focus on integrated soil fertility management (ISFM) and investigate how the concept is put into practice in South-Kivu, eastern Democratic Republic of the Congo (DRC). ISFM necessarily includes the use of improved germplasm, organic inputs and mineral fertilizer, and strongly emphasizes the complementarities and synergies that can arise when these technologies are jointly applied. We investigate whether these different ISFM technology components are applied jointly, sequentially or independently, and whether that matters for the long term use of the technology. We use original survey data from 500 farms in two territories in South-Kivu. We combine a descriptive statistical analysis and a factor analysis to understand interrelationships in the application of ISFM technologies, and relate it to technology characteristics and the local context. We find that few farmers in the area have reached "full ISFM", and that application of ISFM technologies occurs sequentially, rather than simultaneously. At plot level two subsets of technologies can be distinguished. The first subset is characterized by more resource-intensive technologies (row planting and mineral fertilizer). The second consists of less resource-intensive technologies (improved legume and maize varieties). These subsets behave as supplements rather than as complements, and adoption within and among each subset is more sequential than simultaneous. Generally, farmers adopt less resource-intensive technologies first, and then adopt more resource-intensive technologies. Our results imply that there is a disconnect between the theoretical arguments in the agronomic ISFM literature, and the actual patterns of ISFM application on farmers' fields.

Keywords: sustainable intensification; complementary agricultural technologies; application patterns; integrated soil fertility management; sub-Saharan Africa; eastern DR Congo.

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1. Introduction

Despite recent positive trends, Sub-Saharan Africa (SSA) is the only region in which the share of people living in extreme poverty is still as high as 30 years ago, and in which per capita food production did not enjoy a substantial growth over this period (World Bank, 2013). It has been shown that an increase in agricultural production can strongly contribute to the alleviation of food insecurity and the reduction of poverty (Irz et al., 2001; Kaya et al., 2013). In many areas, it is either impossible or undesirable to expand the area under cultivation. Increasing output thus requires agricultural intensification and productivity growth. Achieving this in a sustainable way is a main challenge.

During the past decades, a plethora of views, paradigms and concepts have arisen related to sustainable agriculture and natural resource management, such as integrated natural resource management (INRM), integrated nutrient management (INM), system of rice intensification (SRI), conservation agriculture (CA), organic agriculture (OA), integrated pest management (IPM), agroforestry (AF), precision agriculture (PA), integrated soil fertility management (ISFM) and many others (Lee, 2005; Rosegrant et al., 2014). These concepts all promote a combination of different agricultural technologies. These are generally not mutually exclusive nor completely overlapping, and while the titles might sound novel, several technologies have long been employed by farmers (Knowler and Bradshaw, 2007). Despite this diversity in concepts, all praise the merits that come from combining different technologies (Rosegrant et al., 2014).

In this paper, we focus on integrated soil fertility management (ISFM) and investigate how the concept is put into practice in South-Kivu, eastern Democratic Republic of the Congo (DRC). The fundamentals of ISFM are that agricultural intensification cannot occur without investments in soil fertility, and that both organic and mineral inputs are needed to sustain soil health and increase crop production (Vanlauwe et al., 2010). ISFM necessarily includes the use of improved germplasm, organic inputs, and mineral fertilizer, applied using good agronomic practices, and adapted to local conditions (Vanlauwe et al., 2010). The concept strongly emphasizes the complementarities and synergies that can arise when several technologies are jointly applied (Place et al., 2003; Vanlauwe et al., 2010).

We specifically explore how the emphasis of ISFM on integrating agricultural technologies is translated in practice. We investigate whether the different ISFM technology components are applied jointly, sequentially or independently, and whether that matters for the long term use of the technology. With this we address a specific knowledge gap in the agricultural literature. There is rapid progress in biophysical and agronomic research on ISFM and related concepts of agricultural sustainability and agricultural intensification, leading to insights into the complementarities and synergies between agricultural technologies. Little is known about the implementation of such concepts and the application of complementary technologies on farmers' fields (Place et al., 2003). Evidence on whether and how farmers combine (or substitute) different agricultural technologies and complementary components of composite technology packages such has ISFM is scarce (Place et al., 2003). How farmers combine different agricultural technologies is crucial as it determines how concepts such as ISFM are put into practice, which may be very important for the success of these concepts in bringing about agricultural productivity growth and increased sustainability.

We specifically focus on ISFM in South-Kivu, eastern DRC. This focus is particularly relevant because of the urgent need for agricultural intensification and agricultural productivity growth in the region. High population density and intensive cultivation without the application of external inputs or other nutrient management technologies are leading to severe problems of soil depletion and erosion (Pypers et al., 2011), which reinforces a problem of severe poverty and food insecurity. In addition, South-Kivu is an interesting area to study how different ISFM components are applied on farmers' fields because farmers have been exposed to new agricultural technologies only recently. Only since 5 to 10 years, interventions other than emergency relief are being organized in the region (Rossi et al., 2006).

2. Putting concepts into practice

2.1 Interrelated decisions for technology application by farmers

Many paradigms on sustainable agriculture adhere to a combination of different and complementary agricultural technologies. Whether such a paradigm survives in practice depends on how farmers combine (or substitute) these technologies on their fields. Based on the work by Rauniyar and Goode (1992), we classify interrelationships in the application of different technologies by farmers in three main categories: independent, sequential, or simultaneous. Technologies are independent if the probability of application of one technology is not conditioned by the adoption of another technology. Sequential adoption takes place when the probability of application is conditioned on the adoption of another technology that precedes it. Finally, simultaneous adoption occurs when the probability of applying one technology is conditional on the adoption of another technology (Rauniyar and Goode, 1992).

The main biophysical rationale for farmers to combine different technologies is the existence of interaction effects on yield. Joint or sequential application of several technologies can have important non-linear effects, reducing or reinforcing the impact of a single technology on agricultural output, and/or leading to lasting effects on soil fertility and future productivity (Vanlauwe et al., 2010). For example, the agronomic efficiency of nitrogen (NAE) in inorganic fertilizers is shown to significantly improve in combination with manure, and similarly, NAE is significantly higher when applied on improved varieties (Vanlauwe et al., 2011).

However, these yield interaction effects do not necessarily translate into genuine complementarity (Feder, 1982). Several studies show that farmers apply only a subset of technologies, even though applying the whole package would be more profitable (Byerlee and de Polanco, 1986; Leathers and Smale, 1991; Moser and Barrett, 2003; Van den Broeck et al., 2013). There are different reasons that can explain this phenomenon. When making agricultural management decisions, farmers face constraints in access to and allocation of agricultural resources (cash, labour, land etc.), and risk, and social or cultural constraints (Byerlee and de Polanco, 1986; Feder, 1982; Moser and Barrett, 2006). Such constraints for different technologies can interact, leading to a socio-economic rationale for interrelationships in the application of different technologies that possibly contradicts the biophysical rationale.

First, farmers can only adopt a specific technology if they know about it (Diagne and Demont, 2007; Kabunga et al., 2012; Lambrecht et al., 2014b). In some areas, awareness of some agricultural technologies is still limited, and therefore adoption of these technologies is simply not considered by many farmers (Lambrecht et al., 2014b), even if they are complementary to other technologies they do know. Furthermore, insufficient availability is repeatedly found to constrain the use of technologies such as mineral fertilizer or improved seed varieties (e.g. Croppenstedt et al., 2003; Shiferaw et al., 2008). Technologies are often introduced at different time periods, and awareness and availability diffuses at different times and with different speeds in the population, providing a very simple explanation for sequential adoption patterns. In other cases, technologies are diffused in packages, for example seed and fertilizer, which favors simultaneous adoption patterns (Smale and Heisey, 1993).

Second, if technologies resulting in reinforcing yield effects are demanding high levels of the same resources, farmers may be forced to choose between, rather than combine, these technologies. Credit constraints are shown to inhibit the application of cash-intensive technologies such as mineral fertilizer or improved varieties (Croppenstedt et al., 2003; Leathers and Smale, 1991). Similarly, the adoption of labour intensive technologies may be limited due to constraints in access to family labour or hired labour (Lee, 2005; Marenya and Barrett, 2007; Moser and Barrett, 2003). For example, Moser and Barrett (2006) find that seasonal labor and liquidity constraints impede poor Malagasy farmers to adopt the high-yielding SRI system, since it necessitates the joint application of several labour-intensive technologies. In such cases, the most profitable technology is likely to be adopted first (Byerlee and de Polanco, 1986; Leathers and Smale, 1991).

Third, risk may play a role. On the one hand, a farmer may choose to apply a single component rather than the whole composite technology package in order to reduce risk and learn more about an innovation (Foltz et al., 2011; Leathers and Smale, 1991; Smale and Heisey, 1993). Most smallholder farmers in developing countries are to some extent risk-averse. As new technologies are often perceived riskier, they may not be widely adopted until they are properly understood (Kabunga et al., 2012). Early adopters will then adopt the components of a package sequentially, while those adopting later may adopt the whole package simultaneously (Leathers and Smale, 1991). On the other hand, risk complementarities may exists as well. For example, Wakeyo and Gardebroek (2013) find that application of water harvesting technologies stimulates the use of mineral fertilizer by smallholder farmers in Ethiopia through its risk-reducing effects.

Fourth, the degree of complementarity among different technologies can also explain why some technologies are adopted simultaneously, while others are adopted sequentially or independently. To the extreme, some technologies are by nature sequential (Khanna, 2001). This means that the first technology can be used separately, but the second technology cannot be used unless the first technology is applied. This has been noted for example by Khanna (2001) for the use of variable rate technology and soil testing in precision agriculture.

Finally, a package of newly introduced technologies is not always a-priori better than the local technologies or a subset of technologies (Doss, 2006; Moser and Barrett, 2003). The outcome of experiments on research stations, or researcher-led or -supported on-farm experiments, is often significantly higher compared to output on farmer-managed plots. This may be due to different agro-ecological conditions and managerial capacities, or due to significant variations in local prices for inputs and outputs, affecting profitability. Moreover, technologies that are very different compared to the local practices are less easily adopted than technologies that are less distorting towards cultural traditions (Moser and Barrett, 2003; 2006).

2.2 Analyzing interrelationships

Despite clear indications of interdependence in the application of agricultural technologies, the majority of studies do not, or inadequately, address these interrelationships when analyzing farmers' technology adoption behavior. Most adoption studies focus on one single technology. For composite technology paradigms, some studies analyze the adoption of any of the technology components (e.g. Knowler and Bradshaw, 2007; Puente et al., 2011) while others analyze the adoption of all technology components jointly (e.g. Moser and Barrett, 2006). There are a number of studies in which adoption of two or more technologies are analyzed simultaneously, allowing for correlation between the adoption decisions (e.g. Kassie et al., 2013; Marenya and Barrett, 2007; Teklewold et al., 2013). Several other studies look at the number of technologies adopted as a measure of adoption intensity (e.g. Wollni et al., 2010; Sharma et al., 2010; Teklewold et al., 2013). While leading to important insights, these studies do not take into account the typical interactions between different technology components.

A limited amount of studies have convincingly treated the interrelationship between two technologies (Dorfman, 1996; Ersado et al., 2004; Smale and Heisey, 1993; Wakeyo and Gardebroek, 2013), but studies that focus on the interrelationships between more than two different agricultural technologies are scarce. Byerlee and de Polanco (1986) describe the adoption of three agricultural technologies and show that farmers follow a stepwise approach to adopt a package, even though the components are strongly complimentary, and that the followed steps rationally reflect the characteristics of each component and the interactions.

Rauniyar and Goode (1992) investigate the interrelationships between seven different technologies using factor analysis, and observe an adoption pattern consisting of three distinct packages of technologies.

In this paper, we combine a descriptive statistical analysis and a factor analysis to understand interrelationships in the application of ISFM technologies, and relate it to technology characteristics and the local context.

3. Context

3.1 The case study

Our research area comprises two territories, Walungu and Kabare, in the highlands of South-Kivu, Eastern DRC. DRC is ranked lowest in the human development index ranking (United Nations Development Program, 2013) and in the GDP per capita ranking (World Bank, 2013). An estimated 71% of the population in DRC lives below the national poverty line. In South-Kivu, the poverty rate is even higher, with up to 85% of the population living below the national poverty line (World Bank, 2013; Ansoms and Marivoet, 2010).

Agriculture accounts for 45% of GDP in the country (World Bank, 2013). For the rural population in South-Kivu, agriculture is the main income-generating activity. Farmers 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, with more than 250 inhabitants per km² in Kabare and Walungu territories (Unité de Pilotage du Processus DRSP, 2005), which results in high land pressure. For more than a decade, violent conflict in the region has inhibited research and development initiatives other than emergency relief (Rossi et al., 2006). Agricultural intensification and investment in land productivity are urgently needed in the region, but most farmers have no access to information about improved agricultural technologies nor to agricultural inputs such as mineral fertilizer and improved seeds (Pypers et al., 2011).

In 2006, the Consortium for Improving Agriculture-based Livelihoods in Central-Africa (CIALCA)[3] started a research and extension program on ISFM in South-Kivu. The program is

[3] The Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA) coordinates projects by Bioversity International, TSBF-CIAT and IITA, and works specifically in DRC, Burundi and Rwanda.

located in selected program villages in four groupements[4]: Burhale and Lurhala in Walungu territory, and Kabamba and Luhihi in Kabare territory. 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 range of extension activities, such as radio programs, discussion meetings, demonstration trials, and on-farm trials, were carried out to distribute information on ISFM technologies (Lambrecht et al., 2014b).

3.2 ISFM in South-Kivu

Vanlauwe et al. (2010) define ISFM as "*a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs and improved germplasm, combined with the knowledge on how to adapt these practices to local conditions, aiming to maximize agronomic use efficiency of the applied nutrients and improved crop productivity*". ISFM can be described as a set of good soil management technologies that can be applied in an integrated fashion. While each component can have a positive contribution to soil fertility and crop productivity, the aim is to integrate multiple technologies in order to exploit complementarities among different technologies (Marenya and Barrett, 2007; Place et al., 2003; Vanlauwe et al., 2010).

The use of animal manure, organic fertilizer and legume intercropping are well-established technologies in South-Kivu (Ouma et al., 2011), but mineral fertilizer, row planting, and several improved crop varieties were newly introduced by the program (Lambrecht et al., 2014a). The program set up demonstration trials on plots of the participants (either plots belonging to the association or plots belonging to individual farmers) to show differences between the traditional practice and the use of improved ISFM technologies. The latter include improved legume, cassava, and maize varieties, specific crop arrangements (hereafter referred to as 'row planting'), and mineral fertilizer application, which are also the technologies we are specifically looking at in this study.

[4] The groupement (grouping) is the administrative unit above the village in DRC. A territory comprises sectors, groupings within the sectors, and villages within the groupings.

Legumes play an important role in ISFM strategies as a source of nitrogen on smallholders' farms (Vanlauwe and Giller, 2006). Legumes are not only appreciated for their potential beneficial effects on soil fertility through their nitrogen fixation capacity, but they are also known for their contribution to human nutrition, as they are rich in protein (Crews and Peoples, 2004; Odendo et al., 2011). Legumes are a staple food for households in South-Kivu: we estimate that they are cultivated on 91% of the farms and on 59% of the plots in our research area. Several improved legume varieties were already used in the region before the start of the program, and were promoted and distributed in the villages and on local markets by traders and governmental and non-governmental organizations (Lambrecht et al., 2014a). Additionally, seen their importance in ISFM, the program set up legume germplasm evaluation trials to identify varieties that were particularly suited to the local environment (CIALCA, 2007). With the help of program associations, these varieties were multiplied in collective fields and germplasm was sold in the area.

Cassava and maize are also major staples in the area. We estimate that cassava is grown on 89% of the farms and on 59% of the plots, and maize is grown on 49% of the farms and on 23% of the plots in our research area. In collaboration with INERA[5], the project identified and introduced mosaic-virus-resistant cassava varieties and improved maize varieties that performed equally well or better than the local varieties (CIALCA, 2007). Studies in other areas have shown that the adoption of improved crop varieties can increase household income and consumption, and reduce poverty and inequality (Asfaw et al., 2012; Kassie et al., 2011; Mathenge et al., 2014; Mendola, 2007).

Traditionally, legumes and maize are broadcasted, and cassava cuttings are planted in an apparently random fashion. Farmers commonly intercrop or rotate legumes with maize or cassava. The program has introduced planting methods with specific crop arrangements (row planting), in which cassava or maize is planted in rows at specific distances, with one or several lines of legumes in between. Field trials showed that pod yields for traditional legume varieties increased by 50% using an alternative intercropping space (CIALCA, 2007). Row planting requires less planting material or seeds, diminishes competition between the individual seedlings, reduces labour requirements for weeding, and can allow a second bean

[5] INERA is the National Institute for Agricultural Research and Studies (Institut National des Etudes et de la Recherche Agricole). CIALCA and the International Institute for Tropical Agriculture (IITA) have formed a partnership with INERA, and supported scientific skills development. This center is present in the Northern territory of our research area.

intercrop for cassava. However, row planting also requires more labour at the start of the season when labour is scarce (Pypers et al., 2011).

Mineral fertilizer is an essential component in ISFM (Vanlauwe et al., 2010), and fertilizer interventions are prominent in rural poverty reduction programs in Africa (Marenya and Barrett, 2009; Sheahan et al., 2013). Many studies find positive returns to mineral fertilizer use (Duflo et al., 2008; Marenya and Barrett, 2009; Sheahan et al., 2013), but degraded soils can limit the marginal return to fertilizer (Marenya and Barrett, 2009), and mineral fertilizer application can be unprofitable at high commercial prices (Jayne and Rashid, 2013). The ISFM paradigm in general, and the program specifically, emphasize the importance of thoughtful application of small amounts of mineral fertilizer (Vanlauwe et al., 2010). In most field experiments and demonstration trials mineral fertilizer is not broadcasted but incorporated in the soil, which reduces run-off and volatilization losses (Timmons et al. 1973). Moreover, fertilizer is applied in small quantities, added in the cassava planting hole or in the bean line at planting, or at a specific distance from the maize seed. Fertilizer use is shown to be profitable in cassava-legume intercropping systems on the relatively fertile soils in Kabare territory, but is not profitable on the less fertile soils in Walungu territory at local commercial prices (Pypers et al., 2011). Before the start of the program, mineral fertilizer was virtually unknown in the area (Ouma et al., 2011).

Both in the broader agronomic literature and in the specific context of the project, important yield interactions are detected between different ISFM technologies. Mineral fertilizer and improved varieties are often seen as complementary inputs (Rauniyar and Goode, 1992). In South-Kivu, the introduced maize varieties yield more than the local varieties without the use of mineral fertilizer, but in addition, they also have a higher response to fertilizer application (Vanlauwe et al., 2012). Similarly, the response to fertilizer of the mosaic-resistant cassava varieties was higher than the response of the local varieties (Vanlauwe et al., 2012). The dual-purpose legume varieties introduced by the project give similar grain yields as local varieties, but fixate more biological nitrogen and produce more biomass, thus leading to improved soil fertility. As a result, a significant yield increase occurs for the maize crop following these legume varieties (Vanlauwe et al., 2012), and the improved soil conditions further enhance the effect of mineral fertilizer application (Vanlauwe et al., 2010).

4. Methods

4.1 Data and sampling

Farm survey data were collected in the period February - June 2011 in the northern Walungu territory and the southern Kabare territory in South-Kivu. We purposively selected the four groupements (Lurhala, Burhale, Kabamba and Luhihi) most intensively involved in the CIALCA program. Villages and farms were selected with a two-stage stratified random cluster sampling strategy (Lambrecht et al., 2014b). To ensure a sufficiently high number of program participants in the sample, program farm-households were oversampled. To correct for this oversampling, we use sampling weights, calculated as the inverse of the probability that the farm-household is selected into the sample. The total sample includes data from 412 farm-households, 772 respondents (including male and female farmers from the same households), and all (1595) plots of these farms.

The questionnaire consisted of different modules on different topics, including agronomic and socio-economic questions. Respondents were asked about awareness and use of improved agricultural technologies, specifically those introduced by the project. For each technology, respondents were first asked if they had ever heard about the technology. If so, they were asked if and when they first used the technology. If they disadopted or abandoned the technology, they were asked in which year and why. In addition, for each plot of the farm and for each season during the past year, respondents were asked which crops were grown on the plots and which agricultural technologies were applied.

4.2 Analysis

To understand how ISFM is applied in practice in South Kivu, we focus on five main technologies that are introduced in the region: 1/ improved legume varieties, 2/ improved maize varieties, 3/ improved cassava varieties, 4/ mineral fertilizer, and 5/ row planting. We first look at summary statistics, then we analyze clusters of technologies, and finally we look at dynamic effects.

As awareness is a necessary condition for adoption (Lambrecht et al., 2014b), we first look at awareness of farmers about ISFM technologies in our research area. A farmer is aware if he/she has ever heard about the technology. At the household level, we define aware households as those households in which at least one farmer is aware of the technology. Adoption is defined as the application of the technology on at least one plot of the farm (farm-level) or on at least a part of the plot (plot-level) during the past agricultural year. Disadoption occurs when a technology is no longer used on a farm where it had previously been applied. Disadoption rates are calculated at farm level, conditional on having tried the technology at least once on the farm.

For each technology, we also calculate awareness rates conditional on awareness of other ISFM technologies. If information on ISFM technologies has spread independently, conditional awareness rates should equal unconditional awareness rates. In such case, awareness on interaction effects between different technologies is expected to be low. If conditional awareness rates are higher than unconditional awareness rates, information on technologies has spread jointly and/or farmers may have specific characteristics that influence the likelihood of being aware of different technologies.

Similarly, we calculate adoption rates conditional on adoption of other ISFM technologies at farm and plot level. In theory, if technologies are adopted independently, the probability of adoption does not change conditional on using another technology. However, farmers that adopt agricultural technologies can have observed and unobserved characteristics that make them more likely to adopt another agricultural technology. Therefore, we also compare adoption at the farm and plot level. If farmers purposefully exploit interrelationships between different technologies, we expect higher conditional adoption rates for complementary technologies, and lower conditional adoption rates for independent or substitute technologies at plot level. We visualize the overlap in adoption of technologies with venndiagrams that are proportional to the population size.

We use factor analysis to identify underlying patterns in the application of the ISFM technologies. Factor analysis is a method to describe the covariance relationships among different variables in terms of a few underlying, unobservable, factors (Johnson and Wichern, 2007). Since we have binary adoption variables, the factor analysis is based on polychoric correlations (Holgado-Tello et al., 2010) and a varimax rotation is executed to increase interpretability of the results. If application of ISFM technologies is independent, there will be no correlations among these technologies, and factor analysis will generate an independent factor for each technology. If technologies are applied sequentially or simultaneously, they will be correlated, and factor analysis will generate a single factor. If technologies are applied in several subsets, factor analysis will generate a factor for each set of technologies that are adopted sequentially or simultaneously (Rauniyar and Goode, 1992). This pattern is both influenced by agricultural decision making as well as by correlations that exist due to other unobserved characteristics influencing adoption of agricultural technologies.

Finally, we use recall data at farm-level to explore dynamics in the application of ISFM technologies. We visualize application rates, and cumulative adoption and disadoption for the different technologies. We also look whether tryout of agricultural technologies occurs simultaneously or sequentially, and which technologies are applied first. To see which adoption pattern resulted in the lowest levels of disadoption we calculate the share of households disadopting ISFM technologies of technology subsets conditional on the adoption pattern.

5. Results and discussion

5.1 Awareness and adoption rates

In table 1, we show the awareness rates for the five ISFM technologies. Only five years after the introduction in the region, awareness is relatively high, albeit still incomplete. Only 15% of the population does not know any of the five technologies. Awareness of improved varieties is highest for legumes (79%) and cassava (60%), and lower for maize (37%). Several improved legume varieties were already known and used before the start of the program, but improved maize and cassava varieties were rare (Lambrecht et al., 2014a). Row planting is known by 65% of the farmers. Row planting was uncommon for subsistence crops and on smallholders' fields, but farmers observed a similar concept on the tea and coffee plantations in the area.

[Table 1]

Table 1 also shows conditional awareness rates across the different technologies. Generally, the results show that farmers aware of at least one technology are also more likely to be aware of other technologies. Two interesting patterns emerge. First, nearly all farmers that are aware of at least one technology, are also aware of improved legume varieties, but not vice versa. Second, up to 95% of farmers that are aware of mineral fertilizer are also aware of row planting, but only 67% of farmers that are aware of row planting know mineral fertilizer. Row planting is more widely known by respondents through casual observations of the technology on commercial crops on plantations in the region, but mineral fertilizer was promoted firstly and solely by the program. Moreover, the impact of mineral fertilizer application was mainly demonstrated in combination with row planting to facilitate micro-dosing of fertilizer.

In table 2, we show the adoption rates for the five ISFM technologies at farm and plot level. The highest adoption rate is found for improved legume varieties, which are adopted on 39% of the farms and on 17% of the plots. Improved cassava varieties and row planting are adopted on respectively 16% and 13% of the farms, and on 5% and 6% of the plots. The lowest adoption rates are for improved maize varieties and mineral fertilizer, which are used on only 10% and 6% of the farms, and on 3% and 2% of the plots.

[Table 2]

If we compare adoption rates on the full sample of farms compared to adoption rates on farms where the male and/or female farmer are aware of the technology, we find that some technologies have been more widely adopted than others. Conditional on awareness, improved legume varieties are adopted on 43% of all farms. This is relatively high, compared to conditional adoption of improved maize and cassava varieties which occurs on 21% of aware farms. For row planting, the conditional adoption rate is 15%. Finally, the lowest conditional adoption is for mineral fertilizer, which is applied on 10% of the respective farms. This suggests that more familiar and relatively simple technologies such as improved varieties are more easily adopted compared to less common and more knowledge- and resource-demanding technologies such as row planting and mineral fertilizer.

Figure 1 shows the overlap of adoption of ISFM technologies at farm and plot level[6]. Joint adoption of technologies differs if we compare adoption rates at the farm and plot level. We see that there is relatively less joint adoption of improved cassava and legume varieties, and relatively more joint adoption of improved legume and maize varieties at plot level compared to the farm level. The overlap in adoption of row planting, mineral fertilizer and improved cassava varieties is not too different at plot and farm level.

[Fig. 1]

[6] A large number of different combinations of ISFM practices can be shown in venndiagrams. These combinations were chosen based on the patterns distinguished above, and informed by the results of the factor analysis below.

From the conditional adoption rates in table 2 and figure 1, we can gain more insight in the interrelationship of adoption of different technologies[7]. We find that conditional adoption rates are higher than the unconditional adoption rates. In comparing conditional adoption rates at farm level (table 2) and plot level (table 3), at least two interesting patterns emerge. First, for several technologies, we find that conditional adoption rates are lower at plot level compared to the farm level. Conditional on mineral fertilizer use or row planting, improved legume varieties and improved maize varieties are less frequently applied. Also, conditional on adoption of improved legume or maize varieties, adoption rates of improved cassava varieties, row planting, and mineral fertilizer adoption rates are relatively low. It is possible that farmers consider these technologies as independent or substitutes rather than complements, as they are less frequently applied on the same plot. This is in line with the findings of Sheahan and Barrett (2014) using LSMS-IS data from Ethiopia and Niger.

Secondly, other technologies have relatively high conditional adoption rates at plot level. On plots with mineral fertilizer, the rate of row planting is very high (0.96), but not vice versa. Similarly, improved maize varieties are more frequently adopted conditional on the use of improved legume varieties (0.79), but the result is less strong vice versa. If technologies are adopted jointly (as packages), conditional adoption will be near unity. If the adoption pattern is sequential, the adoption rate of the first technology will be near unity conditional on the following technology, but not vice versa. We find strong evidence of sequential adoption of mineral fertilizer following row planting, and weaker evidence of sequential adoption of improved maize varieties following improved legume varieties.

5.2 Application patterns

We conduct a factor analysis to detect latent structures in the adoption of agricultural technologies. At farm level, we only find one main factor explaining up to 82% of the variance (results not shown here). Hence, adoption of different technologies is interdependent at farm level, but no specific subsets of technologies appear. We also analyze adoption at plot

[7] Plot level data on adoption of ISFM practices is only available for the past agricultural year, which consists of the two main wet seasons (A and B) and the dry season (C). The data of these seasons are combined, although the ISFM practices that we study are generally not applied in the dry seasons. This implies that we do not distinguish between intercropping and rotation of practices within the same agricultural year, and that we cannot take into account rotation of practices among different agricultural years.

level[8]. The polychoric correlations are shown in table 3, and the scores of the factor analysis can be found in table 4. Two main factors appear, indicating independence among the factors, but simultaneous or sequential adoption behavior within the factors. The first factor mainly consists of row planting and mineral fertilizer, and will be further referred to as the row-fertilizer package. Improved cassava adoption also has relatively high factor loadings, but the high uniqueness indicates a relatively high independence towards the other two technologies. The application of row planting and mineral fertilizer represent good agronomic practices and inorganic inputs in the ISFM paradigm, and are knowledge-intensive, labour-intensive, and/or cash-intensive for the farmers in South-Kivu. The first factor can therefore also be characterized as *"more resource-intensive"* technologies.

[Table 3]

[Table 4]

The second factor consists of *"less resource-intensive"* technologies. It contains improved legume and maize varieties, and we will further refer to it as the legume-maize package. It represents the two other components of the ISFM paradigm: organic inputs and improved varieties. While intercropping of maize and cassava is a common practice in the region (Pypers et al., 2011), we find that improved varieties of maize and cassava are generally adopted on different fields. Maize and legumes are often used in rotation, and both have been distributed by the program. The program has also specifically emphasized the beneficial impact of rotation of maize (in the first season) and legumes (in the second season) on soil fertility and future crop productivity.

In table 5, we show a cross-tabulation of application of the components of the two packages at farm level. Three patterns are found. First, row planting is more frequently applied on farms that do not apply mineral fertilizer. Yet, fertilizer is rarely applied if a farmer did not plant in rows. This points at sequential adoption with row planting as a first step, and mineral fertilizer as a second step. Second, for the legume-maize package we find that improved legume varieties are more frequently applied than improved maize varieties. Yet, the improved maize varieties are applied in almost equal proportions by farmers that do and do not use the improved legume varieties. Third, we find that farmers applying the legume-maize package

[8] We included all plots. Results are robust if we exclude plots that are not relevant considering ISFM in our case study (N=1439), i.e. plots that were used exclusively for growing trees, coffee or quinquina, pastures and fallow plots.

(especially improved legume varieties) are more likely to apply row planting and/or mineral fertilizer, than vice versa. Again, this suggests an adoption sequence in which first the legume-maize package is adopted, and later also the row-fertilizer package. At plot level, we find that the two packages are rarely combined on the same plot (results not shown).

[Table 5]

5.3 Dynamic application patterns

Figure 2 shows how the use of ISFM technologies has evolved over time. In 2005, before the program started, improved legume varieties was the only technology used on a small share (10%) of farms. The use of all technologies increased gradually from 2006 till 2011. Table 6 shows that improved legume varieties are often adopted first (before or jointly with other technologies). Among those farms on which at least one of the ISFM technologies is applied, 73% adopted improved legume varieties (jointly or) first, 20% adopted improved cassava (jointly or) first, and 16% adopted row planting (jointly or) first. On less than 1% of the farms, all ISFM technologies were adopted for the first time in the same year. In addition, we look at the two subsets of technology packages. Farmers who tried the row-fertilizer package generally adopted row planting first (72%). On 21% of the farms, row planting and mineral fertilizer were adopted in the same year. Farmers who tried the legume-maize package generally adopted improved legumes first (87%). The first year of adoption of improved legume and maize varieties was rarely (7%) the same.

[Fig. 2]

[Table 6]

On several farms, ISFM technologies were tried but later abandoned. In figure 3, we compare the cumulative percentages of households trying and disadopting ISFM practices. Over time, the percentage of households that tried ISFM practices increases, but so does the percentage of households that disadopt. Overall, of those households that tried a practice, a considerable share continues to apply the practice. The highest disadoption rate (44%) was found for improved cassava varieties in 2008. However, as only few households had tried these varieties at that time, the absolute number of disadopters is small. By 2011, disadoption of improved legume and maize varieties occurs on about one out of four farms and improved cassava varieties are disadopted on one out of three farms. Most disadopting farmers were not impressed with the yield of the improved varieties (23% to 32%) or had no access to the varieties (21% to 27%). A surprising result is the problem of theft of the crop, which is an important reason for disadoption of improved cassava varieties (19%). Mineral fertilizer was abandoned on one out of four farms. Disadopting farmers said that mineral fertilizer was too expensive (42%), not available (26%), or they did not have enough labour for its application (19%). Row planting was abandoned on 38% of the farms, because it was too complex (31%), or farmers had insufficient labour to apply row planting (18%).

In table 7, we show the share of households disadopting ISFM technologies of the two packages, conditional on the adoption pattern. This way, we can see which adoption pattern has resulted in the lowest levels of disadoption (highest levels of continued adoption). For the legume-maize package we find that disadoption is lowest for those households that tried both components simultaneously. For the row-fertilizer package, we find lowest disadoption rates if components are adopted sequentially. Interestingly, for each package disadoption rates of the two components are different, even for households that simultaneously tried both components of a package. This means that, after having tried both technologies, some farmers decide to continue with only one of these technologies and disadopt the other technology.

[Table 7]

6. Conclusion

In this study, we look at how the ISFM paradigm is put into practice on farmers' fields in South-Kivu, eastern DRC. We specifically look at the interrelationships in application of five components of ISFM: improved legume, maize, and cassava varieties, row planting, and mineral fertilizer. We find that the application of different ISFM technologies are not independent, and at plot level, we distinguish two subsets of technologies. The first subset is characterized by more resource-intensive technologies (row planting and mineral fertilizer). The second consists of less resource-intensive technologies (improved legume and maize varieties). These subsets behave as supplements rather than as complements, and adoption within and among each subset is more sequential than simultaneous. Generally, farmers adopt less resource-intensive technologies first, and then adopt more resource-intensive technologies.

We find that adoption behavior and patterns are mainly related to three different factors: technologies have been introduced at different times (e.g. improved legume varieties were available in the region before improved maize or cassava varieties), in specific combinations (mineral fertilizer use was demonstrated in combination with row planting), and have specific characteristics that render adoption more or less easy (resource-intensity of technologies). Application of "full ISFM" is low in the region, especially because of a low adoption of mineral fertilizer. Yet, the adoption process studied here is still very young and highly influenced by non-exposure to technologies and non-availability of inputs. Different studies have shown both an impressive increase (e.g. deGraft-Johnson et al., 2014) or a disappointing decrease in adoption (e.g. Moser and Barrett, 2006) after the activities of an extension project are reduced or stopped.

To conclude, our results show that there is a disconnect between the theoretical arguments in the agronomic ISFM literature, and the actual patterns of ISFM application. In the agronomic literature, by definition, ISFM necessarily includes the use of mineral fertilizer, and ISFM is sometimes explained as a method to increase the agronomic use efficiency of mineral fertilizer (Vanlauwe et al., 2010). In several settings, indeed, mineral fertilizer is a well-known technology and sometimes used more frequently than improved germplasm, such as in neighboring Burundi (Lambrecht et al., 2013). However, in South-Kivu, mineral fertilizer is still rarely observed in farmers' fields and is less easily adopted than other newly introduced technologies. In this and similar areas, increasing mineral fertilizer use is a challenge that may require considerable effort and time to achieve. Moreover, ISFM technologies that have been shown to express high and significant yield interaction effects are not frequently combined on farmers' plots. More socio-economic research is needed for a thorough understanding why farmers are or are not exploiting interactions between agricultural technologies. In the agronomic literature, more biophysical research should compare results from alternative, and realistic, combinations and sequences of ISFM technologies. A stronger cooperation between agronomic and socio-economic research could then lead to the formulation of a paradigm for sustainable agricultural productivity growth that is both conceptually sound from an agronomic perspective and applicable in practice from a socio-economic perspective.

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8. Tables

Table 1 : Unconditional and conditional technology awareness rates at respondent level, 2011

	Unconditional awareness	Conditional on being aware of …				
		Improved legume	Improved maize	Improved cassava	Mineral fertilizer	Row planting
Improved legume	0.79	1	0.96	0.94	0.97	0.94
Improved maize	0.37	0.45	1	0.56	0.55	0.50
Improved cassava	0.60	0.72	0.91	1	0.86	0.80
Mineral fertilizer	0.46	0.56	0.68	0.66	1	0.67
Row planting	0.65	0.78	0.88	0.87	0.95	1
Number of observations	*772*	*656*	*365*	*518*	*437*	*589*

Source: Estimated from survey data

Table 2 : Unconditional and conditional adoption rates at farm and plot level, 2011

	Unconditional adoption	Conditional on using …				
		Improved legume	Improved maize	Improved cassava	Mineral fertilizer	Row planting
Farm level						
Improved legume	0.39	1	0.61	0.54	0.78	0.63
Improved maize	0.10	0.16	1	0.39	0.30	0.30
Improved cassava	0.16	0.21	0.60	1	0.42	0.40
Mineral fertilizer	0.06	0.13	0.19	0.17	1	0.38
Row planting	0.13	0.21	0.38	0.33	0.77	1
Number of observations	*411*	*193*	*66*	*94*	*52*	*76*
Plot level						
Improved legume	0.17	1	0.79	0.33	0.41	0.41
Improved maize	0.03	0.15	1	0.14	0.15	0.11
Improved cassava	0.05	0.09	0.20	1	0.36	0.23
Mineral fertilizer	0.02	0.05	0.11	0.18	1	0.37
Row planting	0.06	0.14	0.20	0.30	0.96	1
Number of observations	*1591*	*281*	*73*	*103*	*68*	*131*

Source: Estimated from survey data

Table 3: Polychoric correlation matrix of adoption at plot level, 2011 (N=1591)

	Improved Legume	Improved Maize	Improved Cassava	Row planting
Improved Maize	0.698	1		
Improved Cassava	0.257	0.405	1	
Row planting	0.369	0.345	0.530	1
Mineral fertilizer	0.315	0.370	0.591	0.951

Table 4: Factor analysis of adoption at plot level, 2011 (N=1591)

	Factor 1	Factor 2	Uniqueness
Improved Legume	0.211	0.758	0.380
Improved Maize	0.236	0.760	0.348
Improved Cassava	0.517	0.259	0.569
Row planting	0.949	0.193	0.062
Mineral Fertilizer	0.951	0.165	0.050
% variance explained	0.528	0.164	

Table 5: Share of farms (jointly) applying components of packages, 2011 (N = 412)

		Row - Fertilizer Package				
		None	Row	Fertilizer	Row & fertilizer	Total
Legume-Maize Package	None	0.544	0.028	0.001	0.006	0.579
	Legume	0.261	0.029	0.011	0.026	0.326
	Maize	0.032	0.002	0.000	0.006	0.040
	Legume & Maize	0.028	0.015	0.002	0.010	0.056
	Total	0.865	0.074	0.014	0.047	1

Table 6: Adoption sequence of individual agricultural technologies (share of farms)

Farms on which at least one technology was tried (N=282)	
Improved legume (joint) first adopted	0.728
Improved maize (joint) first adopted	0.063
Improved cassava (joint) first adopted	0.196
Row planting (joint) first adopted	0.159
Mineral fertilizer (joint) first adopted	0.041
All technologies jointly	0.005
Farms on which at least 1 component of row-fertilizer package was tried (N=131)	
Row planting first adopted	0.721
Mineral fertilizer first adopted	0.069
Row planting and mineral fertilizer at same time adopted	0.206
Farms on which at least 1 component of legume-maize package was tried(N=258)	
Improved legume first adopted	0.866
Improved maize first adopted	0.066
Improved maize and legumes at same time adopted	0.068

Table 7: Share of farms disadopting technologies conditional on pattern of adoption

Disadoption	**Tried only 1 component of package**		**Tried both components of package**	
	Legume	*Maize*	*Sequential*	*Simultaneous*
Legume	0.220		0.332	0.044
Maize		0.420	0.373	0.095
Number of observations	172	7	49	30
	Row	*Fertilizer*	*Sequential*	*Simultaneous*
Row	0.343		0.194	0.387
Fertilizer		0.235	0.097	0.422
Number of observations	58	12	25	36

9. Figures

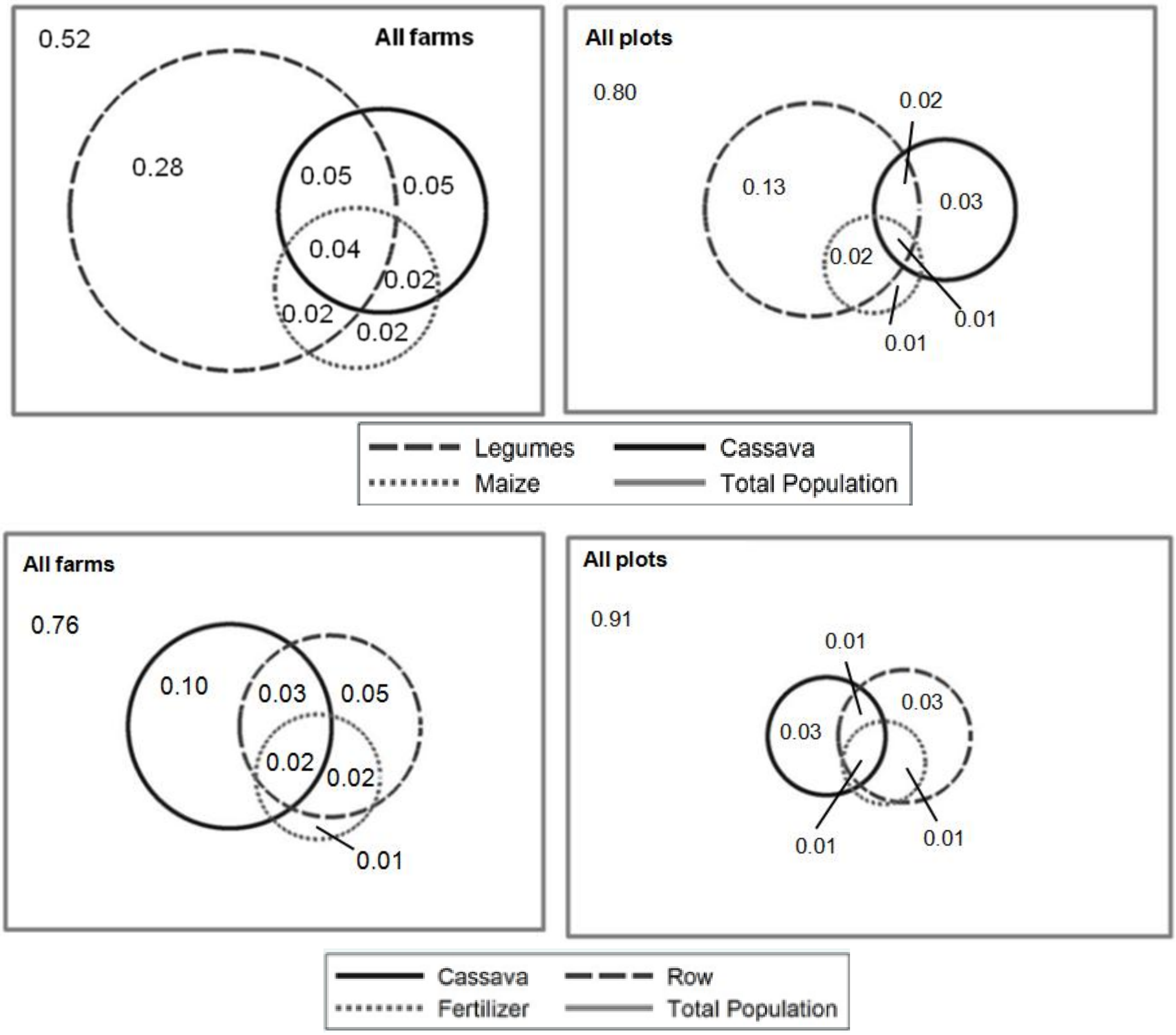

Fig. 1 : Joint adoption of ISFM technologies at farm and plot level in 2011

Note : The zones are proportional to the population size. The respective shares in the total population are indicated in the figures, unless smaller than 0.01.

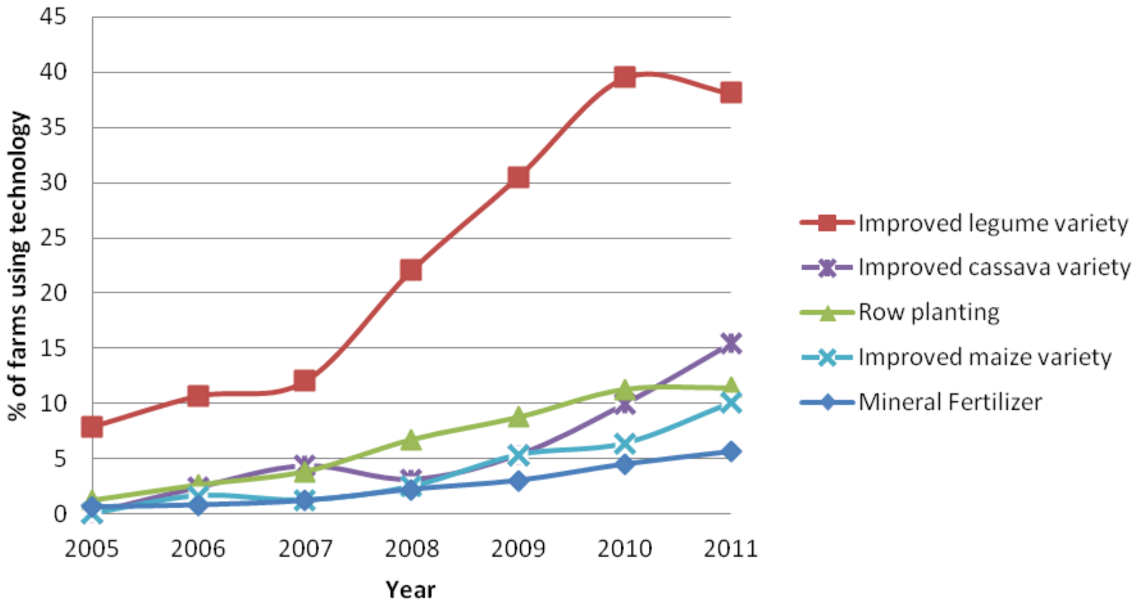

Fig. 2: Percentage of farms using different ISFM technologies, 2005-2011

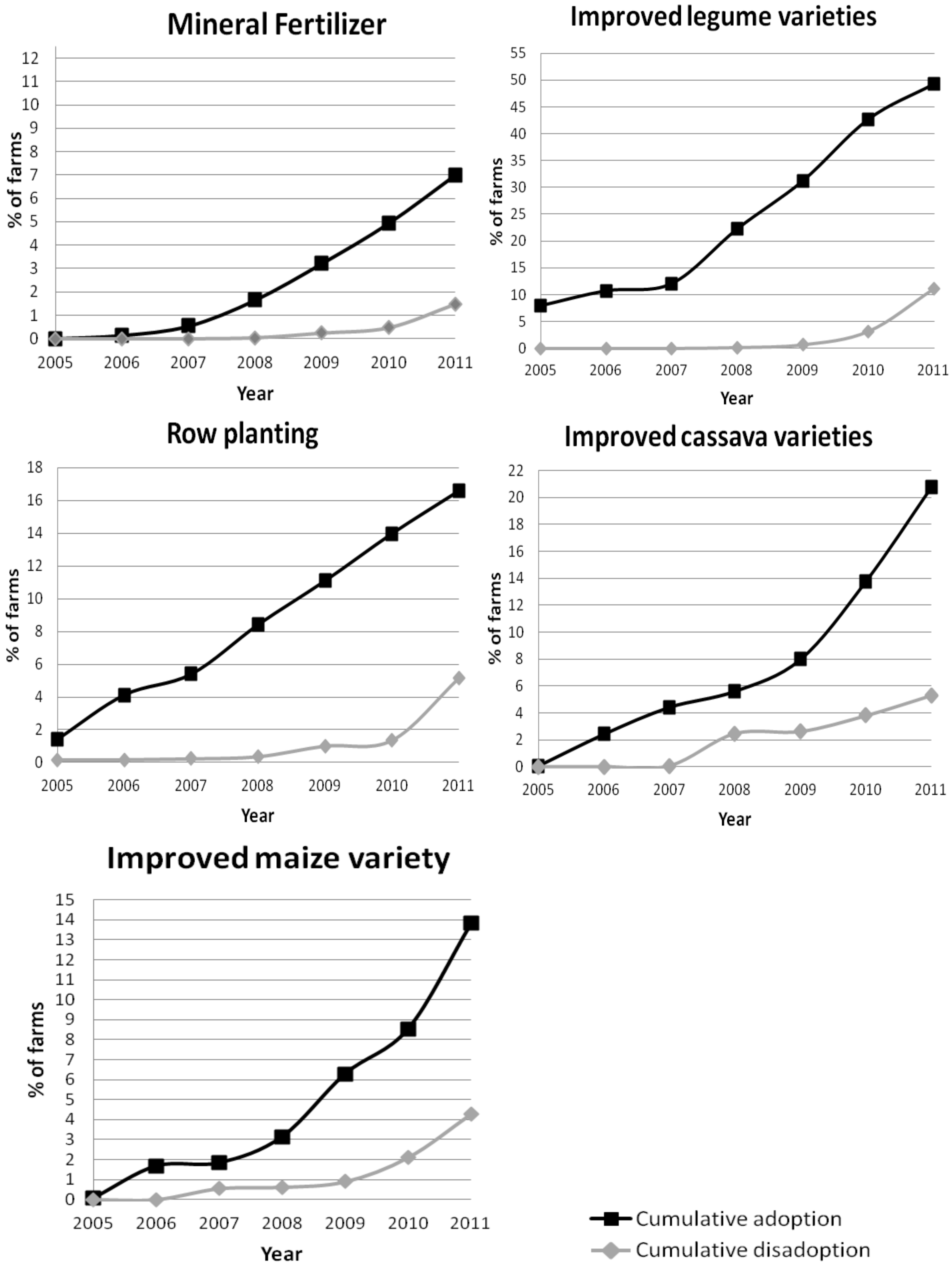

Fig. 3: Cumulative percentage of households adopting and disadopting, 2005-2011