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Impact evaluation of the Integrated Soil Fertility Management Dissemination Programme in Burkina Faso

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3ie accepted the final version of the report, *Impact evaluation of the integrated soil fertility management dissemination programme in Burkina Faso*, as partial fulfilment of requirements under grant TW4.1028 awarded through Agricultural Innovation Evidence Programme. The report is technically sound and 3ie is making it available to the public in this final report version as it was received. No further work has been done.

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Impact evaluation of the integrated soil fertility management dissemination programme in Burkina Faso

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Last but not least we would like to thank our colleagues at the Center for Evaluation and Development (C4ED) at the University of Mannheim for their extremely useful feedback and suggestions during our internal seminars and individual discussions.

Executive summary

Programme overview

Smallholder farmers in Burkina Faso have recently experienced decreasing yields which, together with increasing production costs, exposes the already vulnerable population to food insecurity and extreme poverty. The main factors contributing to the diminishing agricultural productivity are frequent droughts, poor availability of key agricultural inputs such as chemical fertiliser, high-quality seeds or improved varieties, inefficient government subsidy programmes, limited access to credit, and decreasing soil fertility.

Integrated soil fertility management is a crucial strategy to address low agricultural productivity in Sub-Saharan Africa as it allows to compensate for the lack of financial resources by an increased labour input. integrated soil fertility management consists especially in an integrated use of chemical fertiliser and organic matter, improved crop varieties, and specific soil preparation technologies to increase water retention and avoid land erosion. The key aspect of integrated soil fertility management is to adapt these technologies to the local agronomic conditions in order to maximise the use of nutrients present in the soil and to increase crop yields. Successful implementation of integrated soil fertility management technologies requires government support to allow timely and affordable access to key inputs and efficient agricultural extension services that help to popularise the innovative methods among smallholder farmers.

The programme *Scaling-Out Integrated Soil Fertility Management Technologies to Improve Smallholder Farmers' Livelihood* in Burkina Faso aimed at improving food security and increasing revenues of smallholder farmers in the provinces of Sanmatenga and Gnagna in Burkina Faso by promoting adoption of the integrated soil fertility management technologies. The programme was funded by the Alliance for a Green Revolution in Africa and implemented by the *Groupe de Recherche et d'Action pour le Développement* between 2015 and 2017. It was designed to reach up to 3,000 farmers in 5 *communes* in both intervention provinces. The programme focused on cowpea producers in Sanmatenga and on rice producers in Gnagna and the main activity consisted in setting up demonstration plots in each farming organisation, where different integrated soil fertility management options were presented. For the cowpea crop, the promoted technologies were micro-dosing of fertiliser, integrated use of compost or manure together with inorganic fertiliser, intercropping of cereals (sorghum or millet) and legumes (cowpea), and zaï or contour bunding to mitigate adverse effects of drought episodes.

Impact evaluation overview

Typically, the agricultural extension services use a top-down approach to promote good practices – extension agents meet with farmers and explain the benefits of new technologies. By contrast, demonstration plots can be considered a more bottom-up approach since a local farmer is designated in each community to present the new technologies on one of her own parcels. Evaluating the impact of the present programme can provide useful evidence on the effectiveness of bottom-up popularisation strategies and of demonstration plots in particular. The impact evaluation is policy relevant as it can help inform the design of other agricultural extension programmes that aim at diffusing new technologies in developing countries. The impact evaluation was funded by the International Initiative for Impact Evaluation under its Agricultural Innovation Evidence Programme. Three priority questions are addressed by this evaluation:

1. How do the integrated soil fertility management technologies compare with traditional farming practices? Although integrated soil fertility management technologies have already been validated by multiple agronomic studies, very few rigorously examined how such technologies perform in the environment in which smallholder farmers in developing countries usually operate.
2. Are demonstration plots an effective dissemination strategy for increasing adoption of agricultural technologies? What are the impacts of the present programme on yields and income?
3. What are the constraints to adoption of the integrated soil fertility management technologies?

Methodology and identification strategy

The evaluation followed a randomised control trial design. Out of the 262 farming organisations present in Sanmatenga, 99 were selected to form the study sample. As our implementation partner's capacities were limited to treat only 40 farming organisations, the sample was split accordingly: 40 treatment and 59 control farming organisations. Assignment to the treatment status was generated randomly. In each farming organisation we designated a demonstrator who would set up demonstration plots on one of her fields. Finally, we sampled up to 18 regular farmers in the network of each demonstrator. The resulting sample of 1,601 farmers consisted of 658 treated farmers and 943 control farmers.

The study used several waves of qualitative and quantitative data collections. First, a census at the farming organisation level was carried out with the president of each farming organisation in order to identify the demonstrator and gather information about the farming organisation's activities to be used for stratification. Second, a pre-baseline survey with all members of each selected farming organisation served to establish a reliable sampling frame and to be able to create a roster of all farming organisation members for the social network part of the baseline questionnaire. Third, a baseline survey was carried out with farmers in our final study sample to verify comparability between the treatment and the control groups and to collect key baseline control variables. Next, we conducted a crop cut survey with demonstrators and one randomly picked farmer from their networks. Midline and endline surveys allowed us to measure impacts of the programme right after its roll-out and one year later – thus estimating a medium-term effect. Finally, we collected some qualitative data through focus group discussions and key informant interviews between the midline and endline surveys, which allowed us to shed more light on quantitative findings and evaluate the implementation of the programme.

Main findings

According to the results of our analysis, the present programme led to an increase in cowpea yields in the season of the programme implementation but failed to produce the same effect in the medium-term (i.e. during the subsequent season following the programme implementation). The findings also suggest that the treatment farmers were more likely to adopt integrated soil fertility management technologies during both midline and endline periods, although the impact on technological adoption remains modest. Since the crop cut survey confirmed effectiveness of integrated soil fertility management technologies in terms of agricultural productivity, the absence of a significant positive impact on yields at endline can be possibly explained by the low impact on adoption. Measurement error might also have played an important role as it is challenging to correctly estimate yields using self-reported data on total production and surfaces of agricultural fields.

Focus group discussions with low adopters revealed the most important barriers to adoption of the new integrated soil fertility management technologies. In particular, producers mentioned insufficient financial resources to purchase fertiliser, which is a crucial component of integrated soil fertility management. Another important barrier was the lack of agricultural tools necessary for implementation of some of the technologies (i.e. ploughs and traction animals to carry out line seeding or special tools called “triangles A” that allow farmers to identify points of the same level across the slope). Furthermore, lack of means of transportation prevents some households from delivering compost and manure, which are needed in large quantities, to their fields if those are far away from their homes. According to the key informant interviews with demonstrators and the programme’s extension agents, almost all beneficiary producers were convinced about the effectiveness of integrated soil fertility management technologies. However, some producers were not able to acquire the necessary know-how through demonstration plots alone.

We further identified some challenges in the programme implementation. In particular, demonstrators did not always respect the experimental protocol and so the demonstration plots were not exactly identical in each farming organisation. Furthermore, midline data revealed potential contamination of the control group – some producers declared having participated in agricultural demonstrations of the integrated soil fertility management technologies for cowpea. Indeed, qualitative research later confirmed that some of the farming organisations were already acquainted with integrated soil fertility management through a similar programme implemented in the region several years ago.

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List of figures and tables

Abbreviations and acronyms

AGRA	Alliance for a Green Revolution in Africa
C4ED	Center for Evaluation and Development
DAP	Diammonium Phosphate
FAO	Food and Agriculture Organization of the United Nations
FCFA	*Franc de la Communauté Financière en Afrique*
FGD	Focus Group Discussions
FO	Farming Organisation
GRAD	*Groupe de Recherche et d'Action pour le Développement*, Group of Research and Action for Development
IMF	International Monetary Fund
IPA	Innovations for Poverty Action
ISFM	Integrated Soil Fertility Management
ITT	Intent-to-Treat
KII	Key Informant Interviews
LI	Labour-Intensive Technologies
LI+	Combined Labour- and Capital-Intensive Technologies
MAAH	*Ministère de l'Agriculture et de l'Aménagement Hydraulique*, Ministry of Agriculture and Water Management
MAFAP	Monitoring and Analysing Food and Agricultural Policies
NPK	Nitrogen, Phosphorus, and Potassium
OLS	Ordinary Least Squares
PNDES	*Plan National du Développement Économique et Social*, National Economic and Social Development Plan
PP	*Pratiques Paysannes*, traditional farming practices
PP+	*Pratiques Paysannes* + chemical fertiliser
pp	Percentage Points
RCT	Randomised Control Trial
SISFeM	Scaling-Out Integrated Soil Fertility Management Technologies to Improve Smallholder Farmers Livelihood in Burkina Faso
SPAAA	*Suivi des Politiques Agricoles et Alimentaires en Afrique*, Monitoring of Agricultural and Food Policies in Africa
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
UPPNS	*Union Provinciale des Producteurs du Niébé du Sanmatenga*, Provincial Union of Sanmatenga Cowpea Producers
USD	United States Dollar
VIM	*Victoire sur la Malnutrition*, Victory over Malnutrition

1. Introduction

The Center for Evaluation and Development (C4ED) together with the University of Mannheim were contracted by the International Initiative for Impact Evaluation to conduct an impact evaluation of the Scaling-Out Integrated Soil Fertility Management Technologies to Improve Smallholder Farmers Livelihood in Burkina Faso (SISFeM) programme. The programme was carried out by the *Groupe de Recherche et d'Action pour le Développement* (GRAD) and funded by the Alliance for a Green Revolution in Africa (AGRA). C4ED further sub-contracted Innovations for Poverty Action (IPA) Burkina Faso to conduct data collection. C4ED started the impact evaluation at a later stage of the programme implementation; SISFeM had already been under way for two years and was entering in its third and last year.

The SISFeM programme's overarching goal was to improve food security and increase revenues of smallholder farmers in the regions of Sanmatenga and Gnagna in Burkina Faso. In recent years, farmers have been facing decreasing crop yields and growing insecurity. Soil fertility diminished drastically due to demographic pressure and the related over-exploitation of agricultural fields. Climatic changes and ever more frequent episodes of drought are another factor contributing to low agricultural productivity.

These recent developments pose a particular threat to livelihoods. Burkina Faso is a landlocked country where agriculture is the main source of subsistence for people living in rural areas. According to the Food and Agriculture Organization (FAO, 2014), in 2012 agriculture accounted for 92% of the total employment and for 29.9% of the total output. The sector is dominated by smallholder farmers, with 72% of farms being smaller than five hectares (Monitoring and Analysing Food and Agricultural Policies, MAFAP, 2013). Despite its significance, the agricultural sector lags behind its potential and faces substantial challenges. For instance, according to the data from the annual agricultural survey conducted by the Ministry of Agriculture (*Ministère de l'Agriculture et de l'Aménagement Hydraulique*, MAAH, 2015), yields of the main cereals (sorghum, millet, maize, and rice) were well below their yield potential.

Poor farming practices, such as inadequate soil preparation before the season and low use of agricultural inputs, continue to exacerbate the situation. Duflo, Kremer, and Robinson (2008) find that many farmers in Western Kenya fail to take advantage of potentially profitable capital investments such as inorganic fertiliser. Koussoubé (2015) further substantiates these findings in the context of Burkina Faso with evidence that chemical inputs such as fertiliser are underused in Burkina Faso, even though they were proven to be profitable. According to FAO (2016), overall fertiliser use in Burkina Faso was only 21.77 kg/ha, while the recommended rate for cowpea is 100 kg/ha for NPK (nitrogen, phosphorus and potassium). The insufficient use of agricultural inputs is mostly explained by the lack of financial resources coupled with limited access to credit, high prices, difficult access to the supply source, and limited information.

To improve agricultural productivity, the issue of the nutrient-poor soil needs to be addressed. Restoration of degraded agricultural land can be achieved through adoption of integrated soil fertility management (ISFM). The ISFM strategy stems from agronomic research conducted in the past two decades and stresses the importance of combining organic resources, such as compost and manure, with inorganic fertilisers, improved crop varieties, and soil conservation technologies. A specific focus is put on adapting recommendations to local conditions in order to optimise agronomic efficiency of soil nutrients. The pre-season soil preparation components of ISFM can prevent rainwater run-off and soil erosion, thus preventing fertiliser and organic matter from being carried away. In a similar way, micro-dosing of fertiliser also allows increased efficiency and lower quantities of inputs needed. Adequate soil preparation can therefore reduce costs since fertiliser and organic matter can be applied in quantities smaller than otherwise needed while preserving the same level of productivity. Such technologies nevertheless require additional effort from producers and can be considered "labour-intensive". The ISFM approach is likely to be effective in areas where labour is abundant but barriers to the adoption of "capital-intensive" technologies (i.e. chemical fertiliser) are high.

The SISFeM programme focuses on increasing productivity of rice producers in the region of Gnagna and cowpea producers in the region of Sanmatenga. This study specifically evaluates the impact of the programme on cowpea producers. Cowpea plays an important role in the context of Burkina Faso. A predominantly women's leguminous crop, it is often grown together with cereals such as sorghum, millet, or maize. It is mostly produced for households' own consumption but also constitutes an important source of income for farmers whose production surpasses their alimentation needs and who manage to preserve a part of their harvest for sale. The main ISFM options for cowpea promoted by the SISFeM programme were zaï[1], contour bunding[2], intercropping of cowpea with sorghum or millet, combined use of chemical fertiliser appropriate for cowpea and organic matter (i.e. compost or manure), using improved varieties, and fertiliser micro-dosing.

Increasing productivity of smallholder farmers requires shaping their behaviours and beliefs. Previous literature has focused on identifying the best way of convincing farmers in developing countries to change their practices and adopt new yield-enhancing technologies. Most programmes rely on traditional government agricultural extension services for diffusion of innovative technologies. Activities carried out by these extension services tend to be delivered using a top-down approach. They include broadcasting information through radio, distributing flyers, conducting classroom-based trainings, or organising visits by extension agents. Such approaches have proved to be mostly ineffective in convincing farmers to adopt new technologies, especially since the information delivered is not always tailored to each farmer's particular situation and often not delivered in a timely manner.

On the other hand, as documented in previous literature, bottom-up approaches tend to have more positive effects. Decentralised and participatory models, such as farmer field schools or trainings where farmers learn from their peers, lead to higher technological adoption rates (BenYishay and Mobarak, 2018, Feder et al., 2004, Kondylis et al., 2017, Waddington et al., 2014). The impact of such bottom-up approaches among female producers is of particular importance: female producers face specific challenges when adopting new technologies (Kondylis et al. 2016) and might be less receptive to a

[1] Zaï consists of digging small pits in the soil during the pre-season and applying small quantities of compost and fertiliser in these pits.

[2] Contour bunding consists of organising a field along contours. It involves placing permanent lines of stones along the natural rises of the slope.

programme solely relying on extension workers. Besides, considerable evidence exists on the role that social networks play in information transmission (Vasilaky and Leonard 2017; Vasilaky and Islam 2018). Our study of the programme, targeted to female cowpea farmers and our survey that collected detailed social network data, will bring more evidence to this stream of literature.

The SISFeM programme also uses a decentralised approach with a learning-from-peers component. In each farming organisation (FO), demonstration plots are implemented by regular FO members, who regularly interact with other farmers in their network. The programme's extension agents support the demonstrators by providing agricultural inputs, teaching ISFM technologies, helping to set up the experiment, and monitoring progress. Extension agents also organise guided visits to demonstration plots for other FO members in order to discuss the different ISFM options and their results.

Previous studies have also shown that leveraging social networks can help technological diffusion (Foster and Rosenzweig,1995, Bandiera and Rasul, 2006, Conley and Udry, 2010, BenYishay and Mobarak, 2018). In particular, farmers are more likely to trust someone who is similar to them, rather than an extension agent external to their community. Therefore, they are more likely to adopt new technologies if someone they already know well is also an adopter (BenYishay and Mobarak, 2018). Sometimes, farmers become more convinced about a new technology when they see multiple members of their network, rather than just one person, practicing it (Beaman et al., 2018, Tjernström, 2016).

Even when farmers become convinced of the effectiveness of new technologies, it might not be easy for them to apply these new technologies on their own. Understanding constraints to adoption of "capital-intensive" technologies (i.e. fertiliser and improved seeds) and finding ways to overcome those has been a subject of many agricultural economics studies (Duflo et al., 2011, Delavallade and Godlonton, 2015, Dillon and Barrett, 2016). On the other hand, much less is known about constraints to adoption of labour-intensive practices. This study aims at better understanding these constraints.

The study assesses the extent to which ISFM technologies and demonstration plots as a means for technological diffusion can be recommended at the policy level. It presents a contribution to the previous literature in that it rigorously compares performance of ISFM technologies relative to traditional farming practices using the crop cut methodology. Although agronomic research has previously validated ISFM technologies (Vanlauwe et al., 2005), the fact that these studies are conducted in a very controlled environment does not allow us to understand how ISFM performs in a more natural environment in which farmers in developing countries operate. Second, by measuring the impact of the SISFeM programme on adoption rates, cowpea yields and households' revenues, we want to evaluate how effective demonstration plots are in diffusing a new technology. Last but not least, the present impact evaluation draws on mixed methods to better understand underlying mechanisms that lead to adoption of ISFM technologies.

Even though the SISFeM programme was already entering its third year when C4ED became involved in the impact evaluation, not all FOs had been reached by the programme up to that point. Furthermore, GRAD could cover only 40 FOs in the third year, while around one hundred organisations were considered eligible. This presented a perfect opportunity to conduct a rigorous impact evaluation and a randomised control trial (RCT) in particular. Ninety-nine FOs have been selected to participate in the study and randomly assigned to control and treatment groups. Our sample consisted of 40 treatment and 59 control FOs. In each FO we sampled a maximum of 19 households – one demonstrator and up to 18 farmers from their respective networks (some FOs had less than 19 members in total and so the target could not always be reached). For baseline, 1,510 households were surveyed (885 control and 625 treatment households). We rely on a mixed methods approach. The quantitative part of the impact evaluation consists of three waves of data collection – baseline, midline, and endline – thus considering both short-term and medium-term impacts of the programme. For the qualitative component we conducted focus group discussions (FGDs) in eight FOs as well as key informant interviews (KIIs) with demonstrators and extension agents.

The pre-analysis plan (PAP) proposed to answer ten research questions:

1. How well was the SISFeM programme implemented?
2. How well do ISFM technologies perform, in terms of yields, relative to the traditional farming practices on the demonstration plots?
3. How well do ISFM technologies perform relative to the traditional farming practices of the control demonstrators?[3]
4. What is the impact of the SISFeM programme on adoption rates of new technologies?
5. What is the impact of the SISFeM programme on knowledge about ISFM technologies?
6. How do the adoption rates depend on centrality of the demonstrator within her network?
7. How does the adoption of labour- or capital-intensive technologies depend on farmers' labour or capital constraints?
8. What is the impact of the SISFeM programme on cowpea yields and revenues?
9. Is the yield and revenue impact of the SISFeM programme heterogeneous with respect to the social proximity of farmers to the demonstrator?
10. Is the diffusion of technology different in female and male networks?

Besides the ten research questions, our PAP also considered exploring the following heterogeneous effects on adoption, yields and revenues:

1. Demonstrators versus non-demonstrators;
2. Quartiles of social proximity to the demonstrator;
3. Gender;
4. Cognitive skills (quartiles of the Raven test score);
5. Non-cognitive skills (quartiles of four dimensions of the Big Five test).

The present study answers all of the original research questions but two. First, it proved impossible to analyse differential diffusion in male and female networks (research question 10) since many of the 99 FOs in our study sample are mixed-gender, and thus we would not have enough data points to compare adoption rates in female-only and male-only networks. As for the heterogeneous effects, we decided to split the sample into terciles

[3] We use the term "control demonstrators" to refer to the individuals who were designated as demonstrators but then did not implement any demonstration plots because they were randomly assigned to the control group.

rather than quartiles. The variables used to create the quantiles do not have sufficiently different values, and furthermore it facilitates the interpretation. Second, we do not study the heterogeneous impacts with respect to the social proximity of farmers to the demonstrator (research question 9). It turned out that our measure of social proximity was too fuzzy and such analysis would not be of interest. We also decided not to consider heterogeneous effects by gender of the sampled FO member since the fact that the FO member is female does not necessarily imply that the female makes decisions about practices adopted on the cowpea plots (usually the male household head makes all the decisions, which was confirmed during the FGDs). Instead, we consider female-headed households for the gender heterogeneity analysis. For brevity, we do not include all of the heterogeneous impacts tables in the main report (they can be found in Online Appendix O).

The report is structured in the following way: Section 2 describes the intervention, theory of change, and research hypotheses; Section 3 provides geographic context of the study; Section 4 illustrates the timeline of the programme implementation and the impact evaluation; Section 5 summarises the evaluation design and empirical methodology; Section 6 further revisits the programme and its implementation; Section 7 presents the main results; Section 8 discusses potential threats to internal and external validity; and finally, Section 9 concludes with specific policy recommendations and lessons learned.

2. Intervention, theory of change, and research hypotheses

2.1 Description of the intervention

The GRAD carried out and monitored the intervention in partnership with the University of Mannheim. In the beginning, GRAD selected 99 FOs from the existing 262 in the Sanmatenga province of Burkina Faso. While the ISFM programme included both rice and cowpea, we decided to focus on a single crop – cowpea. Cowpea producers present several interesting characteristics compared to rice producers: cowpea is a cash and subsistence crop, harvested at the end of the lean season (September). Cowpea has interesting nutritive properties (high protein content) and can therefore have important impacts on nutrition. Cowpea is generally produced by women and is generally cultivated with minimal technologies. We therefore had reasons to believe that an intervention such as ISFM may have larger and more detectable impacts on a crop that benefited from a low level of capital and labour intensive technologies to begin with. Last but not least, cowpea FOs are small and numerous while the rice FOs where large and spread out across villages. The design of the ISFM experiment on rice would have been more cumbersome and costly.

We selected the 99 FOs from the 262 FOs available in the Sanmatenga province. These 99 were selected based on the following criteria: they have not been previously exposed to GRAD’s interventions, they have not been exposed to similar interventions run by other non-governmental organisations, and they are sufficiently spread out to limit the risk of spillovers. Once these 99 FOs had nominated a demonstrator and were randomly assigned to the treatment or control group, GRAD began implementing the dissemination activities in the treated FOs. The activities had three specific objectives: 1. to disseminate and increase the adoption of ISFM technologies, 2. to facilitate access to agricultural inputs and credit via the establishment and support of aggregation centres, 3. to strengthen the capacities of FOs.

The dissemination activities were implemented through various channels, one of which was the demonstration plots. The nominated demonstrator selected a plot in their field where they implemented one or several ISFM options. This normally included a purely labour-intensive (LI) and a combined labour- and capital-intensive option (LI+). The ISFM training included a comprehensive list of technologies and inputs including zaï, micro-dosing, intercropping and contour bunding. These options were demonstrated against the traditional farming practices (PP, *pratiques paysannes*). Field visits were organised for the FO members to observe the effects of ISFM technologies at different stages of crop growth. ISFM technologies are further disseminated through study trips, flyers, brochures, video screenings held in villages in the local language, radio broadcasts, and a mobile-phone based platform (M-farm).

In addition, GRAD assisted FOs in improving access to inputs and credit by connecting them to market actors. Specifically, it supported provincial-level centres in Sanmatenga in their responsibilities to buy inputs, sell produce, and receive credit. GRAD further supported unions in improving their technical capacities and ability to widely disseminate knowledge. The evaluation does not directly focus on the part of the programme covered by objectives 2 and 3. In fact, the number of aggregation centres is too small and it proved impossible to exclude any FOs from objective 3.

The intervention aimed to reach 15,000 smallholder farmers across the Sanmatenga province, who are members of cowpea or rice FOs. In line with the above-mentioned research questions, outcomes of interest include the dissemination and take-up of ISFM technologies, access to inputs, organisational capacities of aggregation centres and FOs, and ultimately agricultural productivity and income generation. The evaluation will directly investigate impacts in terms of dissemination, take-up, productivity, and income.

2.2 Theory of change

We lay out below the theory of change associated with the demonstration plots as a means of dissemination for ISFM technologies.

The resources, such as qualified staff, budget and agricultural know-how were provided by our implementation partner GRAD. The implementation of demonstration plots required further inputs, in particular: training of extension agents, providing information to and training of demonstrators, ensuring availability of agricultural inputs needed for the demonstration plots (fertilisers, seeds, tools, etc.). In order to ensure a successful implementation of demonstration plots, good organisational capacities of the participating FOs were also needed. Inputs specific to other dissemination activities included translation of flyers and video content into local languages, material to print the flyers, etc.

The actions at the core of the intervention are demonstration plots for ISFM technologies, distribution of flyers, and screening of videos. Specifically, ISFM technologies were applied on the selected demonstration plots in the presence of other FO members. The information about ISFM technologies provided to the demonstrator and other farmers needed to be clear enough and all the necessary inputs needed to be available in sufficient quantity and on time.

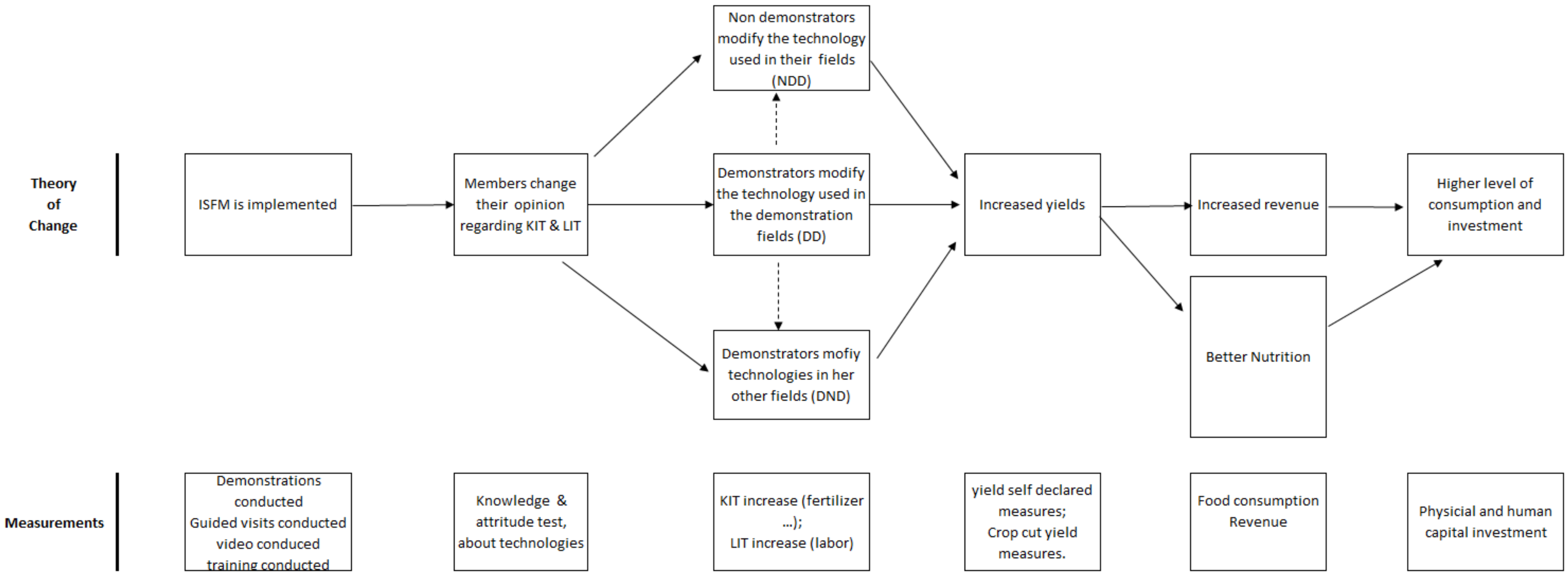
Through the inputs and activities of the SISFeM programme we should achieve a higher exposure to demonstration plots and other dissemination activities in the treatment group. The successful completion of the output stage can be measured in terms of the number of the farmers who report having participated in demonstrations organised by GRAD and being exposed to other dissemination activities (trainings, flyers, videos, radio shows).

If the target group benefits from the elements described in the output stage, we should be able to measure first results in terms of enhanced knowledge, attitudes and practices. In order to observe an effect on knowledge, the information delivery must be clear and frequent enough. The demonstration of ISFM technologies should be highly effective especially for a mostly illiterate population as farmers in the Sanmatenga province are. Attitudes are also an important channel through which we can generate an effect on the practices. Lack of trust, cultural barriers or simply unwillingness to change one's farming routine could act as constraints to the adoption of ISFM technologies. Knowledge and attitudes translate then into a change in behaviour. In particular, take-up of ISFM technologies is the key intermediate outcome of our study and was measured for FO members as well as for the demonstrators themselves. The adoption rates can be affected by the social centrality of a given FO member and by their financial or geographical ability to access inputs, as is highlighted in literature on capital-intensive agricultural practices.

The programme goals envisioned by GRAD and examined as outcomes of interest in the evaluation study are cowpea yields and revenues generated from selling the crop. The increased yields and revenues could ultimately lead to a reduction in poverty and in food insecurity. Long-term impacts on health and education could also be envisioned.

We summarise the theory of change in the following chart:

Figure 1: Theory of change



2.3 Primary outcomes and impacts of interest

The study answers several research questions.

RQ 1: How well was the SISFeM programme implemented?

Here we are interested in the quantity of interventions that each treated FO benefitted from, their fidelity to the implementation protocols, and whether the control group was subject to any of the interventions meant only for the treated FOs. We have identified five types of interventions: demonstration plots, video, flyers, guided visits (to the demonstration plots), and the training. For each activity, we rely on midline data to determine the degree to which the activity was implemented and if the activity was restricted to the treatment group.

RQ 2: How well do ISFM technologies perform, in terms of yields, relative to the traditional farming practices on the demonstration plots?

Here we use the crop cut results within the demonstration plots in the treatment group. We can rigorously compare PP with LI and LI+ technologies. This is a very controlled environment (though probably still less controlled than in many agronomic studies) because GRAD directly supervised the way the demonstration plots were implemented. This is also an effect estimated on the field of a demonstrator who is expected to be a very motivated farmer.

RQ 3: How well do ISFM technologies perform relative to the traditional farming practices of the control demonstrators?

Here we compare the demonstration plots in the treatment and in the control group. Both were identified before randomisation, hence we can argue that these parcels are comparable. This effect is less controlled than in RQ 2 as it leaves all the freedom to the control demonstrator to implement any technology in her control parcels. As a result, we believe that the yield impact captured here will be both of smaller magnitude and probably closer to what would have happened in the absence of the experiment. Again this effect is measured among demonstrators who are likely more educated and motivated than an average farmer.

RQ 4: What is the impact of the SISFeM programme on adoption rates of new technologies?

Here we rely on the 18 farmers who are FO members and who did not implement a demonstration plot. We want to know how many ISFM technologies are being used by the farmers and if the programme significantly modified their agricultural practices.

RQ 5: What is the impact of the SISFeM programme on knowledge about ISFM technologies?

One potential bottleneck of the ISFM diffusion could be information about the technologies. We would like to ascertain that farmers know about benefits of each demonstrated technology. We are also interested in the degree of knowledge for each technology (whether the farmer only heard about it versus whether she actually knows how to implement it). If information is available to farmers, are skills, personal traits, or education good predictors of technological adoption and agricultural productivity?

RQ 6: How do the adoption rates depend on centrality of the demonstrator within her network?

Network data collected at baseline can be used to document each farmer's closest friends or family. Using the demonstrator's network, we can see if social proximity helps diffusion. Network data helps to create an index of social proximity. From there we establish a ranking from the closest to the farthest farmers to the demonstrator. This ranking, identified before randomisation, is completely independent from the treatment. Using the index of technology adoption, we can hence identify the treatment effect at different degrees of social proximity. The index of social proximity will be based on five questions asked to all members about other members of their network. The five questions are binary and related to whether or not the household has communicated, exchanged inputs, exchanged agricultural tools, or worked in or helped financially other OP members in the village.

RQ 7: How does the adoption of labour- or capital-intensive technologies depend on farmers' labour or capital constraints?

The ISFM technologies are labour-intensive but they can also rely on capital-intensive inputs. We are interested in how the treatment effects differ for households who face labour or capital constraints. The labour constraint is estimated by the availability of a household's workforce, while the capital constraint is measured by access to agricultural mechanical tools.

RQ 8: What is the impact of the SISFeM programme on cowpea yields and revenues?

Cowpea yields and revenues are the main outcomes of interest. We look at the overall treatment effects of the programme.

3. Context

Burkina Faso is a landlocked country in West Africa. In 2018, the country ranked 182nd out of 189 countries on the United Nations Development Programme Human Development Index (UNDP, 2018). Gross per capita income was 690 USD as of 2014, with a poverty rate estimated at 40.1% in the same year. Economic growth reached 6.8% in 2018 (World Bank, 2019). A very large share of the active population (80%) relies on subsistence agriculture (World Bank, 2011), a sector which accounts for around 40% of the GDP. Smallholder farmers prevail, with 72% of farms smaller than five hectares (MAFAP, 2013). Despite its significance, the agricultural sector lags behind and faces substantial challenges. Productivity in crops and livestock is extremely low (International Monetary Fund, IMF, 2012). For instance, according to data from the 2008 agricultural census, yields of the main cereals (sorghum, millet, maize, rice) were well below their yield potential (see van Ittersum et al., 2016 for estimates of yield gaps in selected African countries). According to the annual agricultural survey conducted by the Ministry of Agriculture (MAAH, 2015), the national average yield for cowpea is slightly increasing. In particular, the national average cowpea yield rose from 772 kg/ha in 2013/2014 to 782 kg/ha in 2014/2015. But the increase is only relative and does not affect all regions and all producers in the same way since yield improvements largely depend on how the crop is cultivated. Also, the average national yield still lags behind the cowpea potential yield which reaches about 1500 kg/ha. Poor farming practices such as continuous monoculture and in particular low use of agricultural inputs contribute to explaining low yields. In 2016, the overall fertiliser use was only 21.77 kg/ha in Burkina Faso (FAO, 2016) while the recommended rates are 100 kg/ha for NPK and DAP fertilisers and 400 kg/ha for Burkina phosphate. Several factors underlie the low use of agricultural inputs. This includes lack of financial resources to purchase inputs (coupled with limited access to credit), high prices of inputs, large distance to the supply source and/or unavailable transportation, and limited information. On the supply side, provision of quality inputs in a timely manner and sufficient quantity remains a challenge. In the light of the rapid demographic growth faced by the country and the consequences of climate change and soil degradation, efforts to increase agricultural yields in the intervention areas are crucial.

3.1 Programme targeting

Burkina Faso has just begun implementing a five-year national development plan named *Plan National de Développement Economique et Social* (PNDES) for the period 2016-2020. This plan has three strategic areas: (i) institutional reform and modernisation of the administration, (ii) development of human capital, and (iii) invigoration of economic sectors for the economy and employment. Agriculture has been identified as one of the crucial sectors that hold the greatest opportunities for investment. The current government is keen on investing in sustainable technologies that will boost agricultural productivity and improve income for smallholder farmers. PNDES sets a goal of a 50% increase in agricultural productivity between 2015 and 2020. Hence, PNDES can be seen as a significant window of opportunity for the use of evidence generated by the impact evaluation of the SISFeM programme.

Increasing adoption of sustainable agricultural technologies is key for increasing agricultural productivity in Burkina Faso (Koussoubé and Nauges, 2016). As a country in which most households are capital-constrained, labour-intensive agricultural practices (e.g. some of the ISFM technologies) can represent viable alternatives to capital-intensive technologies such as fertiliser. Yet research still needs to be undertaken to determine whether ISFM technologies outperform traditional practices in the field and to understand the determinants and impacts of adoption. Providing evidence on the impact of ISFM technologies on agricultural productivity and income can contribute to and inform the design of policies so as to attain the ambitious goals set out under PNDES.

Moreover, the evaluation of the SISFeM programme should also contribute to the design and implementation of policies intended to reduce gender inequality in Burkina Faso and other Sub-Saharan African countries. Indeed, the programme targets farmers who produce cowpea, a crop that in Burkina Faso is mainly grown by women (Koussoubé, 2015). Although the detrimental effects of gender inequality in access to agricultural information and other inputs in Africa are well-documented, evidence on the impact of interventions designed to reduce these inequalities is lacking. The evaluation of the SISFeM programme should contribute to filling this gap. In particular, the SISFEM programme aimed at addressing gender inequality by targeting all-female FOs, which should help overcome the barrier in access to information. However, as it is discussed later in the part on heterogeneous treatment effects for female-headed households, the barrier of access to key inputs and know-how remains present. Qualitative research also unveiled the fact women in male-headed households do not necessarily have the power to decide which practices will be adopted on their cowpea plots. More broadly, this evaluation shows that any agricultural programme with a goal of reducing gender inequality should also consider intra-household gender dynamics in their theory of change and design.

The overall goal of the programme under evaluation is to improve food security and increase income of smallholder farmers. The programme's specific objectives are: i) to disseminate and thereby increase adoption of ISFM technologies, understood as a set of agricultural practices that combines use of inputs (improved varieties, organic and mineral fertilisers), relevant knowledge and improved land-use planning; ii) to facilitate access to agricultural inputs and credit via establishing and supporting aggregation centres; iii) to strengthen capacities of FOs for further dissemination of ISFM technologies. The present impact evaluation focuses solely on cowpea FOs of the Sanmatenga province.

Villages and FOs that would participate in the impact evaluation within Sanmatenga province were determined by GRAD based on the following criteria: the villages were to be at least one kilometre away from other participating villages, they had to have at least one FO; the FOs within the villages should have never worked with GRAD before and had to be active (that is, they held at least one meeting in the last 12 months). The treatment status was assigned by randomisation.

3.2 Study site selection

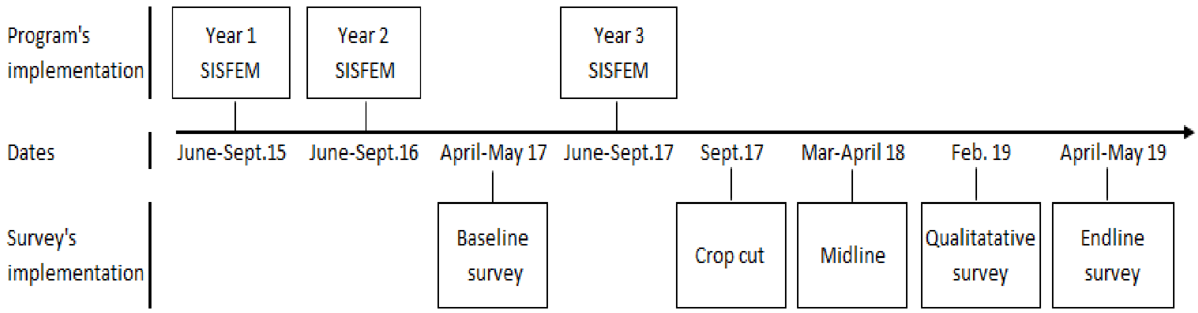
The intervention took place in the province of Sanmatenga, located in the Sudano-Sahelian agro-ecological zone. This semi-arid area is characterised by erratic climatic conditions and subsequent challenges regarding soil fertility and water management. Agricultural yields remain low. Poor farming practices such as continuous monoculture and in particular low use of agricultural inputs such as fertiliser contribute to low yields.

The impact evaluation is expected to generate valuable insights into key issues relevant to agricultural and economic development of Burkina Faso. In light of the importance of the agricultural sector and of the new development plan recently launched by the government (PNDES), providing evidence on the impacts of ISFM technologies on agricultural productivity and incomes can contribute to directly feed in the design and implementation of upcoming policies. The fact that cowpea is a crop with relatively low capital intensity and that it is widely grown across the whole country reinforces the relevance of the study and its potential uptake by policymakers. Findings on the impact of ISFM technologies are likely to be relevant in other provinces of Burkina Faso, as well as in other countries located in the same agro-ecological zone. The dense network of agriculture-oriented public, private and non-profit stakeholders in Burkina Faso, as well as the already established linkages with the Ministry of Agriculture, farmers' unions and private companies will furthermore facilitate evidence dissemination and uptake.

4. Timeline

Figure 2 depicts the stages of the programme implementation and impact evaluation. Given the RCT design, the baseline survey was carried out before the start of the programme implementation in year 3. Also, in years 1 and 2 the programme was implemented in different villages than in year 3. Note that the implementation in the first two years took place outside of the current study site.

Figure 2: Timeline



5. Evaluation: design, methods and implementation

5.1 Institutional review board

The data collection procedures and survey instruments were reviewed and approved by the ethics commission of the University of Mannheim (*Ethikkommission der Universität Mannheim*). Furthermore, the IPA enumerators read a consent statement explaining the purpose of the study and emphasising that participants had the option to end the interview at any time or decide not to answer any of the questions. Without an explicit consent by the participant the interview could not continue.

5.2 Identification strategy

The impact evaluation is based on a two-stage cluster RCT. In the first stage, we assess the yield impact of LI and LI+ technologies against PP. This was allowed by randomising FOs in Sanmatenga province into treatment and control groups. Our implementation partner GRAD selected 99 FOs from the existing ones throughout the province. After identifying these FOs, each of them was asked to nominate a potential demonstrator, i.e., a farmer willing to set up demonstration plots for farmers within his or her network. Forty of these FOs and their selected demonstrators were assigned to the treatment group and the remaining 59 were assigned to the control group. Demonstrators assigned to the treatment received assistance and expertise from GRAD in setting up the demonstration plots, while demonstrators assigned to the control were not instructed to set up any demonstration plots. The outcomes of interest in the first stage are crop yields, which were measured in a very precise way using the crop cut methodology. We are thus able to compare yields of farmers in the control group to those in the treatment groups, and further compare the outcomes of the labour-intensive technologies alone to the combination of labour- and capital-intensive technologies.

In the second stage, we investigate how technologies are adopted throughout the demonstrators' network. In our data we include a maximum of 18 network farmers (non-demonstrators) per FO. In some FOs we did not find as many as 19 members, therefore, we sometimes have less than 19 observations per cluster. Comparing the 18 farmers in the FO in the treatment and control groups captures how fast new technologies trickle down within an FO. Data on the rate of dissemination and adoption of new technologies were collected in a midline survey, which also captured information on agricultural knowledge and practices. The qualitative data collection allows us to understand reasons behind farmers' decisions to adopt or not adopt ISFM technologies.

FOs are particularly well suited to be the unit of interest for this impact evaluation. The cowpea FOs in Sanmatenga province are small (composed of 28 members on average; with a maximum of 72 members and a minimum of nine members), they are often run by women (70% of the FOs are run by women, 50% are exclusively female, while 10% are exclusively male), and they are organised at the village level.

5.3 Sampling

We selected 99 FOs from the 262 FOs available in Sanmatenga province. The 99 FOs were selected based on the following criteria: they have not been previously exposed to GRAD's interventions or similar interventions run by other non-governmental organisations, and they are sufficiently spread out to limit the risk of spillovers. We also excluded FOs that were located in urban areas, that were inactive or located in villages that the GRAD considered inaccessible. We reached a total of 162 eligible FOs. We then conducted a census in these 162 FOs to obtain precise information on each FO and exclude those that were not operational. Using the data from the census, we further eliminated FOs that did not organise any meeting in the last 12 months, that were too small (fewer than ten members as we ideally wanted to sample 18 members per FO) and that were located less than one kilometre from each other (to avoid contamination). We conducted the randomisation on 99 FOs in 99 villages (one FO per village to avoid contamination). In Table 1, we use data collected by GRAD prior to the randomisation in order to compare selected and non-selected FOs. Not surprisingly, the selected FOs have more members, the selected villages have fewer FOs, and prior to the randomisation the selected FOs had no demonstration plots and limited access to flyers and video screenings. These data also confirm that at baseline the FOs in our study had low exposure to ISFM.

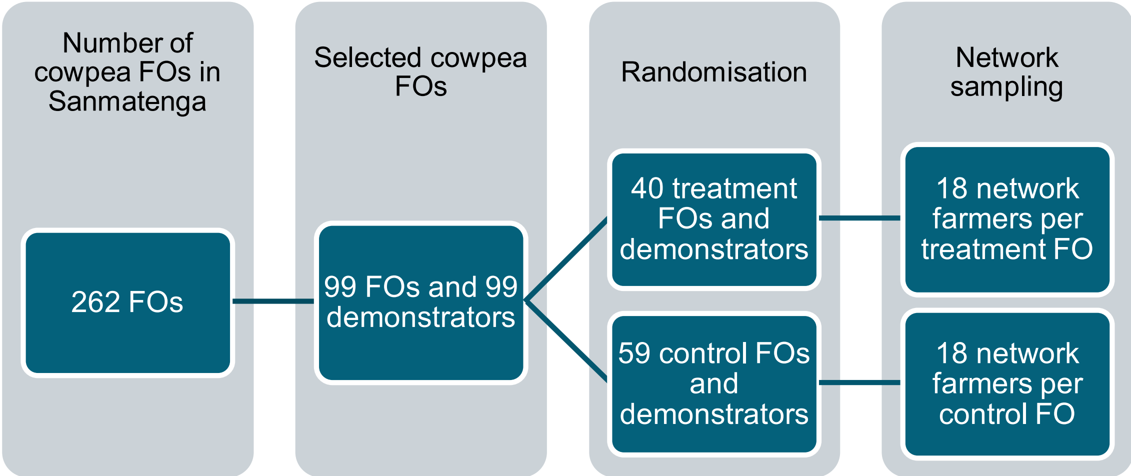
Table 1: Comparison between selected and non-selected FOs before baseline

	Obs.	Mean non-selected (NS)	Difference selected / non-selected (S-NS)
# of members in FO	262	21.638	4.271 ***
			(1.386)
# of FOs per village	262	2.141	-0.474 ***
			(0.149)
Pre-baseline demonstration	262	0.153	-0.143 ***
			(0.030)
Pre-baseline visits	262	0.098	-0.098 ***
			(0.023)
Pre-baseline flyers distribution	262	0.141	-0.131 ***
			(0.029)
Pre-baseline video	262	0.037	-0.027
			(0.018)

Note: The table compares the pre-experimental differences between the 99 selected FOs and the ones not included in the study. * significant at 10% ** significant at 5% *** significant at 1%.

Further, we summarise in Figure 3 our sampling approach:

Figure 3: Sampling design



5.4 Different methods for measuring causal effects

Based on this sampling design, different analyses can be conducted. Items (1) – (4) below can be answered using the crop cut data because it provides us with parcel-level yields. The crop cut methodology also allows us to obtain true impacts of the LI and LI+ technologies since the yields can be precisely calculated. The yield we calculate is thus the true yield (as opposed to the self-reported baseline, midline, and endline measures where the yield estimates may suffer from a recall bias when respondents have to remember the total amount of cowpea harvested during the last season, as well as from an estimation bias since respondents might not know the correct surface of their fields). Items (5) – (7) can be answered using midline and endline data, in which we don't have parcel-level information, but rather cowpea yields on the total agricultural land of each household.

Using crop cut data:

1) "Within-treatment" demonstrator yield impact, the "agronomic effect": Here we compare different practices (PP, LI, LI+) within the treatment demonstration plots of the same demonstrator. This gives us the potentiality of each practice implemented by an average farmer who we assume to be motivated and skilled. This is as close as we can get to an "agronomic" analysis implemented in an environment that is similar to the one farmers usually experience in developing countries. Yet, this impact is expected to remain quite artificial as GRAD was supposed to monitor the demonstration plots closely and the PP experiment should have excluded all innovative ISFM technologies, and especially the fertilisers (we will see later that this wasn't necessarily the case during the implementation).
2) "Within-treatment" demonstrator yield impact, the "weak potential effect" using non-demonstration plots of the treated demonstrators: Another possible comparison in yields is between the LI and LI+ technologies on the demonstration plot and on one of the non-demonstration plots of the treated demonstrators. We expect this impact to be lower than the pure "agronomic effect" as demonstrators might already be applying on their non-demonstration

plots some of the ISFM options that GRAD showed them. We can partly consider this effect as what would potentially be an impact in the absence of the closely monitored demonstration plots, but this "potential effect" is weaker than in the case when we are using the actual control group as our counterfactual.

3) "Between-demonstrators yield impact" (between treatment and control groups), the "strong potential effect": Since the demonstration plots were identified before the randomisation, the treatment and control demonstration plots can be compared in order to estimate the "between" yield impact. This effect is arguably less "controlled" than the impacts in (1) and (2) as it leaves all the freedom to the control demonstrator to implement any technology on her plots. As a result, we believe that the yield impact captured here will be both of smaller magnitude than (1), and that the control condition is probably closer to what would have happened in the absence of the experiment. Yet, this effect is measured among demonstrators (probably more educated and motivated than the average farmer). It does not fully capture what would have been the impact on an average cowpea producer in Burkina Faso.
4) "Within-treatment" network yield impact (between demonstrators and network farmers in the treatment group), the "potential effect": We can already analyse from the crop cut data the difference between demonstrators and network farmers. By comparing yields of the LI and LI+ technologies on demonstration plots and yields of plots belonging to non-demonstrators in the treatment group, we can already see whether network farmers are behaving in the same way as demonstrators during the time of the experiment. On the one hand, network farmers might act similarly to the demonstrators because they trust them, in which case the plots of network farmers would be similar to non-demonstration plots of the demonstrators. This effect would then be comparable to the "weak potential effect" in (2). This similar behaviour might consist in (partly) adopting the ISFM options even before seeing results on the demonstration plots, which would affect the magnitude of this effect. On the other hand, network farmers might act differently due to the lack of trust in the demonstrator, in the new ISFM technologies or due to a general lack of motivation and willingness to change their routine. In this case the effect would be different from (2).

Using midline/endline data:

5) "Intent-to-treat (ITT) overall impact": Due to the RCT design of our study a simple comparison of average yields between the treatment and control groups allows us to estimate the ITT impact. The ITT represents the effect of the treatment as assigned, i.e. the overall effect of the SISFeM programme as implemented by GRAD. Note that farmers are exposed to both LI and LI+ technologies and hence are in a position to choose which one to implement. Therefore, the ITT estimate does not let us understand whether the change in yields arises from adoption of LI+ or LI technologies only and vice versa. The ITT estimate furthermore does not take into account the level of compliance with the treatment assignment (the actual diffusion of ISFM technologies among demonstrators and network farmers).
6) "ITT demonstrator impact": We can also consider the ITT estimate for demonstrators separately. Demonstrators in the treatment group had direct and close interactions with the GRAD personnel and the impact is likely to be stronger than the overall ITT estimate in (5).

7) "ITT network impact" or the "diffusion effect": Similarly to (6), we can consider the ITT estimate for non-demonstrators separately. Comparing the 18 farmers in the FO in the treatment and control groups will capture how fast new technologies trickle down in an FO.

Figure 4 below summarises the different groups for analyses that we will be able to undertake.

Figure 4: Different groups for the analysis

		Treated (T)			Control (C)
(I)	99 demonstrators: demonstration plots	PP	LI	LI+	LI/LI+/PP
(II)	99 demonstrators: non-demonstration plots	LI/LI+/PP			
(III)	Network farmers(18*100=1800)	LI/LI+/PP			LI/LI+/PP

The first two rows (I) and (II) correspond to the "agronomic" and "potential effect" analyses performed using the crop cut data and described in (1), (2), (3) and (4), while the third row (III) corresponds to the diffusion analysis as described in (7). All three rows combined represent the "overall ITT" analysis in (5) and the first two rows combined represent the "demonstrator ITT" analysis in (6).

The cell T(I) represents the demonstration plots in the treatment group (which are divided into three experiments), the cells T(II) and T(III) will benefit from the programme through diffusion and hence the 18 network farmers and demonstrators on their non-demonstration plots will adopt a mix between LI, LI+ and PP. The C(I)/(II) cell corresponds to regular farming practices PP of demonstrators in the control group. The cell C(III) corresponds to the regular practices of network farmers in the control group. For the sake of simplicity, we consider PP as homogeneous in T and C, while it might happen that PP will be influenced by the experiment. For instance, PP in T(I) might be different from PP in T(III), C(I)/(II) or C(III) as they are not implemented by the same farmers and may be influenced by the presence of GRAD in the treatment group, especially for demonstrators.

5.5 Qualitative design

A qualitative analysis is used to complement the quantitative analysis in order to fully address all research questions. Specifically, the qualitative interviews provide insights about both the fidelity of the programme implementation, and the reasons behind farmers' decisions to adopt or not adopt ISFM technologies.

As for the quality of the intervention, the qualitative interviews provide evidence on the following questions:

- Was there any intervention in the control group?
- How was the intervention rolled out in the treatment group?
- Were the network farmers able to observe the demonstration plots?
- Was the experiment well-explained to the participants and were the results well-communicated?
- In case the demonstrators did not respect the experimental protocol, why did this occur?

Regarding the reasons for farmers to decide to adopt or not adopt ISFM technologies, the qualitative interviews provide information on the following questions:

- Are farmers willing to adopt ISFM technologies?
- For farmers willing to adopt ISFM technologies, why do they want to do so?
- For farmers not willing to adopt ISFM technologies, why don't they want to do so?
- For farmers who wanted to adopt ISFM technologies but did not, what constraints did they face?

Two types of qualitative interviews were conducted. In a sub-sample of both treatment and control FOs, we conducted FGDs, a data collection method that allows a group of individuals to share their opinions in the presence of a moderator who guides the discussion while following an interview guide. FGDs were held in four control FOs and four treated FOs in a group of eight farmers. The selection of FOs relied on purposive sampling; we selected FOs according to their characteristics, and specifically chose the ones with the most extreme adoption rates at midline in order to get a more accurate understanding of the reasons behind the difference in adoption rates.

We also carried out KIIs with eight demonstrators from the FOs selected for the FGDs and two workers from the *Union Provinciale des Producteurs du Niébé du Sanamtenga* (UPPNS) who assisted in the implementation of the SISFeM programme. KIIs correspond to semi-structured interviews that allow us to orient the talk to the pre-determined topics.

6. Programme: design, methods and implementation

6.1 Choice of demonstrators

Within each FO, a demonstrator was identified. The criteria for the choice of demonstration plots were the availability of organic matter, the availability of labour, and geographical accessibility. Also, criteria such as positive attitude towards innovation, openness and willingness to comply with the experimental protocol were taken into account in the choice of demonstrators. These selection criteria lead us to believe that demonstrators are on average more motivated and successful farmers than the other members of an FO, which justifies the heterogeneous treatment effects analysis. We verify how demonstrators differ from the other members of the FO in Table 2:

Table 2: Baseline comparison between demonstrators and non-demonstrators

	Obs.	Clust.	Mean non-demonstrator (ND)	Diff. demonstrator ND (D-ND)
Ethnicity of the household				
is Mossi	1510	99	0.946	0.013
				(0.017)
is muslim	1510	99	0.605	-0.009
				(0.039)
is catholic	1510	99	0.189	0.023
				(0.034)
is protestant	1510	99	0.056	0.045 *
				(0.027)
isanimist	1510	99	0.144	-0.063 **
				(0.029)
Social network				
occupies an official FO position	1407	99	0.276	0.641 ***
				(0.033)
occupied an official FO position	1407	99	0.175	0.440 ***
				(0.050)
is the village chief	1510	99	0.079	0.083 **
				(0.035)
# of groups involved in (max 9)	1510	99	1.017	0.478 ***
				(0.124)
ever been a demonstrator	1510	99	0.072	0.574 ***
				(0.047)
# of interactions (max 5*21=105)	1503	99	35.870	3.746 *
				(2.111)
index of social interactions	1503	99	0.454	0.088 ***
				(0.024)
% of known FO members you have…				
talked about farming	1510	99	12.734	0.973 **
				(0.480)
exchanged inputs	1510	99	4.785	1.700 ***
				(0.628)
exchanged tools	1510	99	3.327	0.218
				(0.533)
worked in each other's fields	1510	99	11.363	0.061
				(0.621)
helped financially	1510	99	3.483	0.972 *
				(0.578)

We see that demonstrators are very different from the rest of the FO: they are more socially connected to other members, they occupy leading roles, and have a lot of agriculture-related relationships with the other members. Importantly, the selection of demonstrators is not a cause of concern for internal validity in our experiment as they were designated before the randomised assignment into the treatment and control groups. There is no reason to believe that treatment demonstrators are different from control demonstrators and so our estimates should not suffer from selection bias. However, it is also important to highlight the difference between demonstrators and non-demonstrators. The higher social connectedness and leadership roles of farmers selected to demonstrate ISFM technologies might be crucial characteristics that make the remaining farmers susceptible to new practices.

6.2 Description of the experiment

First, the demonstrators were asked to choose between two technologies allowing for management of heavy rains and reducing risks of soil erosion: zaï or contour bunding. One of these technologies had to be applied on demonstration plots. The experiment was then different for those who chose zaï and those who opted for contour bunding.

6.2.1 Experiment with zaï

Zaï is a soil fertility improving technology that is suitable for impermeable land. It consists of digging holes that are 80 centimetres apart, five to 50 centimetres deep and with a diameter of 15 to 50 centimetres, in which seeds are subsequently planted. The holes must be deepened before every rainy season. Heavy rains usually cause damage to crops by contributing to soil erosion and zaï improves infiltration of the run-off water by capturing it. In combination with fertiliser and organic matter, zaï has been proven to dramatically increase yields. Zaï is a simple technology that requires no specific equipment, however, it is very demanding in terms of labour since digging of holes is very time-consuming. According to the United Nations Environment Programme (UNEP et al., 1998), it requires between 30 and 70 person-days per hectare.

A zaï demonstration plot is composed of five parcels. Each parcel has a surface of 50 metres squared and the total surface of the demonstration plot is 300 metres squared (distance between parcels must be 2 metres). The five experimental parcels consist of:

1) PP: crop association of sorghum/millet and cowpea;
2) LI: Cowpea and sorghum grown separately (not in association), without fertiliser;
3) LI: Intercropping of cowpea and sorghum/millet, without fertiliser;
4) LI+: Intercropping of cowpea and sorghum/millet, with NPK;
5) LI+: Intercropping of cowpea and sorghum/millet, with DAP.

6.2.2 Experiment with contour bunding

Contour bunding is another soil fertility improving technology pioneered in Burkina Faso in the 1980s that helps to manage heavy rains. It is suitable for semi-arid lands with a sufficient supply of stones. It consists of laying stones along contours, thus creating permanent structures that are up to 25 centimetres tall, 40 centimetres wide and 20 to 50 metres far away from each other. Stone contours keep the run-off water spread, thus reducing risks of soil erosion and allowing rehabilitation of degraded lands.

A demonstration plot using contour bunding is one half to one hectare large and divided into three equally sized parts:

1) PP: crop association of sorghum/millet and cowpea;
2) LI+: Intercropping of cowpea and sorghum/millet, with NPK;
3) LI+: Intercropping of cowpea and sorghum/millet, with DAP.

Demonstrators were also instructed on how to prepare the soil, when and in what quantity to use chemical fertilisers and organic matter, and how to maintain the crops (through weeding and mounding). The role of extension agents from the UPPNS was to delimit the demonstration plots, raise awareness, present demonstration tools, communicate with FOs and organise field visits. The role of GRAD was practical organisation of activities linked to the demonstration plots together with the UPPNS extension agents, sending text messages to cowpea producers to remind them of the

ISFM technologies, organising radio shows and video screenings, distributing flyers, organising guided visits of the demonstration plots and trainings for the network farmers on ISFM technologies for cowpea production.

7. Impact analysis and results of the key evaluation questions

7.1 Specification

As mentioned previously, the RCT design allows for the principal identification strategy to consist of a simple ordinary least squares (OLS) regression of the variables of interest on the treatment status. The primary impacts are estimated using the following regression model:

$$Y_i = \alpha + \beta T_i + \boldsymbol{\delta X_i} + \varepsilon_i \qquad (1)$$

where Y_i refers to the outcome of interest of a household i, α to the intercept, T_i to the treatment status, β to the coefficient of interest (impact), $\boldsymbol{X_i}$ to the vector of control covariates (strata variables), $\boldsymbol{\delta}$ to the vector of coefficients on the control covariates (not reported), and ε_i to the error term. We do not run into any endogeneity issue because of the randomised assignment to the treatment status (i.e. the regressor T_i and the error term ε_i are uncorrelated). Standard errors are clustered at the FO level to account for correlation of treatment effects within an FO.

The secondary analysis consists mainly of estimating heterogeneous effects. There are two types of heterogeneous effects equations: the first one uses only the dummy variable determining whether an observation is a demonstrator, while the second one uses the quantiles that divide our sample into three groups. In the first case, the regression model is the following:

$$Y_i = \alpha + \delta_T T_i + \delta_D D_i + \beta_1 (T_i \times D_i) + \boldsymbol{\delta X_i} + \varepsilon_i \qquad (2)$$

where Y_i, α, T_i, $\boldsymbol{X_i}$, $\boldsymbol{\delta}$, and ε_i are defined as before, δ_T corresponds to the coefficient on the treatment, D_i to the dummy variable for heterogeneous effects, δ_D to the coefficient on this dummy variable, $(T_i \times D_i)$ to the interaction term between the treatment status and the heterogeneity dummy variable, β_1 to the coefficient of interest (heterogeneous effect). In the second case, the regression model is the following:

$$Y_i = \alpha + \delta_T T_i + \delta_{Q1} Q_{1,i} + \delta_{Q3} Q_{3,i} + \beta_1 (T_i \times Q_{1,i}) + \beta_2 (T_i \times Q_{3,i}) + \boldsymbol{\delta X_i} + \varepsilon_i \qquad (3)$$

where Y_i, α, T_i, δ_T, $\boldsymbol{X_i}$, $\boldsymbol{\delta}$, and ε_i are defined as before, $Q_{1,i}$ and $Q_{3,i}$ correspond to the first and third terciles of a given category considered for the heterogeneous effects, δ_{Q1} and δ_{Q3} to the coefficients on the first and third terciles, $(T_i \times Q_{1,i})$ and $(T_i \times Q_{3,i})$ to the interaction terms between the treatment status and the terciles considered for the heterogeneity, and β_1 and β_2 to the coefficients of interest (heterogeneous effects of the lowest and the highest tercile).

7.2 Balance tests

Balance tests were performed using baseline data to confirm validity of the randomisation. Results are shown in Table 3.

Table 3: Balance tests on household demographics

	Obs.	Clust.	Mean treated (T)	Mean control (C)	Mean difference (T-C)
Ethnicity of the household					
is Mossi	1510	99	0.95	0.96	-0.04
					-(0.03)
is muslim	1510	99	0.60	0.57	0.09
					-(0.07)
Age of the household member (full sample)					
Age in years	15576	99	20.62	20.38	0.61
					-(0.55)
is adult (>14 years old)	15597	99	0.47	0.46	0.02
					-(0.01)
is child (<14 years old)	15597	99	0.50	0.51	-0.02
					-(0.02)
Education (for those 5 years or older)					
Any schooling	12955	99	0.44	0.42	0.04
					-(0.04)
Primary or more	12955	99	0.30	0.29	0.02
					-(0.03)
Secondary or more	12955	99	0.06	0.06	0.01
					-(0.01)
In the last 12 months					
Main activity is farming	7825	99	0.79	0.81	-0.05
					-(0.03)
Worked in farm	7825	99	0.95	0.95	0.01
					-(0.01)
Worked in family business	7818	99	0.25	0.23	0.05 *
					-(0.03)
Revenue from family business (€)	1525	99	352.64	305.72	101.77
					-(69.86)
Worked outside job	7815	99	0.06	0.05	0.02 *
					-(0.01)
Revenue from the outside job (€)	320	81	420.77	363.24	105.80
					-(134.51)

Note: The table is at the household member level (1510*max 10 individual). It gives the number of household members (obs.), the number of villages (clust.), the average in both experimental groups (T), the average in the control group (C) and the difference between treatment and control (T-C) for each dependant variable in rows. The T-C coefficient is obtained regressing the dependant variables with the treatment variable. The standard errors, clustered at the village level, are given below the coefficient in parenthesis. * significant at 10% ** significant at 5% *** significant at 1%

The column T-C compares the characteristics of both experimental groups before the beginning of the intervention. From the household demographics section, we see that most characteristics are balanced (i.e. education and age distribution, ethnicity, religion). We do observe, however, some marginally significant differences in terms of non-farming activities (job outside the family farm and the family business). Household members in the treatment group seem to perform professional activities outside of the family farm more often than in the control group; they are more likely to work in the family business or in an outside job and less likely to have farming as the main activity. However, the revenue derived from these activities remains unchanged. Since working in an outside job is relatively rare, a few individuals may drive the difference between the treatment and the control group. We hence believe that the validity of the randomisation is not endangered.

Next, we verify whether our groups are well-balanced in terms of household wealth (Table 4). In particular, we consider type of housing, size of the livestock, agricultural equipment, as well as the overall revenue of the household. We can observe a slight misbalance on the index of equipment (5% of a standard deviation).

Table 4: Balance tests on household wealth

	Obs.	Clust.	Mean treated (T)	Mean control (C)	Mean difference (T-C)
Index of food security	1510	99	0.00	-0.01	0.01 (0.06)
Total household revenue	1480	99	267.070	263.128	9.627 (33.91)
Index of equipment	1510	99	0.00	0.02	-0.05 * (0.03)
Number of animals	1509	99	30.94	32.54	-3.87 (2.82)
Index of bad housing	1510	99	0.00	0.06	-0.15 (0.14)

The table gives the number of household members (obs.), the number of villages (clust.), the average in both experimental groups (T), the average in the control group (C) and the difference between treatment and control (T-C) for each dependant variable in rows. The T-C coefficient is obtained regressing the dependant variables with the treatment variable. The standard errors, clustered at the village level, are given below the coefficient in parenthesis.
* significant at 10% ** significant at 5% *** significant at 1%.

As to the agricultural characteristics (Table 5), farmers in the control group report having a greater number of parcels overall, a slightly higher area cultivated, and a slightly higher number of parcels with cowpea only. On average, respondents own just less than four parcels, each of about one hectare. Interestingly, while cowpea is the main crop (80%), only a minority of parcels were used only for cowpea production (26%). Most of the time, cowpea is produced at the same time as other cereals (usually millet or sorghum). Traditionally, farmers tend to produce cereal and cowpea crops simultaneously (the cowpea is harvested in September, while the cereal crops are usually harvested in October or November) and provide a source of alimentation during the lean period. There are no significant differences between the control and the treatment groups in terms of cowpea yields or revenues generated from the cowpea sales.

Table 5: Balance tests on agricultural characteristics

	Obs.	Clust.	Mean treated (T)	Mean control (C)	Mean difference (T-C)
Area cultivated (ha)	1496	99	4.42	4.65	-0.55 * (0.29)
Area where cowpea is cultivated (ha)	1483	99	3.50	3.65	-0.35 (0.25)
Total number of parcels	1510	99	3.77	3.91	-0.34 * (0.20)
Number of parcels where cowpea is cultivated	1498	99	2.78	2.84	-0.16 (0.15)
Cowpea yield (kg/ha)	1370	99	291	287	11 (20.95)
Cowpea revenue (€)	1370	99	171.17	176.59	-12.98 (17.92)

Note: The table gives the number of household members (obs.), the number of villages (clust.), the average in both experimental groups (T), the average in the control group (C) and the difference between treatment and control (T-C) for each dependant variable in rows. The T-C coefficient is obtained regressing the dependant variables with the treatment variable. The standard errors, clustered at the village level, are given below the coefficient in parenthesis. * significant at 10% ** significant at 5% *** significant at 1%.

Table 6 shows the balance in terms of skills and knowledge of the FO members sampled for our study. Reassuringly, all indicators are well-balanced between the treatment and the control groups. Farmers' performance on the knowledge test is low. They rarely know the correct amount of fertiliser that should be used and tend to underestimate it. Although a majority of them know which is the best fertiliser for cowpea (NPK), only 19%

of respondents know the recommended rate. Similarly, respondents are not aware of the correct dosage of organic fertiliser (compost and manure) and again tend to underestimate it. This demonstrates the farmers' low level of knowledge about soil fertilisation. Finally, their performance on the Raven test is also low. They answer correctly only 33% of the questions.

Table 6: Balance tests on skills and knowledge

	Obs.	Clust.	Mean treated (T)	Mean control (C)	Mean difference (T-C)
Cognitive skills					
Raven score (out of 10)	1510	99	3.32	3.41	-0.22 (0.15)
Non cognitive skills					
Agreeableness / trust	1509	99	0.00	0.02	-0.04 (0.05)
Consciousness	1509	99	0.00	0.01	-0.03 (0.05)
Neuroticism	1509	99	0.00	0.02	-0.04 (0.05)
Openness to experience	1509	99	0.00	0.00	-0.01 (0.06)
Knowledge test					
Number of ways to combat pests (6 max)	1510	99	1.14	1.13	0.018 (0.04)
Correct fertiliwer for cowpea	1510	99	0.71	0.74	-0.09 ** (0.04)
Right period for fertilizer	1510	99	0.59	0.59	-0.01 (0.05)
Right amount of NPK	1510	99	0.19	0.19	0.00 (0.03)
Right amount of DAP	1510	99	0.05	0.05	0.02 (0.02)
Right amount of phospate	1510	99	0.00	0.00	0.00 (0.00)
Right amount of compost	1510	99	0.19	0.19	-0.02 (0.02)
Right amount of manure	1510	99	0.18	0.19	-0.01 (0.02)
Know countour bunding	1510	99	0.15	0.15	-0.01 (0.03)

Note: The table gives the number of household members (obs.), the number of villages (clust.), the average in both experimental groups (T), the average in the control group (C) and the difference between treatment and control (T-C) for each dependant variable in rows. The T-C coefficient is obtained regressing the dependant variables with the treatment variable. The standard errors, clustered at the village level, are given below the coefficient in parenthesis. * significant at 10% ** significant at 5% *** significant at 1%.

There is no evidence of differential attrition between the control and the treatment groups at endline or at midline. Attrition rates at midline and at endline are extremely low – 2.8% and 1.8% respectively. We base the endline attrition rate calculations on the original baseline sample (including households not found at midline). There are no signs of differential attrition either at midline or at endline (see Table 7).

Table 7: Differential attrition

	Attrition	
	Midline	Endline
Treatment	-0.009 (0.009)	-0.0101 (0.0061)
N	1510	1510
Constant	0.028	0.018

Note: Dependent variable attrition is equal to 1 if the household was not interviewed for a given survey. *** significant at 1%, ** significant at 5%, * significant at 10%.

7.3 Primary results

7.3.1 Implementation of the programme

We begin the presentation of the programme impacts by first considering the quality of the programme implementation (research question 1). Table 8 summarises the impact of the treatment on participation in agriculture-related programmes using the midline data. The questions on participation were asked for the period of the last 12 months and so the SISFeM programme implementation dates should be covered for the treatment group respondents. Therefore, we can evaluate whether the intervention was well-delivered.

Table 8: Impact on participation in agricultural interventions at midline

	Number of observations (N)	Mean control (C)	ITT
Ever heard of the SISFeM project	1473	0.53 (0.50)	0.15 *** (0.04)
Participated in at least one demonstration	1347	0.48 (0.50)	0.18 *** (0.04)
Demonstrations organized by FO/GRAD	644	0.31 (0.46)	0.27 *** (0.06)
Participated in at least one training	1473	0.27 (0.45)	0.05 (0.03)
Training organized by FO/GRAD	356	0.21 (0.41)	0.18 *** (0.06)
Received at least one flyer	1473	0.08 (0.27)	0.02 (0.02)
Flyer distributed by FO/GRAD	98	0.23 (0.42)	0.43 *** (0.08)
Watched at least one video	1473	0.05 (0.22)	0.21 *** (0.05)
Video projected by FO/GRAD	141	0.28 (0.45)	0.36 *** (0.10)
Listened to at least one radio show	1473	0.32 (0.47)	-0.04 (0.03)
FO/GRAD participated in the radio show	224	0.08 (0.27)	0.14 ** (0.05)

Note: Clustered standard errors at the farming organization (FO) level. Controls: strata variables. The questions on participation were asked relative to the last twelve months. * 10% signifcance, ** 5% significance , *** 1% significance.

We observe a significant increase in exposure to agriculture-related programmes, even though it is not as high as we would expect. Treated farmers are more likely to have participated in a guided demonstration, seen videos, received training, or simply have heard of the programme. Yet, the control farmers also have relatively high exposure to agriculture-related interventions. In particular, 48% of the control farmers declare having participated in at least one demonstration.

In order to better understand these surprising results, we turned to qualitative research tools. First, the relatively low take-up in the treatment group was to be expected. Our interviewees in the FGDs underlined the fact that the participation in the ISFM interventions were entirely voluntary. Extension agents and FO leaders made sure that every treatment FO member was aware of the ongoing experiment (demonstration plots), but no one could have been forced to actively participate. Therefore, the fact that not all treatment farmers visited a demonstration plot is not completely unexpected. Another factor is the fact that guided visits of demonstration plots were not conducted in each FO. In fact, out of the 40 treated FOs, UPPNS extension agents carried out only 27 guided visits in 17 FOs. Farmers in treated FOs where no guided visit was organised were simply invited to attend a visit in another village nearby. It is conceivable that many treatment farmers decided not to attend in this case.

Second, it is important to understand that the SISFeM programme is implemented in a context where other programmes took place before the randomisation. For instance, the FGDs revealed that some of the control farmers indeed participated in demonstrations of the ISFM technologies implemented by the United States Agency for International Development (USAID) within the framework of the programme *Victoire sur la Malnutrition* (VIM) implemented between 2011 and 2018. Respondents in the control group are therefore likely referring to the VIM programme when asked about their participation in agricultural demonstrations. It is also possible that they are confusing the time period they are asked about since the VIM programme was probably not rolled out in Sanmatenga simultaneously with the SISFeM programme. According to the FGDs in the treatment FOs, the VIM programme was also rolled out in our treatment areas. Given that the beneficiary FOs of the SISFeM programme were selected randomly and that the misreporting concerned a programme that occurred prior to our intervention, there is no reason to believe that any of the two experimental groups would have been targeted by the VIM programme more than the other one. Therefore, we are convinced that the apparent exposure to treatment of the control group insinuated by the data does not threaten internal validity of our results.

Furthermore, although the extension agents were specifically instructed not to share information about guided visits of the demonstration plots with the control farmers[4], these farmers might still have heard about these visits through some other channels. In particular, during the first two years of the intervention (i.e. before the start of our impact evaluation), the information about demonstration plots was publicly announced on the radio in the whole region of Sanmatenga. Farmers from the control FOs might have thus visited a demonstration plot in another village in one of the two previous years of the programme. Crucially, participation in the guided visits of demonstration plots was not restricted to anyone. This source of contamination will mechanically drive down our estimation and reduce our precision. Note however that, to avoid contamination, we made sure that the FO in the treatment and control groups were located in different villages. We therefore think that if some control farmers did indeed participate in the intervention, this is unlikely to constitute a large number of cases. We strongly believe that most of the control participation is due to previous interventions or interventions that are orthogonal to our study.

[4] In fact, extension agents were in contact with farmers in the control FOs that were participating in the “Mechanism of access to inputs” – a component of the SISFeM programme helping farmers obtain chemical fertiliser. Farmers participating in the mechanism would pay an initial contribution in cash; the collected money would then be used to obtain credit for the purchase of fertiliser from a bank. At the end of the season farmers reimbursed the loan with one bag of cowpea.

Regardless of their origin, these results suggest that the treatment effects are not uniquely driven by the additional 18% who attended the demonstrations ("the compliers") but are also driven by the 48% of "always takers". In our context, the "always takers" are indeed likely to also have received a more intensive programme in the treatment group than in the control group and are likely to contribute to the treatment effect. Given that we cannot ascertain that the quality of the demonstrations is the same in the treatment and in the control group, we are reluctant to use local average treatment effect – treatment-on-the-treated effect or instrumental variable – as it would not respect the exclusion restriction. Therefore, in our context, the local average treatment effect will not be computed and we will only present ITT results. Again, the contamination and/or misreporting may only drive down our ITT estimates and reduce our precision.

7.3.2 Impact on knowledge

Knowledge is an important channel through which changes in behaviour and in agricultural productivity of smallholder farmers can occur. Table 9 reports impacts of the SISFeM programme on farmers' knowledge about ISFM technologies at endline (i.e. one full season after the programme roll-out). The knowledge part of the questionnaire at endline has been modified relative to the baseline and midline survey instruments[5]. The impact on knowledge at endline is measured as a difference between the treatment and the control group at endline. We cannot directly compare the gains in knowledge between baseline, midline, and endline as the instrument changed.

Contrary to the midline results where we found no impact on knowledge, at endline we conclude that the SISFeM programme improved knowledge about ISFM technologies in the treatment group, although the improvements remain modest. The knowledge questionnaire at endline was significantly improved to better reflect farmers' gains in knowledge. To assess knowledge, we first asked farmers to list all the technologies for soil fertility improvement they knew. After that, we asked whether they heard about technologies that they had not mentioned previously. In Table 9 we therefore distinguish between technologies mentioned from memory and technologies heard of. We see that two of the technologies promoted by the SISFeM programme – zaï and compost – are well-known among all farmers in our sample. In the control group, 78% of farmers recall zaï as one of the soil fertility improvement technologies and 76% mention compost. Contour bunding is less widely known; only 9% of control farmers mention it for memory. When asked whether they had heard of specific technologies, 99.5% of control farmers know zaï and 58% of control farmers know contour bunding. Farmers in the treatment group are even more familiar with the zaï and contour bunding technologies (significant increase of 4 percentage points (pp) for mentioning zaï from memory, 6 pp for mentioning contour bunding from memory and 9 pp for having heard of contour bunding). In the second part of the knowledge test, respondents were asked practical questions about the implementation of ISFM technologies. On average, the treatment group farmers answered correctly 0.53 questions more than the control farmers (out of 28 questions).

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[5] The original knowledge questionnaire was designed by our implementation partner GRAD but it was not a good proxy for measuring farmers' knowledge. The test included only a small number of questions which were very technical and required good numerical literacy and knowledge of different types of chemical fertilisers (i.e. asking about recommended rates of different types of fertiliser in kg/ha). The unsuitable knowledge test resulted in us not being able to observe any impact on knowledge at midline.

Table 9: Impact on knowledge at endline

	Obs.	Mean control	ITT
ISFM mentionned from memory			
Number of ISFM mentioned from memory	1489	4.59	0.24
		(2.39)	(0.15)
Mentionned zai	1489	0.78	0.04 *
		(0.41)	(0.02)
Mentioned contour bunding	1489	0.09	0.06 **
		(0.28)	(0.02)
Mentioned intercropping	1489	0.06	0.02
		(0.24)	(0.01)
Mentioned compost	1489	0.76	-0.01
		(0.43)	(0.03)
Mentioned NPK	1489	0.13	0.05 **
		(0.34)	(0.02)
Mentioned microdose	1489	0.07	0.00
		(0.26)	(0.02)
Mentioned improved varieties	1489	0.06	0.00
		(0.24)	(0.01)
ISFM heard of			
Number of ISFM heard of	1489	19.67	0.17
		(3.48)	(0.20)
Heard of zai	1489	1.00	0.00 **
		(0.07)	(0.00)
Heard of contour bunding	1489	0.58	0.09 **
		(0.49)	(0.04)
Heard of intercropping	1489	0.88	0.05 **
		(0.33)	(0.02)
Heard of compost	1489	0.54	0.08 ***
		(0.50)	(0.03)
Heard of NPK	1489	0.90	0.05 ***
		(0.30)	(0.02)
Heard of microdose	1489	0.69	0.01
		(0.46)	(0.03)
Heard of improved varieties	1489	0.95	0.00
		(0.22)	(0.01)
Understanding of practices			
Contour bunding - understands mechanisms	1489	0.54	0.08 ***
		(0.50)	(0.03)
Contour bunding – understands purpose	1489	0.26	0.11 ***
		(0.44)	(0.03)
Zai – understands mechanisms	1489	0.84	-0.01
		(0.37)	(0.03)
Zai – understands purpose	1489	0.54	0.08 ***
		(0.50)	(0.03)
Number of correct answers on knowledge test (out of 28)	1489	19.68	0.53 ***
		(2.84)	(0.20)

Note: ITT estimates are obtained by regressing each outcome on the treatment status (equation 1). Controls: strata variables. Standard errors in parentheses are clustered at the FO level. * indicates 10% significance, ** indicates 5% significance, *** indicates 1% significance.

7.3.3 Impact on technological adoption

Adoption of ISFM technologies by households was one of the principal objectives of the SISFeM programme. Indeed, we observe higher technological adoption rates in the treatment FOs both at midline and at endline. The fact that the programme impacts did not disappear one year after the end of the programme is an encouraging result. Nevertheless, the increase in technological adoption rates remains modest.

Table 10 reports ITT estimates of the impact on the use of different ISFM options at the household level. We considered a household to be an adopter of a given ISFM option if they applied the technology on at least one of their cowpea fields. The SISFeM programme led to a significant increase in the use of labour-intensive ISFM technologies. In particular, the practice of intercropping of cowpea with sorghum or millet increased by 8 pp (in comparison with the control group, where 26% of farmers practice intercropping), the use of zaï increased by 8 pp (in comparison with the 41% control farmers who practice zaï), and the application of contour bunding also increased by 8 pp (in comparison with the 6% control farmers who apply this technology, meaning that the use of contour bunding more than doubled in the treatment group). On the other hand, we do not see any significant increase in the use of capital-intensive ISFM technologies (chemical fertiliser, organic matter, and improved varieties).

We also report a standardised index of technological adoption. To construct it, we apply the methodology from Anderson (2008) in order to allow for covariance between its components. The index is composed based on the following ISFM options: intercropping of cowpea with sorghum or millet, use of the recommended fertiliser (NPK or DAP), use of recommended rates of fertiliser, application of fertiliser at recommended time, use of organic matter (compost or manure), use of zaï, use of contour bunding, micro-dosing fertiliser, and use of improved varieties. These ten components were the ISFM options presented on the demonstration plots, as they are relevant in the context of cowpea producers in the Sanmatenga province. We observe a significant increase in overall technological adoption of 0.17 of a standard deviation, which is a small yet non-negligible effect.

Table 10: Impact on technological adoption at the household level

	Number of obs. (N)	Mean control (C)	ITT
ISFM option used at least once			
Intercropping cowpea and sorghum/millet	1489	0.26 (0.44)	0.08 *** (0.03)
Use of chemical fertilizer (NPK/DAP)	1489	0.68 (0.47)	0.07 ** (0.03)
Use of organic fertilizer (compost/manure)	1489	0.83 (0.38)	0.02 (0.02)
Use of zai	1489	0.42 (0.49)	0.08 ** (0.03)
Use of contour bunding	1489	0.06 (0.24)	0.08 *** (0.03)
Microdose	1489	0.66 (0.47)	0.03 (0.03)
Use of improved varieties of cowpea	1489	0.71 (0.45)	-0.01 (0.03)
Index of technological adoption (Anderson)	1434	-0.11 (0.98)	0.23 *** (0.08)

Note: ITT estimates are obtained by regressing each outcome on the treatment status (equation 1). Controls: strata variables. Standard errors in parentheses are clustered at the FO level. * indicates 10% significance, ** indicates 5% significance, *** indicates 1% significance.

In Table 11 we consider technological adoption at the plot level. In the questionnaire we asked about up to five cowpea plots and thus we were able to determine adoption of ISFM technologies for each plot separately. The plot-level ITT estimates mimic the household-level findings. We observe a significant increase in the adoption of the labour-intensive technologies (intercropping, zaï, contour bunding), while there is no significant effect on the adoption of the capital-intensive technologies (chemical fertiliser and improved varieties). In addition, plots in the treatment group are more often fertilised with organic matter.

Table 11: Impact on technological adoption at the plot level

	Number of obs. (N)	Mean control (C)	ITT
ISFM option used at least once			
Intercropping cowpea and sorghum/millet	5675	0.09 (0.28)	0.05 *** (0.01)
Use of chemical fertilizer (NPK/DAP)	5675	0.32 (0.47)	0.05 *** (0.02)
Use of organic fertilizer (compost/manure)	5675	0.35 (0.48)	0.05 *** (0.02)
Use of zai	5675	0.14 (0.35)	0.04 *** (0.01)
Use of contour bunding	5675	0.02 (0.14)	0.04 *** (0.01)
Microdose	2172	0.80 (0.40)	0.00 (0.03)
Use of improved varieties of cowpea	5675	0.27 (0.44)	0.02 (0.02)

Note: ITT estimates are obtained by regressing each outcome on the treatment status (equation 1). Controls: strata variables. Standard errors in parentheses are clustered at the FO level. * indicates 10% significance, ** indicates 5% significance, *** indicates 1% significance.

7.3.4 Impact on yields and revenues

Table 12 shows the ITT estimates of the SISFeM programme’s impact on cowpea yields and revenues. Although we observed a significant increase in yields at midline, this significant difference does not persist in the medium-run. Also, revenues seem not to be affected by the SISFeM programme at all.

During the midline, we encountered a problem with measuring yields. In particular, it was difficult to correctly assess the area on which cowpea is grown. Farmers were first asked what crops were grown on a given plot and later what proportion of it was devoted to cowpea. This sometimes led to contradictions. For instance, farmers reported that they grew cowpea and millet on a certain plot and then declared that the entire plot was devoted to cowpea rather than saying that “only a part of the plot” was devoted to it. The difficulty then consists in accurately identifying the surface on which cowpea was produced, which is crucial information that we need in order to calculate yields. Therefore, we decided to construct two different measures of cowpea yields. For measure 1, if the farmer declares having grown cowpea on the entire plot, we take 100% of its surface ignoring the fact that the farmer might also have stated that other crops than cowpea were cultivated on the same plot. For measure 2, we rather take into account the number of crops listed and assume that the plot is equally divided between these crops. For both measures we use the same total amount of cowpea produced by the household (on all of their agricultural lands combined), which is a separate question in our survey instrument. During the endline, the survey instrument was adjusted so as to eliminate the issue of ambiguity. We therefore have only one measure of cowpea yields when using the endline data.

The data used to calculate yields are self-reported. We are trimming the extreme values. Observations with more than 2,334 kg/ha are eliminated – this is the maximum cowpea yield reported by Zilli et al. (2009) for Brazil. Any value above that can be considered highly improbable. The trimming process results in losing ten observations from the midline dataset and 54 observations from the endline dataset.

Average yields during the midline season were less than half of average yields during the endline season. The average yield in the control group at midline was 172 kg/ha or 195 kg/ha, depending on the measure, while the average yield at endline was 438 kg/ha. In fact, in 2017 the Sanmatenga province suffered from a severe drought, which prevented the cowpea plants from growing. The fact that the yields during the midline season were much lower than usual has been confirmed to us by our implementation partner GRAD as well as during qualitative interviews with farmers. The results we obtain thus seem consistent. During the endline season, there was no serious drought problem.

Table 12: Impact on yields and revenues

	Midline			Endline	
	Cowpea yield (kg/ha) (measure 1)	Cowpea yield (kg/ha) (measure 2)	Cowpea revenue (in 1000s of FCFA)	Cowpea yield (kg/ha)	Cowpea revenue (in 1000s of FCFA)
Treatment	+38.93 **	+50.21 ***	+9.51	-7.00	-2.39
	(17.59)	(18.26)	(16.30)	(27.48)	(6.46)
Number of obs.	1435	1435	1123	1410	1046
Mean control	171.50	194.74	77.14	438.41	56.89

Note: ITT estimates are obtained by regressing each outcome on the treatment status (equation 1). Controls: strata variables. Standard errors in parentheses are clustered at the FO level. * indicates 10% significance, ** indicates 5% significance, *** indicates 1% significance.

All in all, we observe that the yields increased significantly at midline while this difference has been lost at endline. This could be explained by the low increase in adoption rates of ISFM technologies at endline as opposed to the increase at midline. Another explanatory factor might be the fact that ISFM technologies perform particularly well relative to the traditional farming practices in extreme weather conditions that farmers experienced during the midline season. This seems plausible since the purpose of some of the ISFM technologies, namely of zaï and contour bunding, is to capture and retain rainwater in the field. The observed impact (38.93 kg/ha for measure 1 and 50.21 kg/ha for measure 2) at midline represents an approximately 25% increase with respect to the control group yields.

As for revenues from the cowpea sales, we do not observe any significant impact of the treatment either at midline or at endline.

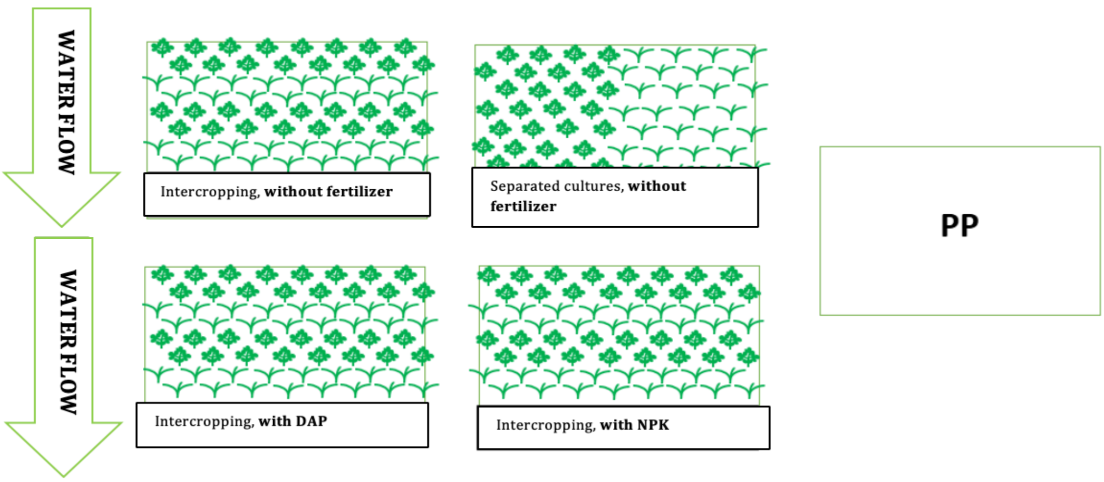
7.4 Secondary results

7.4.1 Crop cut survey

The crop cut data collection was carried out in September 2017. The sample for the crop cut analysis consists of 281 parcels belonging to 136 farmers – 96 demonstrators and 40 network farmers – each from one treatment FO. Demonstrators from the treatment group had the crop cut performed on two of their fields, while demonstrators from the control group and network farmers from the treatment group had the crop cut carried out on only one of their fields. Every demonstration plot was divided in several parcels so as to test different combinations of ISFM technologies. Our data shows that there were two, three, four, or five parcels per demonstration plot, suggesting that often the experimental protocol was not respected (demonstration plots were supposed to be divided into five parcels when using zaï and into three parcels when using contour bunding).

Figure 5 shows how a demonstration plot should have looked for zaï. The top two parcels represent the LI technologies, while the bottom ones represent the LI+ technologies. We see that the experimental parcels are positioned so as to limit the contamination of LI parcels by the fertiliser, i.e. they should be set up “above” the LI+ parcels in the sense of the water flow.

Figure 5: Demonstration plot for zaï



Initially, the idea was to test four combinations of ISFM technologies against one control parcel. This protocol was not always respected. Therefore, our agronomic analysis does not examine the effect of the four separate options but rather each parcel was coded into two treatment branches: LI and LI+. LI refers to crop association of cowpea and sorghum, which can be done either by intercropping (line seeding arrangement), or by planting the two crops separately, each on one half of the parcel, in a staggered arrangement. A crucial characteristic of LI parcels is no use of chemical fertiliser, although pesticides and organic matter (compost and manure) could have been applied. LI+ refers to either intercropping or separate planting in a staggered arrangement with the use of chemical fertiliser (NPK or DAP). The control PP parcels were coded as such whenever the demonstrator declared their sowing method to be “*pratique paysanne”*, irrespective of whether they used fertiliser or whether they applied zaï or contour bunding technologies for this parcel. The same coding procedure was followed for the zaï and contour bunding demonstration plots, even though the demonstration plot should have looked differently for farmers who chose contour bunding rather than zaï: one PP parcel, and two LI+ parcels (intercropping + NPK, intercropping + DAP).

The two treatment branches can be compared to four different control groups (as described earlier in the section on evaluation design):

- C1/C DD: PP parcels of demonstrators on demonstration plots in the treatment group ("agronomic effect");
- C2/C DND: parcels of demonstrators on non-demonstration plots in the treatment group ("weak potential effect");
- C3/C NDND: plots of network farmers in the treatment group ("potential effect");
- C4/C C: parcels of control group demonstrators ("strong potential effect").

Each of the comparisons allows for a different analysis (controlled vs less controlled environment). Hypotheses tested in the crop cut data analysis are:

- LI/LI+ vs C1: very controlled environment ("agronomic effect");
- LI/LI+ vs C2: less controlled environment but the same person (demonstrator in the treatment group);
- LI/LI+ vs C3: less controlled environment but different farmers (non-demonstrators in the treatment group, so possibly less motivated but probably aware of LI and LI+ technologies, and might mimic demonstrators' behaviour);
- LI/LI+ vs C4: the least controlled environment ("strong potential effect"), comparison to the control demonstrators who should be unaware of GRAD's recommendations.

Table 13 summarises to what extent the different agricultural practices were applied across the six groups used in our analysis.

Table 13: Agricultural practices during crop cut

	Mean LI (LI)	Mean LI+ (LI+)	Mean C1 (C DD)	Mean C2 (C DND)	Mean C3 (C NDND)	Mean C4 (C C)
Use of specific farming practices						
Zaï	0.85 (0.36)	0.65 (0.48)	0.66 (0.48)	0.19 (0.40)	0.15 (0.36)	0.14 (0.35)
Contour bunding	0.05 (0.22)	0.22 (0.42)	0.18 (0.39)	0.15 (0.37)	0.03 (0.16)	0.09 (0.29)
None	0.10 (0.30)	0.12 (0.33)	0.16 (0.37)	0.65 (0.49)	0.83 (0.38)	0.77 (0.43)
Sowing method						
"Pratique paysanne" + association of cultures	0.00 (0.00)	0.00 (0.00)	0.89 (0.31)	0.50 (0.51)	0.53 (0.51)	0.25 (0.44)
Intercropping	0.73 (0.45)	0.88 (0.33)	0.00 (0.00)	0.00 (0.00)	0.03 (0.16)	0.09 (0.29)
Line sowing + separated cultures	0.28 (0.45)	0.12 (0.33)	0.00 (0.00)	0.08 (0.27)	0.08 (0.27)	0.16 (0.37)
"Pratique paysanne" + monoculture	0.00 (0.00)	0.00 (0.00)	0.11 (0.31)	0.42 (0.50)	0.38 (0.49)	0.50 (0.50)
Use of fertilizer/organic matter						
Compost	0.60 (0.50)	0.58 (0.50)	0.50 (0.51)	0.19 (0.40)	0.25 (0.44)	0.39 (0.49)
Manure	0.15 (0.36)	0.09 (0.28)	0.08 (0.27)	0.15 (0.37)	0.20 (0.41)	0.23 (0.43)
Chemical fertilizer	0.00 (0.00)	1.00 (0.00)	0.32 (0.47)	0.65 (0.49)	0.75 (0.44)	0.73 (0.45)
Number of parcels (yield squares)	40	81	38	26	40	56
Number of farmers	25	38	28	26	40	56

Note: Robust standard errors. DD = Treatment group, demonstrator, demonstration field. DND = Treatment group, demonstrator, non-demonstration field. NDND = Treatment group, network farmer. C = Control group. * significance at 10%, ** significance at 5%, *** significance at 1%.

The non-compliance with the experimental protocol is easily seen from the number of farmers having implemented LI, LI+ or PP parcels. Out of 40 demonstrators in the treatment group, 38 have an LI+ parcel but only 25 implemented an LI parcel (i.e., restrained from using chemical fertiliser) and only 28 set up a control PP parcel. Therefore, in at least ten out of 40 treated FOs demonstrators did not have a parcel against which the LI and LI+ technologies could be compared, which likely prevented network farmers in these FOs from seeing the benefits of labour-intensive practices. Two treated demonstrators could not be surveyed for the crop cut at all.

The majority of LI parcels uses the zaï technology (85%), which is consistent with the fact that demonstrators having opted for contour bunding were encouraged to always use fertiliser in their three experimental parcels. The proportion of contour bunding in LI+ parcels is thus higher (22% of LI+ parcels use contour bunding and 65% use zaï). However, we can see that most farmers preferred zaï over contour bunding. About 10% of demonstrators did not respect the experimental protocol and did not apply any water management technology on their demonstration plot. Demonstrators mostly used the water management technologies also on their control parcel (PP, column C1/C DD).

By definition, none of the experimental LI and LI+ parcels use the PP sowing method, while all control parcels on the demonstration plots (C1/C DD) are PP (either monoculture or crop association). The use of the two PP sowing methods in other control groups (non-demonstration plots) is also quite high, ranging from 75 to 92%.

As expected, none of the LI parcels and 100% of LI+ parcels use fertiliser. 32% of the strict control parcels on the demonstration plots also use chemical fertiliser, which unfortunately creates a non-homogenous comparison group (a mix of PP and PP+[6]). Surprisingly, we also report high fertiliser use among the other control groups (up to 75%) despite the fact that low fertiliser use is usually considered the main reason for yields being far below their potential in Sub-Saharan Africa. Nonetheless, farmers probably do not apply the recommended rates, which would explain the low yields. We also see that the use of organic matter is more prevalent in the LI and LI+ parcels, which is consistent with GRAD's recommendations.

Below are the main results of the crop cut analysis. Table 14 shows the effects of LI and LI+ technologies on net weight of harvested grains, while Table 15 depicts the effect on biomass. Cowpea, as any other leguminous crop, produces not only edible grain but also dense biomass (haulms, leaves, and peduncles). While it is obvious why harvesting greater amounts of grains is desirable, producing more biomass is also beneficial. In particular, the biomass can be utilized as fodder (to feed animals) and to make compost (to be used as fertiliser). The biomass also has an important role since cowpea is a cover-crop that allows to suppress weeds, helps soil erosion, and in general benefits soil fertility. The four columns represent the four different comparison groups.

[6] PP+ refers to the simultaneous use of the *pratique paysanne* sowing method and of the chemical fertiliser.

Table 14: Effect of LI technologies on cowpea yields, net weight of harvested grains

	Net weight of harvested grains (in kg/ha)						
	C DD		C DND		C NDND		C C
LI	+61.8	+65.7	-5.5	-139.3 *	+90.2	+80.1	+31.7
	(89.6)	(73.2)	(88.2)	(80.4)	(81.0)	(83.0)	(79.6)
LI+	+120.7	+146.9 **	+53.4	-29.8	+149.1 **	+136.6 *	+90.6
	(76.1)	(66.0)	(74.3)	(72.7)	(65.8)	(70.0)	(64.1)
Number of parcels (yield squares)	159	159	147	147	161	161	177
Number of farmers	38	38	40	40	78	78	94
Mean control	397.7	397.7	465.0	465.0	369.3	369.3	427.8
p-value for the test LI = LI+	0.47	0.24	0.48	0.13	0.47	0.44	0.47
Farmer fixed-effects	No	Yes	No	Yes	No	No	No
Village fixed-effects	No	No	No	No	No	Yes	No

Note: DD = Treatment group, demonstrator, demonstration field. DND = Treatment group, demonstrator, non-demonstration field. NDND = Treatment group, network farmer. C = Control group. Robust standard errors. * significance at 10%, ** significance at 5%, *** significance at 1%.

Table 15: Effect of LI technologies on cowpea yields, net weight of harvested biomass

	Net weight of harvested biomass (in kg/ha)						
	C DD		C DND		C NDND		C C
LI	+278.7 **	+185.1 *	+175.0	+28.2	+104.1	+82.9	+127.8
	(135.7)	(100.2)	(139.3)	(125.2)	(147.4)	(140.1)	(133.7)
LI+	+507.3 ***	+402.7 ***	+403.5 ***	+249.8 **	+332.7 ***	+254.4 **	+356.3 ***
	(102.7)	(96.0)	(107.2)	(121.9)	(117.7)	(116.9)	(100.1)
Number of parcels (yield squares)	159	159	147	147	161	161	177
Number of farmers	38	38	40	40	78	78	94
Mean control	401.8	401.8	505.6	505.6	576.4	576.4	552.8
p-value for the test LI = LI+	0.13	0.05	0.13	0.05	0.13	0.15	0.13
Farmer fixed-effects	No	Yes	No	Yes	No	No	No
Village fixed-effects	No	No	No	No	No	Yes	No

DD = Treatment group, demonstrator, demonstration field. DND = Treatment group, demonstrator, non-demonstration field. NDND = Treatment group, network farmer. C = Control group. Robust standard errors. * significance at 10%, ** significance at 5%, *** significance at 1%.

Impacts of labour-intensive technologies are greater for biomass than for grains. This result is confirmed by observations of GRAD, who reported to us that the 2017 agricultural season was extremely dry which caused low harvests in grains but apparently the cowpea plants on experimental parcels were visibly bigger than plants on the control parcels, consistent with the larger increases in the net weight of biomass that we observe.

Also, the LI+ technologies lead to higher and more significant increases in net weight than the LI technologies, which could be driven by the already high use of chemical fertilisers in the control parcels. More specifically, chemical fertilisers are used in 32% of the control PP parcels on the demonstration plots and the use is even higher (65 – 75%) for the other three comparison groups. The fact that LI parcels still produce higher yields despite zero use of fertiliser and despite being compared to parcels that use chemical fertiliser, testifies to the major effectiveness of the labour-intensive ISFM technologies. As already mentioned, a lack of fertiliser use is often cited as the main reason for low agricultural yields in Sub-Saharan Africa. However, we can see that inciting farmers who are capital-constrained and experience substantial barriers to accessing fertiliser to adopt labour-intensive practices instead could indeed lead to positive results.

7.4.2 Barriers to technological adoption

Identifying barriers to adoption of ISFM technologies is one of the main evaluation questions. At endline, respondents were therefore directly asked about the reasons why they do not implement a given ISFM option. Figure 6 and Figure 7 show the barriers to adoption of the labour-intensive and capital-intensive technologies mentioned by respondents in our sample (treatment and control groups combined). The endline survey instrument included a multiple-choice question on what barriers prevented the respondents from adopting a given ISFM technology. We then coded the different answer options into eight categories: does not know the technology, credit-constrained, labour-constrained, lacks the know-how, fears the risk, unsuitable (inadequate for soil or climate), already adopted, and does not wish to adopt.

Figure 6: Barriers to adoption of labour-intensive technologies

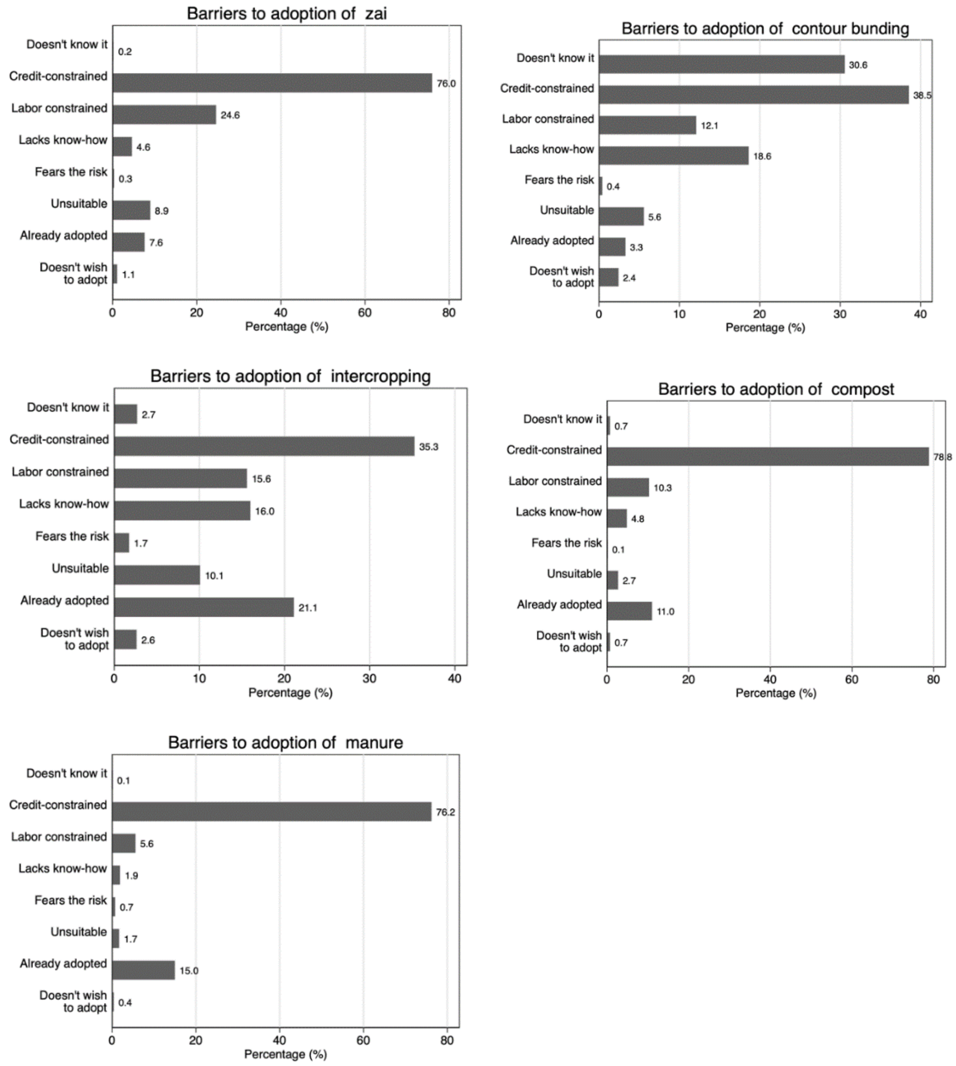
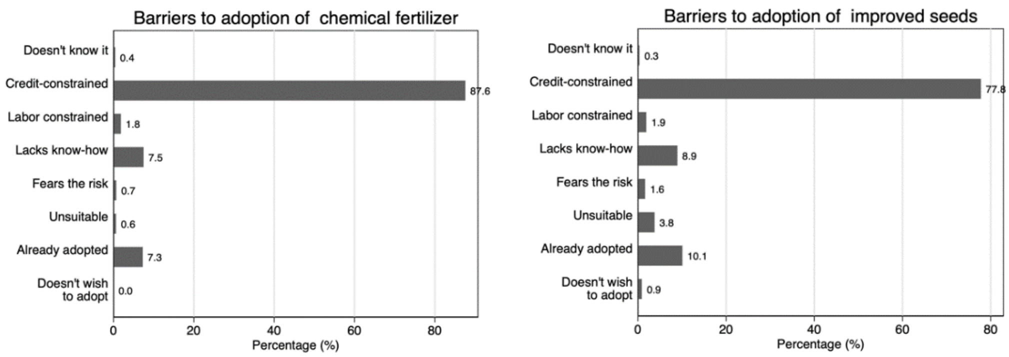


Figure 7: Barriers to adoption of capital-intensive technologies



The barrier to adoption that is most often cited is credit constraints, and that is true, surprisingly, even for labour-intensive technologies for which financial resources should in theory not be a main factor. The only technologies where insufficient knowledge seems to be a factor is contour bunding with 31% of respondents declaring not knowing the technology. Interestingly, 76% of respondents assert that the lack of cash or credit options is the main impediment to the adoption of zaï. Although classified as a labour-intensive technology, the qualitative interviews confirm that zaï also requires several pieces of equipment to be properly implemented (a bull, a cart, tools to dig the pits, etc.). Therefore, credit constraints remain a fundamental impediment to adoption.

More surprisingly, close to 80% mention credit constraints as barriers to adoption of compost and manure. We find it surprising that farmers cite the lack of financial resources as the main barrier to the use of compost and manure. In fact, these two inputs are rarely procured on the market, and are rather auto-produced by each household[7], which has been confirmed during qualitative interviews with farmers. Once again, however, manure and compost do require having a large enough field to collect sufficient manure and compost. Besides, to have manure, farmers need to have access to cattle, which is only available to wealthier households.

Less surprisingly, credit constraints are cited as barriers to adoption of chemical fertiliser by almost 90% of our respondents. Yet, these results should be treated with caution, given that it could well be that part of the respondents justified their choice of not using inputs with the first reason that appeared socially acceptable to them (i.e., lack of resources).

For labour-intensive technologies, the lack of labour is the second most cited barrier (24.6% cite it as a barrier to the adoption of zaï, 12.1% as a barrier for contour bunding, 15.6% for intercropping, 10.3% for compost, and 5.6% for manure). Farmers also seem to be lacking practical knowledge on how to implement contour bunding and intercropping; insufficient know-how has been mentioned as a barrier by 18.6% and 16% of farmers respectively.

Only a few respondents assert that they do not know or do not wish to adopt ISFM technologies. The only notable exception is contour bunding, which is unknown to 30.6% of the respondents. Sometimes respondents mention the unsuitability of their soil. Indeed, zaï is a technology appropriate for lateritic soils and cannot be implemented well on sandy soils or on lowlands. Similarly, contour bunding requires agricultural land with slopes. These results seem to suggest that the problem of low technological adoption does not lie with the lack of trust in new technologies or the information barriers. Farmers are willing to adopt but seem to be incapable of doing so due to credit- or labour-related barriers.

Let us note that the intervention did not change the respondents' perceptions regarding the constraints: those in the treatment group report being as constrained as those in the control group. The only noticeable difference is that the treatment group farmers, who are more knowledgeable of contour bunding, are more likely to declare to be constrained by the lack of credit and/or capital.

[7] Compost is made from the plant-based waste whereas manure is produced from animal waste.

7.4.3 Heterogeneous effects

In the pre-analysis plan (PAP) we planned to explore heterogeneous treatment effects along multiple different categories. In particular, we were going to consider heterogeneous effects based on the demonstrator status, gender, social proximity, cognitive, and non-cognitive skills. While all results from heterogeneous treatment analyses can be found in Online Appendix O, for reasons of concision we decided not to present all of them in this section.

In particular, the gender heterogeneous treatment effects do not seem to have a clear interpretation in the light of the endline survey and qualitative research results. The FGDs revealed the fact that even though a female member of the household might be a member of an FO, and responsible for growing cowpea on the household's plots, it is eventually always the male head of the household who decides which agricultural practices should be adopted. We therefore found it more interesting to consider heterogeneous treatment effects for female-headed households, rather than for female FO members, which has been originally planned.

As for social proximity and non-cognitive skills, we do not find any significant heterogeneous treatment effects. We only present the results for heterogeneity based on cognitive skills. In contrast to the plan outlined in the PAP, we use terciles rather than quartiles to split our sample. It facilitates the interpretation since we can simply compare the low and high groups to the middle group.

Demonstrators versus non-demonstrators

Table 16 shows heterogeneous treatment effects on the main outcomes of interest (technological adoption and cowpea yields) for the demonstrators at midline and at endline. The heterogeneous treatment effects are reported in the row "Treatment x demonstrator". We observe a significant heterogeneous treatment effect for demonstrators at midline. The point estimate is smaller at endline but remains positive and close to the 10% significance level. Our results therefore suggest that being a demonstrator fosters the adoption of new technologies.

Table 16: Heterogeneous treatment effects for demonstrators

	Midline			Endline	
	Index of technol. adoption	Cowpea yield (in kg/ha) (measure 1)	Cowpea yield (in kg/ha) (measure 2)	Index of technol. adoption	Cowpea yield (in kg/ha)
Treatment	+0.20 **	+31.69 *	+42.27 **	+0.16	-11.83
	(0.08)	(18.07)	(18.92)	(0.07)	(27.04)
Demonstrator	-0.16	+1.39	-10.75	+0.01	+124.95 **
	(0.11)	(23.76)	(24.81)	(0.10)	(57.63)
Treatment x demonstrator	+0.41 **	+95.59	+102.43	+0.25	+102.94
	(0.19)	(61.15)	(68.06)	(0.19)	(95.90)
Number of obs.	1450	1451	1451	1489	1410
Mean control	-0.09	171.48	195.53	-0.11	430.23

Note: Clustered standard errors at the farming organization (FO) level. Controls: strata variables. Mean control represents the mean for non-demonstrators in the control group. * 10% signifcance, ** 5% significance , *** 1% significance.

Table 16 also shows the programme impacts when the sample is restricted to demonstrators only. To create these estimates, we add up the "Treatment" and the "Treatment x demonstrator" coefficients. Doing so, we see that demonstrators adopt more and have better yields at midline. At endline, demonstrator farmers still adopt more but the yield impact, while large, is insignificant. The reason behind the low precision at endline is the fact that the measure becomes more noisy (more variance). One of the main factors driving the higher noisiness is the fact that due to the drought at midline, many farmers had simply no cowpea production, which mechanically reduced the variance of the measure. At endline, the number of zero-production farmers is significantly lower.

Cognitive skills

Table 17 shows heterogeneous treatment effects on the main outcome of interest (technological adoption and cowpea yields) based on the tercile of the Raven score at midline and at endline. The heterogeneous treatment effects for the group of those who scored in the lowest tercile are reported in the row "Treatment x Raven score Q1". The heterogeneous treatment effects for the group of those who scored in the highest tercile are reported in the row "Treatment x Raven score Q3". At endline, we observe significant positive heterogeneous effects for those who have the highest cognitive skills.

Table 17: Heterogeneous treatment effects for the Raven score

	Midline			Endline	
	Index of technol. adoption	Cowpea yield (in kg/ha) (measure 1)	Cowpea yield (in kg/ha) (measure 2)	Index of technol. adoption	Cowpea yield (in kg/ha)
Treatment	+0.19 **	+68.59 ***	+70.36 ***	+0.12	-69.36 *
	(0.09)	(25.42)	(25.80)	(0.09)	(36.78)
Raven score Q1	-0.11 *	+21.25	+22.78	-0.05	-41.48
	(0.06)	(17.51)	(21.17)	(0.08)	(29.95)
Raven score Q3	-0.02	+30.68 *	+32.70 *	-0.04	-32.79
	(0.09)	(16.86)	(19.01)	(0.08)	(32.04)
Treat. x Raven score Q1	+0.10	-38.65	-37.42	+0.05	+81.44 **
	(0.11)	(35.11)	(37.37)	(0.11)	(41.01)
Treat. x Raven score Q3	-0.02	-65.48 *	-26.68	+0.13	+135.63 **
	(0.14)	(35.06)	(45.37)	(0.13)	(53.59)
Number of obs.	1450	1451	1451	1489	1410
Mean control	-0.06	153.08	175.93	-0.08	458.00

Note: Clustered standard errors at the farming organization (FO) level. Controls: strata variables. Mean control represents the mean for farmers in the control group with Raven score Q2. * 10% signifcance, ** 5% significance , *** 1% significance.

Labour- and capital-constrained households

One of our research hypotheses stated that capital- or labour-constrained farmers would be less likely to adopt ISFM technologies. Table 18 summarises differential treatment effects of the programme depending on whether households qualify as labour-constrained or capital-constrained.

To estimate the extent to which households are labour-constrained we use the number of household members of working age (ten years or older) per hectare of the household's total agricultural land. We then split the sample into two quantiles; the households in the lower quantile are considered labour-constrained while the households in the upper quantile are considered labour-unconstrained. To estimate the extent to which households are capital-constrained we employ the same methodology as for the labour constraint using the number of mechanical tools used in agriculture[8] owned by the household as the defining variable.

[8] These tools include: tractor, sprayer, cultivator, plough, etc.

Table 18 summarises treatment effects on technological adoption at midline and at endline in each of the four groups: labour-unconstrained, labour-constrained, capital-unconstrained, and capital-constrained households. In the control group, labour-constrained households are worse off in terms of technological adoption than households that face fewer constraints. However, there is no such clear distinction between capital-constrained and capital-unconstrained households in the data. Further investigation will be needed to further understand the constraints.

Table 18: Impact on technological adoption according to capital and labour constraints

	Midline Index of technological adoption				Endline Index of technological adoption			
	Labour-unconstrained	Labour-constrained	Capital-unconstrained	Capital-constrained	Labour-unconstrained	Labour-constrained	Capital-unconstrained	Capital-constrained
Treatment	+0.24 ** (0.12)	+0.25 *** (0.09)	+0.42 *** (0.16)	+0.20 ** (0.09)	+0.11 (0.10)	+0.21 ** (0.08)	+0.19 (0.12)	+0.16 ** (0.08)
Number of obs.	707	743	374	1076	730	759	385	1104
Mean Control	-0.04	-0.16	-0.14	-0.09	-0.07	-0.15	-0.11	-0.11

Note: Clustered standard errors at the farming organization (FO) level. Controls: strata variables. * 10% signifcance, ** 5% significance , *** 1% significance.

Gender

Women are particularly active in the agricultural sector in Burkina Faso. They are also particularly affected by the decreasing soil fertility because men often control better land and because women have limited access to resources (credit, inputs, land rights) and to extension services (trainings, information, know-how). To explore gender heterogeneous treatment effects, it is interesting to look at whether female-headed households benefitted from the treatment differently than male-headed households. A female head of a household is presumably the main decision-maker in farming matters, that is, she takes the decisions on how to cultivate the household's fields and what sowing methods and soil preparation technologies to adopt. On the other hand, if the household head is male, then it is him who is more likely to make agricultural decisions. Such heterogeneity analysis is more informative than looking at female versus male FO members sampled for our study. Table 19 shows that there are almost no significant gender heterogeneous treatment effects. The only exception is technological adoption at midline. Female-headed households in the treatment group were less likely to adopt ISFM technologies than their male-headed counterparts (the index of technological adoption decreases by 0.31 of a standard deviation).

Table 19: Heterogeneous treatment effects for female-headed households

	Midline			Endline	
	Index of technol. adoption	Cowpea yield (in kg/ha) (measure 1)	Cowpea yield (in kg/ha) (measure 2)	Index of technol. adoption	Cowpea yield (in kg/ha)
Treatment	+0.28 ***	+44.55 **	+56.14 ***	+0.18 **	-28.76
	(0.08)	(17.03)	(17.80)	(0.09)	(33.95)
Female-headed household	+0.03	+42.03	+90.21 **	-0.08	-55.40 *
	(0.10)	(26.14)	(35.85)	(0.09)	(31.58)
Treatment x female-headed household	-0.31 **	-40.82	-45.97	-0.03	+60.17
	(0.15)	(41.93)	(58.80)	(0.14)	(62.43)
Number of obs.	1450	1451	1451	1489	1410
Mean control	-0.11	166.02	180.18	-0.08	468.72

Note: Clustered standard errors at the farming organization (FO) level. Controls: strata variables. Mean control represents the mean for male-headed households in the control group. * 10% signifcance, ** 5% significance , *** 1% significance.

7.5 Cost effectiveness analysis

In addition to the evaluation of the impacts, it is worth considering the effectiveness of the intervention along with its costs. The implementation costs for the present intervention include personnel costs, transportation costs for the personnel, as well as the costs for flyers' printing or video making, the costs for supplying inputs such as fertiliser to the demonstrators, or the costs for training and field visits, including some compensation for the time invested by farmers to attend the programmes. Overall, the cost for the implementation of the three-year programme in the provinces of Sanmatenga and Gnagna was USD 556,240 (see Online Appendix P). Since we do not have access to cost data disaggregated by province, and since in the original proposal GRAD planned to reach an equal amount of beneficiaries in both Gnagna and Sanmatenga, we will simply divide the total cost by two in order to estimate the total cost of the programme implementation in Sanmatenga (USD 278,120). To evaluate the cost per beneficiary we need an estimate of the number of beneficiaries. According to the capitalisation report of the SISFeM programme drafted by GRAD, 2,000 to 3,000 farmers were reached in each *commune* during the three years of the programme roll-out. In the province of Sanmatenga, the programme intervened in nine *communes*. Therefore, a conservative estimate of the number of beneficiaries would be 18,000. This corresponds to a cost of USD 15.45 per farmer household.

Since the intervention has multiple impacts, we cannot separate the costs specific to each impact. For that reason, only the cost per household for achieving all impacts can be assessed. When looking at the separate impacts, it is thus important to bear in mind that other impacts also occur in parallel for the same expenses, so that the programme is more cost-effective for society as a whole than what it appears when looking at only one type of impact. Following this method, we can consider some final outcomes and summarise the achieved impacts for every USD 15.45 per household spent on the intervention. When having to choose between competitive interventions that would potentially all have positive impacts, these impact-to-cost ratios can be useful for policymakers to compare the relative effectiveness of the different interventions on a specific outcome for a given amount of spending.

7.5.1 Short-term returns to the intervention (midline)
As for the effectiveness, previous sections extensively presented the multiple impacts of the intervention. Let us first consider the impacts in the short-term (at midline). Although there is no significant impact on revenues from selling cowpea, the programme has a significant impact on yields (+25.74 kg/ha per household, for the most conservative estimate). In terms of intermediate outcomes, we did not observe significant improvements in knowledge but we did observe a significant increase in take-up of ISFM technologies (+0.22 of a standard deviation in the index of technological adoption among the network farmers).

7.5.2 Medium-term returns to the intervention (endline)
At endline, the impact on revenues from selling cowpea remains insignificant. The programme has however a significant impact on the intermediate outcomes. In particular, there is a significant improvement in knowledge about ISFM technologies. On average, farmers answer correctly 0.58 of a question more (out of 28 questions in total). Also, an additional eight percentage points of farmers understand how contour bunding works and an additional 12 percentage points understand its purpose. An additional eight percentage points of farmers understand the purpose of zaï. We further observe a significant increase in take-up of ISFM technologies (+0.17 of a standard deviation in the index of technological adoption). There are no significant impacts on yields in the medium-term (at endline).

In addition to the effectiveness-to-cost ratio of the intervention, it is also critical to contemplate how the cost-effectiveness of the intervention would change should the intervention be scaled up. In particular, the comparative importance of fixed costs to variable costs can be informative about what to expect when scaling up. In the present intervention, a large part of the cost is associated with trainings, demonstration plots and administrative costs, which, as variable costs, are likely to increase as the intervention is being scaled up. We can however expect some economies of scale with expenses like the video screening: the fixed costs associated with the video production are quite high relative to the additional costs that would occur when conducting repeated screenings. This kind of activity would thus be more cost-effective when scaled up.

8. Discussion

The results suggest that the SISFeM programme was successful in changing behaviours, although the impact remains small. The programme also led to a significant increase in yields in the season when the ISFM demonstration plots were active. However, the impact was not sustained one year after the implementation. In the following section, we discuss key challenges to the validity of our results.

8.1 Internal validity

There are some potential threats to the internal validity of our results. As previously pointed out, we noticed some contamination of the control group by interventions similar to the SISFeM programme. Forty-eight per cent of the control group farmers declare having participated in at least one demonstration on agricultural practices for the cowpea production. In particular, the FGDs revealed that the VIM programme, implemented by USAID between 2011 and 2018, was also working on disseminating ISFM technologies in Burkina Faso. On the other hand, the VIM programme was also rolled out in our treatment areas. Furthermore, the government extension services also work on promoting ISFM in the region.

Another potential source of contamination is the SISFeM programme itself. The impact evaluation started only in the third year of the programme. In the previous two years, the SISFeM programme included an extensive communication strategy in the entire Sanmatenga province. Some extension agents working with GRAD were invited to the radio to discuss the benefits of ISFM technologies, and these shows were being broadcast in the entire province. The extension agents could also have mentioned guided visits to the demonstration plots on these radio shows. Therefore, the control group could have been aware of the experimental parcels from the previous years. Also, since the guided visits to demonstration plots were open to anyone, farmers in the control group could have potentially travelled to another village to attend the guided visits. This could explain why 53% of the control group mention having heard of the SISFeM programme before.

An important challenge to the internal validity of our results is the fact that the cowpea yields as well as adoption of ISFM technologies are based on self-reported data. It could be that the treatment farmers, aware of the ongoing experiment, would report higher yields if they believed that the programme they benefitted from was supposed to increase their production and that it was what the interviewer wanted to hear. On the other hand, the bias could also go in the other direction. Farmers in the treatment group could be reporting lower yields in order to increase the likelihood of future interventions in their area. Similarly, treated farmers could be reporting higher or lower adoption of ISFM technologies. However, we are not too concerned about farmers misreporting their yields on purpose. A greater challenge in terms of correctly estimating the yields would be the measurement error, as it is particularly difficult for farmers who are mostly illiterate to recall the exact quantity of cowpea produced as well as to know the exact surface area in hectares of their fields.

We are not concerned about the presence of any compensatory or John Henry effects as the control group was probably unaware of the ongoing experiment. They might have heard of the ISFM technologies from the government extension agents or the previous programmes. However, there is a low chance that a majority of them would be aware of the demonstration plots by GRAD. We are also not concerned about Hawthorne or disruption effects among the network farmers in the treatment group as the network farmers were only indirectly aware of the ongoing experiment. On the other hand, the yield impacts of ISFM technologies measured on the demonstrators' plots during crop cut might have suffered from a Hawthorne effect, as any agronomic research would.

Qualitative findings from FGDs and KIIs supported the quantitative findings. In particular, we observed much lower average cowpea yields at midline than at endline, and the qualitative interviews confirmed that productivity during the midline season was extremely low due to an extreme drought. This could also partly explain why we observe significant yield impacts at midline and not at endline. Since the purpose of ISFM technologies (mainly zaï and contour bunding) is to retain water on the fields, it is plausible that these technologies perform well against traditional farming practices especially in periods of insufficient rainfall.

Overall, we remain confident about the internal validity of our results. Despite the contamination of the control group by previous programmes, there is no reason to believe that the treatment group did not face the same level of contamination. Furthermore, although there are signs of differential attrition at endline, the overall attrition rate remains very small in absolute value (1.39%), implying that the potential bias stemming from the differential attrition should be very small.

8.2 External validity

The results of our study suggest that ISFM technologies are effective in increasing yields, especially in the context of insufficient rainfall. Given the increasingly frequent episodes of drought in Sub-Saharan Africa, the widespread dissemination of ISFM technologies becomes more and more desirable. A programme similar to SISFeM, using demonstration plots to showcase the innovative practices, could be effective in increasing awareness, spreading information, and convincing farmers about their benefits. The programme could be scaled out in other regions of Burkina Faso, in other countries of Sub-Saharan Africa where cowpea is grown, and potentially for other crops as well[9]. During qualitative interviews, the programme staff and the extension agents also expressed their belief that the programme should be extended to other FOs. On the other hand, if the programme's aim is also to increase adoption rates, and thus yields, it is important to further consider the barriers to adoption and ways to overcome them.

The heterogeneous impact analysis shows that while the demonstrators benefitted from higher treatment effects compared to the network farmers at midline, such heterogeneity in treatment effects disappears at endline. Since the main difference between the midline and the endline seasons was the support that the demonstrators received from extension agents in terms of expertise and inputs, this seems to suggest that without such support it is difficult for farmers to adopt new technologies. Therefore, future programmes should particularly focus on ways of helping farmers to overcome the barriers to adoption of new technologies. An interesting component of the SISFeM programme was the "Mechanism of access to inputs" that was helping farmers to obtain credit from a bank in order to purchase fertiliser before the season. Since this component was rolled out in both treatment and control groups, the present study cannot estimate its impact. Furthermore, we observed positive heterogeneous treatment effects for farmers with higher cognitive skills. It would be interesting to consider ways of incorporating this finding into the programme design.

The findings also made us revise some of our *ex ante* priors. In particular, we assumed that labour was abundant. Therefore, we believed there should be no particular barriers to adoption of labour-intensive ISFM technologies, as opposed to capital-intensive ones (chemical fertiliser or improved varieties) where the lack of financial resources and lack of access to credit hinder adoption. However, qualitative as well as quantitative data revealed that the adoption of labour-intensive technologies is not as straightforward as it might seem. In particular, these technologies are not suitable for all types of soil. For instance, zaï is not suitable for sandy soils or lowlands. Farmers might also lack the necessary know-how or tools to implement these technologies. For instance, in order to

[9] For instance, the SISFeM programme included the dissemination of ISFM technologies for the production of rice.

properly implement line seeding, one needs ox carts, and renting traction animals also requires money. Therefore, the labour-intensive ISFM technologies are not as easily adopted.

8.3 Key lessons from the research process

The research process generated some key lessons for similar studies in the future. First, we had difficulties correctly estimating agronomic yield impacts of ISFM technologies on the demonstrators' plots. In fact, there were no clear instructions as to what farmers should do on the control parcels that were supposed to be devoted to PP. For the control parcel, demonstrators were told to simply grow cowpea as they usually do, which led to great heterogeneity. Some demonstrators applied zaï or contour bunding on their control parcels, while others added chemical fertiliser. This was not necessarily problematic in terms of the experiment itself – network farmers were still able to see the comparison between the ISFM technologies and the traditional practices. However, it complicated the interpretation of the crop cut data. Therefore, a study that intends to use the crop cut methodology for an agronomic analysis should carefully consider instructions for the control parcel.

Another important challenge was correctly estimating yields. We used self-reported data for cowpea production and the size of agricultural plots. However, farmers do not always know the exact surface of their fields. It is also challenging to correctly estimate the proportion of the field used to grow cowpea. In fact, the data collected at midline was not precise enough since we observed some contradictions[10], and thus had to construct two different measures of the cowpea yield. At endline, we ensured through better design of the questionnaire that no such contradictions appeared in the data.

The midline data also shows that not all treated network farmers in fact participated in the guided visits of the demonstration plots. Qualitative interviews with GRAD staff confirmed that this is indeed likely since only 27 guided visits were organised during the 2017 season, while there were 40 demonstration plots in 40 FOs. Although farmers from the neighbouring treatment FOs were invited to these visits so as to cover all FOs, it is possible that some treated network farmers did not attend any guided visit, and thus benefitted from the programme only very indirectly. It would have been potentially useful to record attendance at these visits; such data could be later used at the data analysis stage.

During discussions with a key stakeholder – the Ministry of Agriculture – and during the FGDs, it became apparent that farmers were also exposed to messages from government extension workers that conflicted with the advice given under the SISFeM programme. Government extension programmes promote growing cowpea as monoculture, considering that other cereal crops (sorghum and millet) are detrimental to the good development of cowpea plants. On the other hand, the SISFeM programme promoted intercropping of cowpea with sorghum or millet. In fact, associating cowpea with the cereal crops is only detrimental if the crops are sown in the same pouch. If they are associated by intercropping, the development of cowpea is not hindered, and such

[10] Some farmers declared that multiple crops were grown on a given plot, and then later said that 100% of the plot is devoted to cowpea, which is a contradiction.

association is indeed beneficial to cowpea. It would have been useful if the SISFeM extension agents clearly explained the difference between association by sowing in the same pouch and association by intercropping. Therefore, it is important for future programmes to understand what other recommendations are communicated to the farmers by other organisations. If there might be any contradictory messages, it is vital to explain to beneficiaries why the previous recommendation is not applicable anymore.

9. Specific findings for policy and practice

The present study first brings evidence that ISFM technologies, especially the ones that combine labour- and capital-intensive technologies, are an efficient way to increase yields in developing countries. Our crop cut evidence points to a 16% yield increase with labour-intensive technologies and 36% increase when combined with capital-intensive technologies (fertiliser). Second, we show that the demonstration plots, together with information diffusion activities (trainings, videos, guided visits of the demonstration plots) are an effective way to promote new technologies: farmers in the treatment group have improved their knowledge of the technologies and have changed some of their behaviours. Third, we do find some suggestive evidence that not only the practices but the yield have increased in the treatment group. We have suggestive evidence that the yield effect is stronger when the climate is drier which would indicate that ISFM technologies are instrumental in improving resilience to extreme weather shocks. In a context of global warming, this is an encouraging result and deserves additional research.

However, our study also points toward the limitations of an information-only approach. The increases in knowledge and adoption of ISFM technologies remained modest. The modest increase in knowledge is due to the fact that some of the technologies were already well-known and understood prior to the intervention (manure, compost, zaï). The modest increase in adoption is essentially the result of capital constraints that remained very strong in Burkina Faso. Relatedly, while we thought that labour-intensive technologies such as zaï, contour bunding, manure, or compost could easily be implemented without much capital in the context of Burkina Faso, the reality is more complex: as reported by farmers, most technologies require both labour and capital. The clearer example of the complementarity between labour and capital is zaï: although zaï is considered a labour-intensive activity, it requires tools, equipment and animals that are only available to relatively wealthier households. The same can be said about contour bunding which requires stones and tools that are not available to many farmers. The context of cowpea farmers did not help: cowpea producers are generally women who do not have much access to the capital market. More surprisingly, even technologies such as manure or composting are reported to require capital to be properly conducted.

Our report therefore points toward the necessity to release all constraints at once: information, knowledge, access to inputs and to financial services. Future programmes should therefore further focus on teaching farmers the necessary skills as well as on helping farmers access the needed inputs.

Online appendixes

Online appendix A: Survey manual for the endline survey

https://www.3ieimpact.org/sites/default/files/2020-07/TW4.1028-Online-appendix-A-Survey-Manual-Endline.pdf

Online appendix B: Census questionnaire

https://www.3ieimpact.org/sites/default/files/2020-07/TW4.1028-Online-appendix-B-Census-Questionnaire.pdf

Online appendix C: Pre-baseline questionnaire

https://www.3ieimpact.org/sites/default/files/2020-07/TW4.1028-Online-appendix-C-Pre-Baseline-Questionnaire.pdf

Online appendix D: Baseline questionnaire

https://www.3ieimpact.org/sites/default/files/2020-07/TW4.1028-Online-appendix-D-Baseline-Questionnaire.pdf

Online appendix E: Crop cut questionnaire 1

https://www.3ieimpact.org/sites/default/files/2020-07/TW4.1028-Online-appendix-E-Crop-Cut-Questionnaire-1.xlsx

Online appendix F: Crop cut questionnaire 2

https://www.3ieimpact.org/sites/default/files/2020-07/TW4.1028-Online-appendix-F-Crop-Cut-Questionnaire-2.xlsx

Online appendix G: Midline questionnaire

https://www.3ieimpact.org/sites/default/files/2020-07/TW4.1028-Online-appendix-G-Midline-Questionnaire.pdf

Online appendix H: Qualitative interview guide 1

https://www.3ieimpact.org/sites/default/files/2020-07/TW4.1028-Online-appendix-H-Qualitative-Interview-Guide-1.pdf

Online appendix I: Qualitative interview guide 2

https://www.3ieimpact.org/sites/default/files/2020-07/TW4.1028-Online-appendix-I-Qualitative-Interview-Guide-2.pdf

Online appendix J: Qualitative interview guide 3

https://www.3ieimpact.org/sites/default/files/2020-07/TW4.1028-Online-appendix-J-Qualitative-Interview-Guide-3.pdf

Online appendix K: Endline questionnaire

https://www.3ieimpact.org/sites/default/files/2020-07/TW4.1028-Online-appendix-K-Endline-Questionnaire.pdf

Online appendix L: Endline questionnaire phone interview

https://www.3ieimpact.org/sites/default/files/2020-07/TW4.1028-Online-appendix-L-Endline-Questionnaire-Phone-Interview.pdf

Online appendix M: Pre-analysis plan

https://www.3ieimpact.org/sites/default/files/2020-07/TW4.1028-Online-appendix-M-Pre-Analysis-Plan.pdf

Online appendix N: Power calculations

https://www.3ieimpact.org/sites/default/files/2020-07/TW4.1028-Online-appendix-N-Power-Calculations.xlsx

Online appendix O: Heterogeneous effects (not in the main report)

https://www.3ieimpact.org/sites/default/files/2020-07/TW4.1028-Online-appendix-O-Heterogeneous-Effects.xlsx

Online appendix P: Cost Data

https://www.3ieimpact.org/sites/default/files/2020-07/TW4.1028-Online-appendix-P-Cost-Data.pdf

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