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# “That is my farm” – An integrated co-learning approach for whole-farm sustainable intensification in smallholder farming

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A R T I C L E I N F O

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A B S T R A C T

The use of options for sustainable intensification of smallholder farming in sub-Saharan Africa is often limited by knowledge and resource constraints. To address both constraints, we developed and tested an integrated co-learning approach to improve farm level productivity. The approach was tested by differentiating a group of co-learning farmers and a group of comparison farmers in two locations in western Kenya during five seasons. Both groups received a US$ 100 voucher each growing season and the co-learning group also took part in co-learning activities. The integrated co-learning approach was comprised of four complementary elements: input vouchers, an iterative learning process, common grounds for communication, and complementary knowledge. Central to the approach were co-learning workshops before each season. Workshop topics built on topics from previous seasons and on farmers’ feedback and researchers’ observations. Activities during each season included farm management monitoring, yield measurements and evaluation interviews. This resulted in multiple learning loops for both farmers and researchers. The voucher fostered learning through increased and diversified input use. For instance, intercropped legumes were smothered by the prolific growth of maize resulting from increased fertilizer use. After setting up joint demonstrations, farmers started to use alternative spacing options for intercropping. Building common ground on concepts and processes governing farm system functioning fostered a deeper understanding by farmers on the suitability of options to their farm and by researchers on locally relevant content. Soil fertility gradients was such a concept through which judicious use of fertilizers was discussed. After five seasons, co-learning farmers had a more diverse and cohesive knowledge of their farm than comparison farmers. Co-learning farmers highlighted farm level management options, management of the parasitic weed striga and options for integrated soil fertility management as the most important things they learned. A tangible learning outcome was the continued increase in groundnut and soybean area among co-learning farmers, which led to more diversified maize cropping systems. We attribute these differences to the co-learning process. Our results demonstrate how the integrated co-learning approach changed both knowledge and practices of participating farmers and researchers. The amplifying effects of the four key elements appeared to be important for enabling sustainable intensification of smallholder farming systems.

## 1. Introduction

Sustainable intensification of smallholder agriculture is seen as a key pathway to lift smallholder farmers from poverty and to feed the growing population of sub-Saharan Africa (SSA) (e.g. Pretty, 2011; The Montpellier Panel, 2013; Vanlauwe et al., 2014). It aims to enhance productivity per unit land, nutrient and labour, while reducing environmental damage, building resilience and natural capital, and securing the flow of environmental services (e.g. Pretty et al., 2011; The Montpellier Panel, 2013). However, many management options for sustainable intensification are knowledge intensive and require expensive external inputs, making them out of reach for many smallholder farmers. Moreover, riskiness, labour shortage and limited benefits that can be accrued from small farms reduce the adoption potential of sustainable intensification options for smallholder farmers (Giller, 2020; Hazell et al., 2010; Wortmann et al., 2020). Hence, for a large part of the

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population, livelihood improvement through sustainable intensification is beyond reach (e.g. Falconnier et al., 2018; Leonardo et al., 2018; Kamara et al., 2019; Silva et al., 2019). Many of the above-mentioned constraints are intertwined, e.g. lack of capital reduces the need for knowledge on new options, resulting again in little need to avail this knowledge to farmers (Tittonell and Giller, 2013). A combination of structural changes such as input subsidies, land reforms, mechanisation and/or knowledge transfer programs may therefore be needed to make sustainable intensification a feasible pathway for smallholder agriculture.

With the growing population and expected production challenges induced by e.g. poor soils and climate change in SSA (van Ittersum et al., 2016), input subsidies gained renewed attention (Jayne et al., 2018). Support mechanisms such as input subsidies, product price subsidies and extension services in SSA were severely reduced in the 1990s and further deteriorated through poor policies and their implementation (e.g. Poulton and Kanyinga, 2014). Experience in Africa has shown that subsidies (Jayne et al., 2018) or relatively small incentives through nudging (Duflo et al., 2011) can increase input use of smallholders. In Malawi, however, limited impact of increased input use on crop yields was observed, possibly because little advice was given on how to manage the subsidised inputs effectively (Dorward et al., 2008). In other words, when capital constraints are partly alleviated knowledge may become limiting and learning on implementation of new options becomes necessary.

The aim of input subsidies is generally to increase both household and regional level agricultural production, through the increased use of inputs, such as certified seed and mineral fertilizers, often focusing on staple crops such as maize. This focus on staple crops neglects crop diversity, while other crops such as legumes can play an important role in sustainable intensification (Vanlauwe et al., 2014, 2019). Including a larger set of inputs and crops may therefore be useful (Mungai et al., 2016). However, little is known on the type of knowledge required when such a range of farm inputs is included in a subsidy scheme. Which options for sustainable intensification become relevant, for whom, under which conditions, and how can farmers acquire that knowledge? Many farmer learning programs, such as farmer field schools (Braun et al., 2006), focus on options for improvement within the current constraining conditions, as such limiting the 'solution space' (Martin et al., 2013). When reducing the capital constraints a mix of external and farmer knowledge and experience is required for selecting the best fit options. External knowledge, e.g. from research, can provide information about new options, but farmer knowledge is required to check for local relevance and feasibility. Co-learning combines the two perspectives (Röling, 2002), and as part of an iterative learning framework, it facilitates the development of shared and contextualized knowledge (Descheemaeker et al., 2019). The inclusion of farmers in this process inherently includes evaluation from a farm level perspective, the level at which decisions are made (Giller et al., 2006). However, few studies that consider changes at the farm level, include iterative learning with farmers, with some exceptions. Dogliotti et al. (2014) show how multiple seasons of co-innovation led to considerable changes in farm management. Falconnier et al. (2017) describe how combining farmers' and researchers' knowledge and experiences helped them in understanding the diversity of responses to different options. Interactive learning about improving farm management requires methods to communicate between farmers and researchers. Farmers and researchers may understand the farming system in different ways, while shared understanding is needed for effective discussions (Ramisch, 2014; van Paassen et al., 2011). Visual tools, such as resource flow maps, can help in discussing abstract concepts, like nutrient flows on a farm (Defoer et al., 1998). However, developing a shared understanding takes time and requires iterations.

The above motivated us to develop an *integrated co-learning approach* that aims to increase whole farm production of smallholder farmers through sustainable intensification. We refer to this as an integrated approach as it combines input subsidies through an input voucher with iterative learning cycles, communication methods between farmers and researchers and knowledge of both farmers and researchers. The input voucher is a structural component to enable increased input use. Our work was driven by the following objectives: (i) to develop an integrated co-learning approach for farm-level sustainable intensification, (ii) to track and assess the learning outcomes over multiple seasons, (iii) to assess changes in farmer choices and practices. We thereby tested the following overall hypothesis: When resource constraints are partly alleviated, co-learning can be effective in changing both knowledge and practices of farmers and researchers.

## 2. Methodology

The integrated co-learning approach was developed over a period of five seasons. Theoretical understanding on learning informed the development of a range of activities, including co-learning workshops, farm monitoring, and farmer evaluation interviews. These were implemented in iterative cycles and enabled through input vouchers, alleviating resource constraints for farmers. The study took place in western Kenya where we could build on a wide range of earlier experimental and whole-farm modelling studies. We used the learning that took place around integrating legumes in maize based cropping systems and options to reduce incidence of the parasitic weed striga (*Striga hermonthica* (Delile) Benth.) to exemplify how the elements of the integrated approach facilitated learning. We first describe the theoretical grounding for the approach (*sub-section 2.1*) and the tools and data underpinning the co-learning workshops (*sub-section 2.2*). *Sub-section 2.3* explains how the approach was tested.

### 2.1. Theoretical grounding

Co-learning emphasizes the advantages of learning by farmers and facilitators together (Röling, 2002). Descheemaeker et al. (2019) describe how the iterative nature of co-learning cycles helps in adapting farming options to the diversity of local conditions. Learning of participants – farmers, field assistants, researchers – is central in such an approach. Following Defoer (2000), we see learning as the accumulation or reassessment of knowledge. The theory on *experiential learning* (Kolb, 1984) inspired many to develop iterative learning based concepts, e.g. the DEED-cycle (Descheemaeker et al., 2019; Giller et al., 2008) and other decision making frameworks (e.g. Brown et al., 2005; McCown et al., 2009). Kolb's experiential learning cycle contains four stages: *concrete experience*, *reflective observation*, *abstract conceptualisation*, and *active experimentation*. An experience contributes to learning, according to Kolb, if it takes the learner through all four stages. We therefore explicitly included all four stages in our co-learning approach. Moreover, Kolb's definition of learning – "*learning is the process whereby knowledge is created through the transformation of experience*" (Kolb, 1984, p. 41) – emphasizes the link between cognition and action (Loeber et al., 2007), which we implemented in our participatory (action) research (e.g. Defoer, 2000).

Experiential learning does not consider the (social) context in which the learning takes place, nor does it consider the norms and values of the learners (Loeber et al., 2007). Following Argyris and Schön (1996), the importance of changing one's (or a group's) values and interests should be considered in learning. Loeber et al. (2007) refer to changing the '*theories-in-use*', being the underlying values, believes and theories of an individual or a group. An atmosphere of trust and continuity is needed for someone to dare question or discuss their theories-in-use, in particular in group activities (Duveskog et al., 2011; Grin and Hoppe, 1995). We covered this in our design by multiple seasonal meetings and activities that facilitated interaction among farmers and between farmers and researchers.

Leeuwis and Van den Ban (2004) emphasized the importance of quality feedback as part of learning cycles, resulting in a critical role for the facilitator (Loeber et al., 2007). Including new knowledge in such learning cycles is another key role of the facilitator (Ramisch et al., 2006). New knowledge will only be 'well received' if it is relevant to and understandable by the learner (Carberry et al., 2002). Visualization may be a useful tool to introduce new knowledge and communicate about the farming systems (Leeuwis and Van den Ban, 2004). Simple visual diagrams were, for instance, used by others to communicate model results with farmers in Australia (Carberry et al., 2002), France (Duru and Martin-Clouaire, 2011) and in Zimbabwe (Carberry et al., 2004). We incorporated visualization for discussing the processes underlying the farm system functioning.

### 2.2. Case study

Integrated co-learning trajectories were initialised in two contrasting locations in western Kenya in August 2016, Vihiga and Busia, and continued for five seasons over two and a half years. Western Kenya has a bimodal rainfall pattern, with the 'long rains' from March to June and the 'short rains' from September to November. The agro-ecological and socio-ecological context differs between the two locations. Vihiga has a very high population density, among the highest in rural SSA (>1000 people km$^{-2}$), which results in small farm sizes (<0.5 ha per farm) and households being only food self-sufficient for part of the year. Farms in Busia are larger (1.0 ha per farm) and the population is less dense (450 people km$^{-2}$) (Jaetzold et al., 2005; KNBS, 2009; Tittonell et al., 2005a). A maize-legume cropping system is dominant in both locations, with low soil fertility being a major constraint to improving the currently poor yields. Maize self-sufficiency is the main objective for the majority of the farmers, although often not met (Crowley and Carter, 2000; Tittonell et al., 2005a). Moreover, striga strongly affects maize yields, in particular with low inputs and continuous maize cultivation (Jaetzold et al., 2005; Vanlauwe et al., 2008). Cows are important livestock in the area with local breeds used for traction (mainly in Busia) and dowry, while pure and cross-bred dairy breeds such as Friesian, Ayrshire or Guernsey are kept for milk production, in particular by better-off households (Tittonell et al., 2005a).

A large initial farm survey was used to select smaller groups of farmers, for detailed analysis. In each location two sub-locations were selected, which were sufficiently apart to prevent knowledge exchange between groups. A 'co-learning' group of 12–13 farmers in one sub-location took part in the co-learning trajectory including workshops and advice (Fig. 1). The 'comparison group' in the other sub-location ($n$ = 13) did not take part in workshops and received no advice. Both groups received an input voucher each season of US$ 100. The amount was based on the input-loan a new farmer could get from One Acre Fund (OAF), a social enterprise active in the area. Farmers who had repaid initial loans could get loans up to US$ 272 (OAF, 2016). A voucher of US $ 100 was therefore expected to alleviate part of the resource constraints, while not being extraordinarily large. The voucher could be exchanged for farm inputs which were distributed by the project. To select farmers representing the diversity in the area, we used the type and number of livestock owned as criteria. We classified them as farmers owning at least one dairy cow (>1 Tropical Livestock Unit, TLU, of a pure or cross-bred dairy breed); farms owning at least one local cow (>1 TLU) and no dairy cattle; farmers owning only a calf or no cattle at all (< 1 TLU). Four households of each class participated in each group. Both the man and the woman in the household were invited to participate in the workshops and voucher handout.

### 2.3. External knowledge informing the workshops

Seasonal co-learning workshops served as key moments for knowledge transfer, discussion and feedback. The content introduced by the facilitators during these workshops focused on sustainably intensifying farm production expressed as physical yield or value of production. Sustainability inherently considers using production methods that can support current and future generations, meaning that both short and longer term benefits need to be considered (e.g. Zingore et al., 2011). Trade-offs and synergies of the options for different farm components, e.g. investing in crops or livestock, were therefore part of the workshop content. Workshop topics thereby built on the thinking of Integrated Soil Fertility Management (ISFM) (Vanlauwe et al., 2010) and used tools of farming systems analysis (Descheemaeker et al., 2019; Giller et al., 2011).

### 2.4. Assessing the integrated co-learning approach

We tested the approach as an integrated set of elements, not having the aim to test the effectiveness of the separate elements, following (Banerjee et al., 2015). A distinction was made between assessing the learning outcomes (Objective 2) and the farmer choices and practice changes (Objective 3). Learning outcomes were assessed by comparing differences between the comparison group ($T_1$) and the co-learning group ($T_2$, Fig. 1). This was done by monitoring the learning process through the seasonal evaluation interviews and observations during the workshops and through a final evaluation interview with the co-learning and comparison groups. Indicators of learning by farmers were recognition and active discussion about workshop topics and remembering these topics five to six months after the workshops. Learning by researchers was assessed through monitoring changes or evolution in workshop topics. Also, changes in the co-learning trajectory, e.g. in activities or sources of information were seen as learning by the researchers. Convergence or changes in theories-in-use, among farmers and between farmers and researchers, were additional indicators for success of the approach.

Farmer choices and practice changes were assessed by comparing the

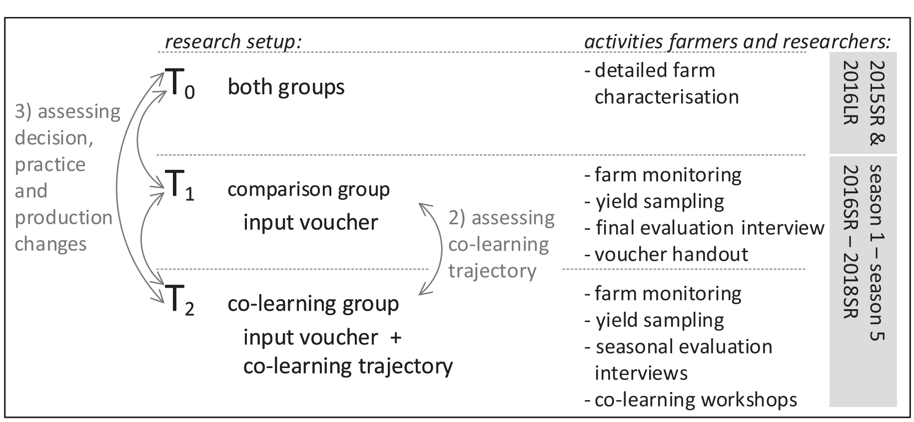


**Fig. 1.** Schematic overview of assessment of the effectiveness of the integrated co-learning approach. SR: short rains cropping season, LR: long rains cropping season.

choices of inputs from the voucher and farm management between both groups during the project ($T_1$ and $T_2$) and by comparing farm management in the initial situation ($T_0$) with that during the project ($T_1$ and $T_2$). Co-learning farmers also filled in a preliminary voucher before the workshop to assess effects of the workshops on their choices. Practice changes were assessed based on the initial detailed farm characterisation and the farm monitoring. As we focused on legume cultivation, and its interactions with other farm components, indicators for practice changes were a change in the cultivated area and cultivation practices of legumes.

## 3. Results

### 3.1. The integrated co-learning approach

The integrated co-learning approach (Fig. 2) resulted from a continuous process over five seasons. Four key elements played an important role: 1) *the input vouchers*, 2) *iterative cycles of activities*, 3) *common grounds for communication*, and 4) *complementary knowledge*. The four elements of Kolb's learning cycle structured how co-learning activities were put together. At the heart of the activities were the seasonal workshops that were held before the start of each cropping season. The workshops facilitated two elements of Kolb's learning cycle, namely reflective observation and abstract conceptualisation. Farmers' and researchers' experiences from the previous cropping season formed the basis for reflective observation, e.g. on the factors and conditions explaining differences in crop yields. Sharing of experiences during the workshops enriched theories-in-use of participants and facilitated the use of *complementary knowledge*. These exchanges were fostered by creating a safe space and reducing hierarchies, among participants. For example, we, as researchers, opened up about our own learning by discussing uncertainties in workshop content. A considerable part of the workshop content dealt with abstract conceptualisation of the processes playing a role in farm productivity. Each co-learning workshop one or two new concepts were introduced to farmers with the aid of a schematic drawing, a metaphor or a photograph. *Common grounds* developed over time and enabled a shared understanding between farmers and us on the farming system functioning. Developing these common grounds forced us to identify pertinent topics and ways of conveying a message. The ensuing interaction between farmers and researchers about these concepts, informed us on the effectiveness of the communication.

Complementary to the workshops, the *input vouchers* supported the other two elements of Kolb's learning cycle, namely, active experimentation and concrete experience. The voucher resulted in a larger decision space, in terms of the amount and diversity of inputs available to farmers. Inputs that were not commonly available in the localities, were made available next to commonly used inputs for maize. The voucher content was linked to the workshop topics and hence evolved over time. The three farm visits each cropping season were used to discuss and monitor farmers' experiences. The evaluation interview ended the seasonal cycle of activities and thereby started the process of reflective observation. Both for farmers and researchers this was a moment to reflect on individual experiences and to take note of emerging questions or issues. Results from the evaluation interviews and the observations made during the other farm visits, were used to determine workshop topics for the following co-learning workshop.

### 3.2. Farmer and researcher learning: evidence from the process of cyclic co-learning

Learning by farmers and researchers took place through various learning loops during the five seasons of co-learning. First, we highlight the specific learning around two major topics: 1) legume cultivation and integration as part of intensified maize-based systems and 2) options to reduce the incidence of striga. Subsequently, we focus on the evolution in workshop topics and communication methods and finally, we reflect on the learning of the researchers.

#### 3.2.1. Integrating legumes in intensified maize-based cropping systems

Workshop topics on legumes evolved over the five seasons based on farmers' experiences and changing needs due to intensified maize cultivation. In the first season, soybean was the only legume offered in the vouchers (Table 1) and new to most farmers. Particular attention was given in the workshops to the possible benefits of soybean, such as rotational effects and presumed market value. However, after the first season co-learning farmers showed widespread discontent with soybean

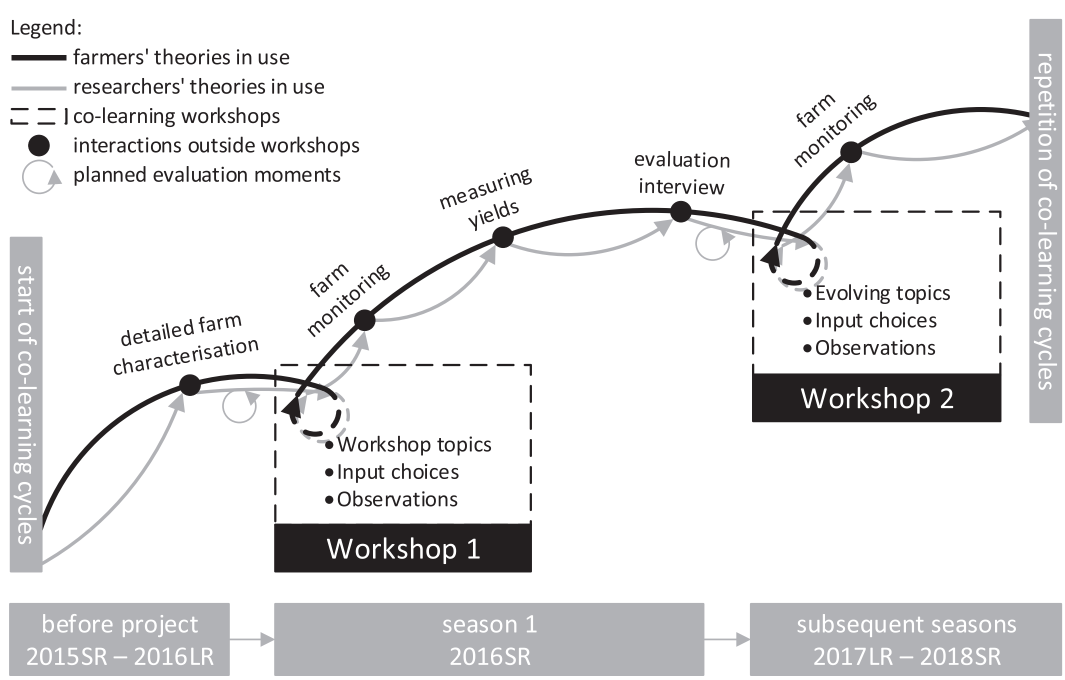


**Fig. 2.** Process diagram of the activities leading to the co-learning workshops each season. All repeated activities and interactions together – monitoring interviews, yield measurements, evaluations interviews and the workshops – formed the co-learning trajectory followed by farmers (black lines) and researchers (grey lines).

**Table 1**
Inputs included in the voucher during the five seasons of the co-learning trajectory.

| Input | Package sizes | Specification where applicable | Commonly available[1] | 2016SR | 2017LR | 2017SR | 2018LR | 2018SR |
|---|---|---|---|---|---|---|---|---|
| DAP[2] | 10, 25, 50 kg | | Yes | x | x | x | x | x |
| CAN[2] | 10, 25, 50 kg | | Yes | x | x | x | x | x |
| Sympal | 2, 10, 25 kg | | No | x | x | x | x | x |
| Maize seed | 2 kg | General | Yes | x | x | x | x | x |
| Maize seed | 2 kg | FRC 425IR[2] | Yes | | x | x | x | x |
| Soybean seed | 2 kg | | No | x | x | x | x | x |
| Biofix inoculant | 10, 20, 50 kg | | No | x | x | x | x | x |
| Dairy meal | 10, 25, 50 kg | | Yes | x | x | x | x | x |
| Groundnut seed | 2 kg | | No | | x | x | x | x |
| Bean seed | 2 kg | Medium duration | Yes | | x | x | x | x |
| Bean seed | 2 kg | Short duration | No | | x | x | x | x |
| Sorghum seed | 2 kg | Only in Busia | No | | | x | x | x |
| Silage bags - roll | 10 bags | | No | | | | x | x |
| Manure sheet | 1 sheet | | Yes | | | | x | x |
| Calliandra | 1 seedling | | Yes | | | | x | x |

[1] Commonly available in agro-input stores in the research sites.
[2] DAP, diammonium phosphate; CAN, Calcium ammonium nitrate. [2]*cv.* FRC 425IR is an open pollinating maize variety (Fresco seed company) of which the seed are coated with Imazapyr to prevent striga infection.

in the evaluation interviews: damage by birds and squirrels and problems of local marketing were major constraints (Supplementary materials 1). The second season a groundnut variety new to farmers, *cv.* CG7, and two varieties of common bean, *cv.* KK8 and *cv.* KAT-B-1 were added to the voucher. Common bean is the most commonly cultivated legume in the area. KAT-B-1 was specifically selected for its short duration, as an option to mitigate drought. KK8 was selected for its high yield and its known performance in the area. In the second co-learning season (2017 long rains), rainfall was good and due to increased fertilizer use, maize growth was prolific. Maize yields increased from 1 to 2 Mg ha$^{-1}$ before the interventions to 4–5 Mg ha$^{-1}$ in the second season. Farmers however, reported that prolific maize growth smothered intercropped legumes (Supplementary materials 1). This was particularly an issue in Vihiga where intercropping is popular due to land scarcity. In response, in the third workshop we introduced sole cropping of legumes and mbili-mbili (double row) intercropping, which improved light availability for the legumes. Although farmers showed great interest during workshops and some made notes about the particular spacing, few tried the

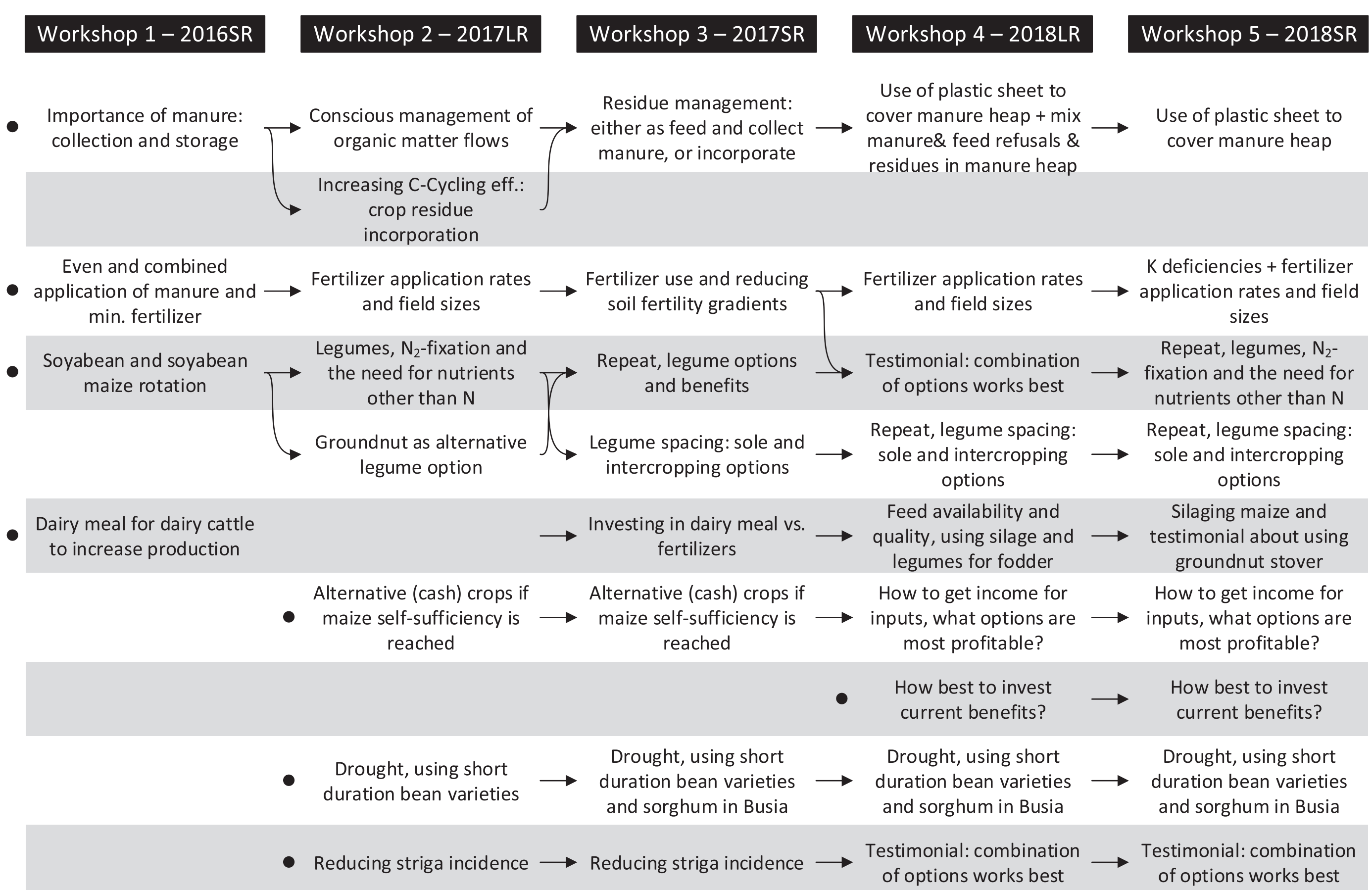


**Fig. 3.** Relational diagram of how workshop topics evolved during the co-learning trajectory. Dots indicate the start of a topic. Arrows indicate a continuing or evolving topic. SR means short rains, LR long rains.

alternative spacing option. As the issue of smothering persisted, an extra effort was made during the fourth and fifth seasons by planting demonstration plots together with farmers. After the fifth season, ten out of thirteen co-learning farmers in Vihiga tried one of the alternative legume spacing options on their own farms. In the final evaluation interview, none of the co-learning farmers reported smothering as an issue, indicating that consecutive activities had supported legume integration in intensifying maize cropping systems.

### *3.2.2. Options to reduce striga incidence*

Management of striga was not among the workshop topics in the first season, but was included later as a topic that integrated farmers' knowledge and learning with options introduced by researchers. Initially, we had not identified striga as a key issue, but its importance clearly surfaced in evaluation interviews (Supplementary materials 1) and farm visits. Options to reduce striga incidence were therefore discussed in the second and third co-learning workshops. These were rotation or intercropping with soybean, use of sufficient manure and mineral fertilizer and a maize variety with Imazapyr (IR) coated seeds (*cv.* FRC 425IR, Fresco seed company) (Fig. 3). The package of IR-coated seeds came with a pair of disposable plastic gloves. One of the wealthier and educated farmers questioned us during the workshop – were these chemical not hazardous? After a brief discussion he noted "*I will not take such seeds, treated with chemicals.*" This statement, by an influential farmer in the community, was likely the reason why none of the co-learning farmers in Busia selected the IR-coated maize that season. In all other groups two to four out of thirteen farmers selected it. Information was repeated in the third season, with less discussion, after which four farmers selected the IR-coated seed option in the co-learning group in Busia. One of them was an elderly widowed woman whose fields were heavily invested with striga. In the evaluation interview after the third season she noted: "*You should not use all the options you presented separately. This season I combined and that works best!*". She had intercropped maize with soybean; applied manure in combination with mineral fertilizer; and planted IR-coated maize. The wealthy farmer who was sceptical early on, visited the female farmer's maize field and noticed the strong performance in the normally heavily infested field. In the following workshop he also selected IR-coated maize. A photograph of the female farmer's field, together with the advice to combine options, was used by the researchers in following workshops. In this example, farmers and researchers learned from each other's knowledge and insights, indicating the importance of complementary and cyclic learning activities.

### *3.2.3. Common grounds facilitated shared understanding*

Common grounds facilitated the discussions on concepts and processes underlying the functioning of the farming system. Soil fertility gradients turned out to be one of the important concepts as it was introduced in the first co-learning workshop and used in all following workshops (Fig. 4A, Table 2). Farms in western Kenya commonly consist of fertile home-fields closer to the homestead and infertile out-fields further away due to preferential application of manure and fertilizer to the home-fields (Tittonell et al., 2005b). When soil fertility gradients were discussed the first time, schematic drawings of typical farms were used. The drawing of a farm with no or little livestock and poor maize yields coaxed a chuckle from one of the farmers. She said: "*That is my farm!*", meaning that she linked the conceptual drawing to the mental model she had of her farm. Quotes from following evaluation interviews indicated that farmers had remembered information related to soil fertility gradients, e.g. "*there was a picture of my farm with the different fields*", or "*it is good to distribute manure and mineral fertilizer evenly across the farm*". In the second and later workshops, some farmers noted that, to their surprise, "*maize was doing equally well*" in poor fields after applying manure and mineral fertilizers. Nine out of thirteen co-learning farmers in Vihiga and nine out of twelve in Busia named something that was related to soil fertility gradients during the final evaluation interview

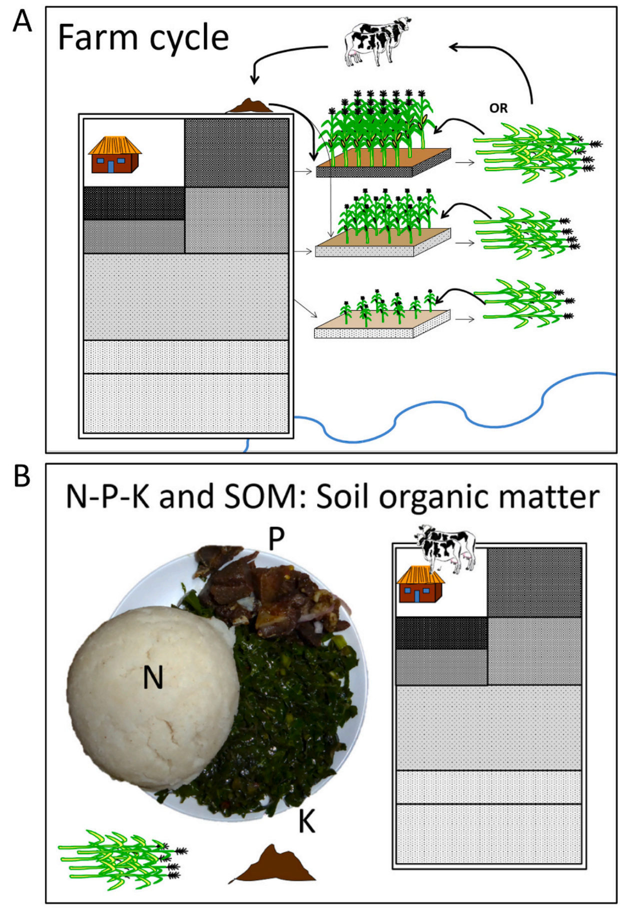


**Fig. 4.** Examples of communication tools used to discuss options for sustainable intensification. A schematic drawing of a farm with a soil fertility gradient (A) presented in the first workshop was used in following workshops to, for instance, discuss the farm (nutrient) cycle. A plate of food was used to discuss the need for balanced nutrition of crops (B). The different types of food represented the different nutrients – N, P and K – whereas the plate itself symbolised soil organic carbon, which was related to the soil fertility gradients.

**Table 2**
New concepts introduced in each workshop with the aim of developing common grounds between farmers and researchers.

| Workshop 1 – 2016SR | Workshop 2: 2017LR | Workshop 3: 2017SR | Workshop 4: 2018LR | Workshop 5: 2018SR |
|---|---|---|---|---|
| -Soil fertility gradients | -'Plate of SOC, filled with N, P and K' | -Diagram of C & nutrient cycling: the 'farm cycle' | -Cost-benefit analysis of crops | -Options without inputs of voucher: legume seed recycling and P&K based fertilizers |
| | -Maize self-sufficiency | -Trade-offs in whole farm production: revenue & maize self-sufficiency | -Legume spacing in intensified systems, field practical | |

(Table 3), indicating that they had understood the concept and applied it on their own farm. Such application of the knowledge, contrary to their previous custom, may indicate that the knowledge was considered relevant. The experience of obtaining similar yield responses to those discussed in the workshop helped in building trust between farmers and researchers.

**Table 3**
Workshop topics remembered by co-learning group farmers in the final evaluation interview. Topics are ordered according to frequency. Topics in italics were not a workshop topic but linked to provision of a voucher. 'Sic' indicates when a topic was never part of the workshops nor related to the voucher.

| Workshop topics | Vihiga | Busia |
|---|---|---|
| Combining manure and mineral fertilizer | 12 | 9 |
| Soil fertility gradients and even fertilizer application | 9 | 9 |
| Combining options against striga | 11 | 7 |
| Sympal fertilizer for legumes | 11 | 6 |
| Mbili-mbili intercropping and pure stand legumes | 9 | 5 |
| Plastic sheet to cover manure heap | 4 | 8 |
| Maize-legume rotation and intercropping | 8 | 4 |
| Groundnut profitability | 4 | 7 |
| Dairy meal for milk production | 7 | 2 |
| Farm nutrient cycle | 3 | 5 |
| $N_2$-fixation by legumes | 5 | 3 |
| Fertilizer rates | 4 | 3 |
| Planting in lines | 4 | 3 |
| *Timely planting* | 2 | 5 |
| Plate of nutrients | 3 | 3 |
| Biofix inoculants for soybean | 4 | 2 |
| To increase production | 1 | 2 |
| Silaging and use of silage bags | 2 | 0 |
| Caliandra as animal feed | 2 | 0 |
| Groundnut residues as animal feed | 0 | 2 |
| Direct application of manure | 0 | 2 |
| Alternatives for when the voucher ends | 0 | 2 |
| Erosion control (sic) | 0 | 2 |
| Using residues as organic input | 0 | 1 |
| Marketability of crops | 1 | 0 |
| 'Photos' of our farm | 1 | 0 |
| *To use improved seed* | 0 | 1 |
| Total workshop topics remembered | 107 | 93 |
| Number of farmers per group | 13 | 12 |

Another example of a metaphor linking to farmers reality and used to develop common ground, was a plate with three locally common foods – ugali (maize porridge), sukumawiki (kale), and meat (Tittonell et al. 2008). These foods were used to discuss the need for balanced crop nutrition, needing nitrogen (N), phosphorus (P) and potassium (K) respectively, with the plate itself representing soil organic matter (Fig. 4B). The 'plate of foods' was then used to discuss the use of P-based fertilizer (i.e. Sympal) for legumes in following workshops. The soil organic matter was linked to soil fertility gradients and organic inputs such as manure and crop residues, illustrating how different concepts linked to each other as part of the farm system.

Not all communication approaches were an immediate success and we had to learn on the right entry-point to discuss certain concepts. For instance, we expected that maize food self-sufficiency at household level could serve as an entry-point to discuss the minimum area required for growing maize and building on that, the choice for more profitable crops when reaching maize self-sufficiency. Yet, this raised little discussion during the workshops. Subsequent interviews revealed that reaching food self-sufficiency was the most important driver to grow maize. In Busia however, farmers produced over three times more maize than required for self-sufficiency from season two onwards (data not shown). Comments like "*when we have more than we need, we can always sell maize*" were common and illustrated the reliability of the maize market. It seemed that reaching maize self-sufficiency was so important to farmers, that low profit from surplus production was not seen as an issue. As an alternative entry point, the concept of profitability (KSH $ha^{-1}$) was discussed using the question "*How to earn KSH 10000 (US $100, the size of the voucher) in order to buy inputs for farming*". This proved to be more effective as it resulted in lively discussions around profitability of crops and the relations between profit (in KSH), yield (kg $ha^{-1}$) and price (KSH $kg^{-1}$). These results illustrate how our interactions with farmers over multiple seasons changed our theory-in-use of what was a useful entry point in discussions with participating farmers.

### 3.2.4. Researchers learning

Workshop topics and voucher content during five seasons were the result of continuous interactions between farmers and researchers and built on previous topics, experiences, questions and observations (Fig. 3). In the second season for instance the following topics originated from farmers' questions and issues: groundnut as alternative legume option, use of short duration (legume) varieties and options to reduce striga incidence. New topics which were solely based on researchers' observations were: fertilizer application rates, and cash generating options in case of maize food self-sufficiency. This was a response to excessive fertilizer application rates observed during monitoring visits, and to increased maize yields which allowed some households to achieve maize self-sufficiency.

In ensuring a safe space, we observed a brittle balance between aiming for open and equal-level discussions and complying with local customs and rules. Our initial intention to reduce the hierarchy during co-learning workshops was difficult to achieve. As an example, when we arrived at the workshop venue, chairs were setup in a classroom-like arrangement by farmers. Although it proved hard to break away from this, over time we managed. The wealthier male farmer reconsidering his opinion about IR-coated maize, based on the experience of the poorer female farmer (section 3.2.2), is an example of how reduced hierarchy enabled co-learning. Besides being explicit about our own learning, we also emphasized the importance of farmers' experiences and knowledge by engaging them in the calculations and assumptions. For instance, before profitability of crops was discussed, the question was raised, "*what can be the yield of maize in one acre?*". Comparing the answers of farmers with our value, which we named after they had named their values, opened up a discussion on whether or not our assumption made sense or should be changed. These open discussions thereby contributed to reducing hierarchy, building trust and a shared understanding in which both farmers and we learned from each other's knowledge and experiences.

## 3.3. Farmer learning: evidence from differences between comparison farmers and co-learning farmers

### 3.3.1. Knowledge on farming

Final evaluation interviews revealed two distinct differences in learning outcomes between comparison farmers and co-learning farmers (Fig. 5.). Firstly, when asked "*What was the most useful you learned during the programme?*", co-learning farmers included knowledge gained from the workshops in their answers. This resulted in more diverse answers from the co-learning farmers, which were specifically linked to the farm system. For instance, the combination of manure with mineral fertilizers and hybrid seed was mentioned most by co-learning farmers. Answers linked to soil fertility gradients also addressed farm-level management. Answers by comparison farmers focused on field level only and were related to inputs provided through the voucher and maize, e.g. timely availability of inputs, sufficient inputs and the use of quality inputs.

Secondly, options mentioned by co-learning farmers were often linked to their individual needs, suggesting that they were contextualising the information from the workshops to their own situation. A co-learning farmer without livestock for instance mentioned that combining mineral fertilizer, hybrid seed and returning crop residues to the fields was most useful to her as she was unable to use manure. Comparison farmers only linked their learning to the voucher content itself and the provision of that voucher.

With respect to the specific question on options to reduce striga, co-learning farmers mentioned more and more diverse options compared with comparison farmers (Table 4).

### 3.3.2. Input choices

No differences in input choices from the voucher between comparison and co-learning farmers were observed (Fig. 6). For both groups, maize inputs were most important with an expenditure of on average

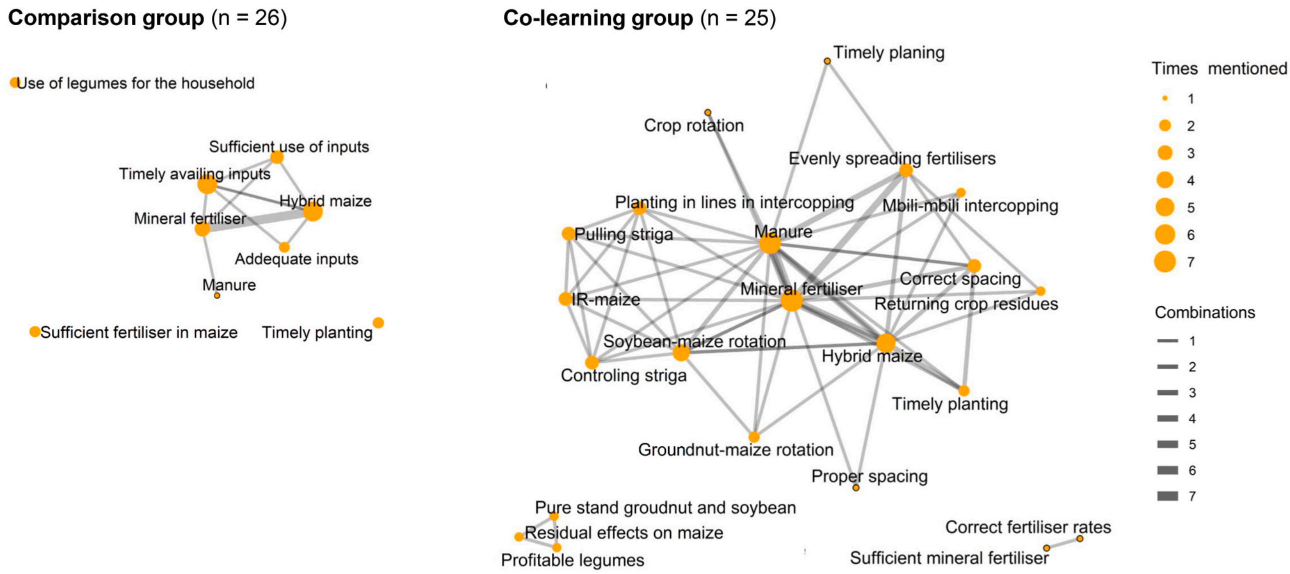


**Fig. 5.** Word-webs of answers given to the question "*What was the most useful of what you learned during the programme?*". 'Times mentioned' (yellow nodes): number of times a learning outcome was mentioned. 'Combinations' (connections between nodes): the number of times the two connected learning outcome were mentioned together. For full answers and their frequencies see supplementary materials 2.

**Table 4**
Options mentioned by comparison and co-learning farmers to the question: "*What options do you know to control striga?*"

| Options | Vihiga | | Busia | |
|---|---|---|---|---|
| | Comparison | Co-learning | Comparison | Co-learning |
| Pulling | 10 | 13 | 8 | 8 |
| Manure | 4 | 12 | 11 | 9 |
| IR coated maize[1] | | 10 | | 4 |
| Soybean | | 6 | | 4 |
| Regular weeding | 2 | 1 | 3 | 3 |
| Mineral fertilizer | | 3 | 1 | 3 |
| Rotation with soybean | | 3 | | 2 |
| Desmodium[2] | | | 2 | 3 |
| Rotation with legumes: soybean, groundnut, common bean | | | 1 | 2 |
| Rotation with cassava | 1 | | 1 | 1 |
| Other answers (named less than twice) | | | 7 | 4 |
| Total | 17 | 48 | 34 | 43 |

[1] IR coated maize are maize seed coated with Imazapyr to prevent striga infection.
[2] Promoted for striga control in previous projects.

60–80% of the voucher. The higher expenditure on dairy meal by the co-learning farmers in Busia was probably not a result of the workshops as similar choices were made in the preliminary voucher before the first workshop (results not shown). This specific interest for dairy meal may be a result of earlier projects on dairy farming (e.g. by Heifer International, ICIPE, ICRAF) in this region.

### *3.3.3. Changes in farming practices: dynamics in soybean and groundnut cultivation*

Co-learning farmers cultivated double the fraction of their farm area with soybean (Vihiga and Busia) and groundnut (Vihiga) compared with the comparison farmers and were continuing to increase their groundnut area (Busia) after five seasons (Fig. 7). Comparison farmers had also increased their legume fraction of farm area compared with before the interventions, but after five seasons this was stable or again decreasing.

The fraction of the farm area strongly differed between the two crops, over the five seasons and among farmers. In the first season, only soybean was part of the voucher (Table 1). Nearly all farmers across groups planted it, on average on 10% of the farm area. Only 30 out of 51 participating farmers had ever planted soybean before and 4 out of 51 planted it in the two seasons before the project. The soybean area fell sharply in the second season due to pest pressure and problems of marketing. Yet several farmers continued its cultivation on a smaller fraction of the farm. After the fifth season, both the fraction of farm area with soybean and the number of farmers cultivating it, were larger for the co-learning groups in both locations. The reason for cultivation mentioned across groups was home consumption. Reduction of striga and soil fertility improvement were only mentioned by co-learning farmers. In Vihiga, where smothering of soybean and other legumes by fertilized maize had become an issue (see Section 3.2.1), eight out of thirteen comparison farmers noted this as a reason for reducing soybean cultivation. None of the co-learning farmers mentioned this as a reason.

In the fifth season a larger fraction of farm area was cultivated with groundnut than with soybean. Main reasons for this were high yields of *cv.* CG7, its large seed and its resistance to groundnut rosette virus, which was a severe problem in western Kenya. Other benefits mentioned by farmers of both groups were the use as food and animal feed (crop residues), improved soil fertility and good marketability. Co-learning farmers however, also noted its ability to fix nitrogen, high price and rotation benefits, which were topics discussed during the workshops.

## 4. Discussion

In this study we developed an integrated co-learning approach of which the complementarity of the following elements was novel and turned out to be key: input vouchers, an iterative learning process, common grounds for communication and complementary knowledge. After five seasons, the co-learning farmers had a more diverse and cohesive knowledge on the functioning of their farm than the comparison farmers. One of the tangible outcomes was the continued increase in groundnut and soybean area among co-learning farmers, which resulted in diversification and a likely increase in profitability. We therefore confirm our hypothesis that: *When resource constraints are partly alleviated, co-learning can be effective in changing both knowledge and practices of*

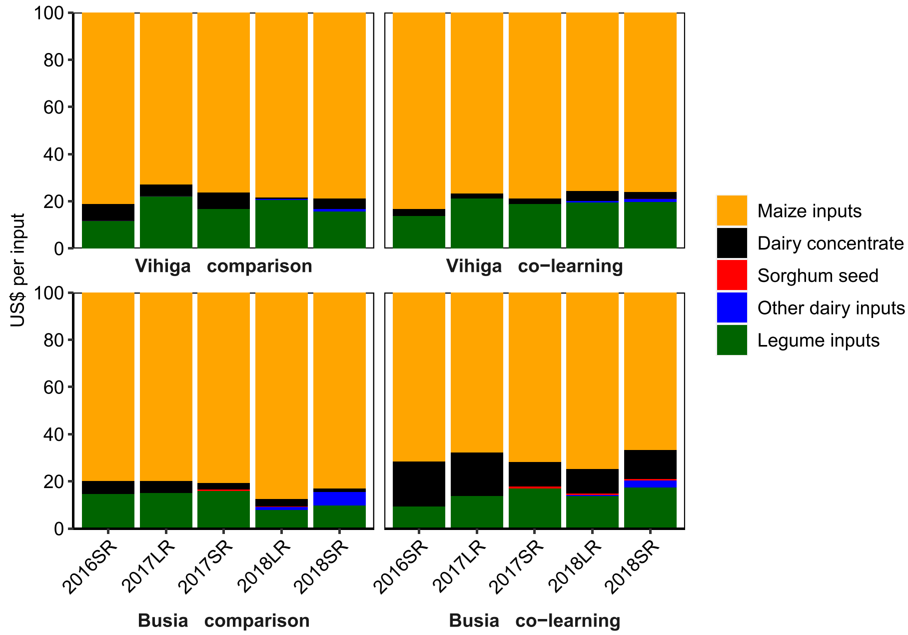


**Fig. 6.** Average expenditure on input types in the input voucher by comparison and co-learning group farmers in Vihiga and Busia.

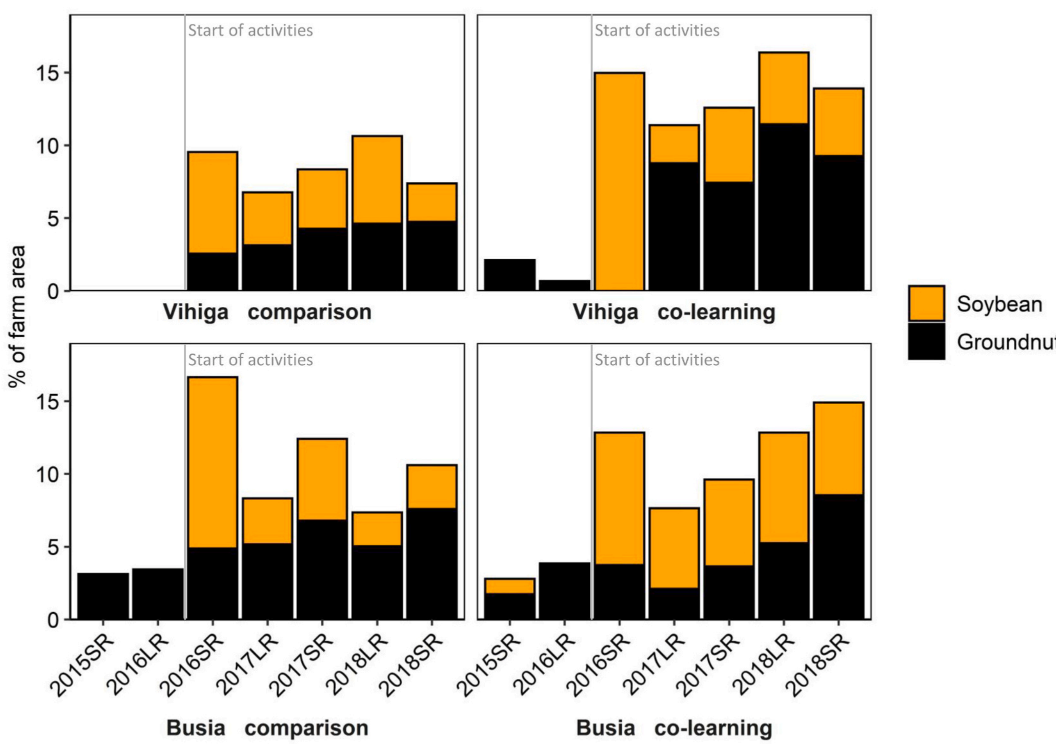


**Fig. 7.** Average fraction of farm area of comparison and co-learning group farmers with grain legumes in Vihiga and Busia. The dashed line indicates the start of the project.

*farmers and researchers.*

### *4.1. Four complementary elements of the integrated co-learning approach*

#### *4.1.1. A voucher for diverse and increased input use*

The voucher provided the opportunity for trying new options, because of its size (US$ 100 per season) and the diverse agricultural inputs offered. The possibility to increase input rates led to new farmer experiences, for both poorer and better-off farmers. Reflective observation on failures (or successes) stimulated farmers to try again, avoiding previous mistakes. Direct-cash handouts, as an alternative to the more traditional development aid (e.g. Bastagli et al., 2016; Blattman et al., 2018) serve the same purpose, but can be spent freely, with the underlying assumption that beneficiaries know best how to spend their money. Sometimes a training element is attached (Blattman et al., 2016). Our voucher was limited to agricultural inputs selected by researchers, thereby limiting the decision space of farmers. The voucher however, effectively increased input use and yields, directly supporting household and local level food self-sufficiency. Somewhat surprisingly, no differences were found between comparison and co-learning farmers in input choices with the voucher. This could be attributed to the overriding importance of maize for farmers in western Kenya and dairy cows for farmers who own them. In addition, certain inputs such as legume seed, can be re-used from own saved seed, so that farmers may have changed their management without changing input choices.

#### *4.1.2. Iterative learning cycles*

There are few studies (e.g. Dogliotti et al., 2014; Falconnier et al., 2017) in which co-learning with smallholder farmers took place over multiple seasons and focused on whole farm productivity. Thanks to the bi-modal rainfall pattern, five iterations in three years resulted in short feedback loops, spurring rapid learning. The cyclic learning activities facilitated all four stages in Kolb's learning cycle and thereby supported the different styles of learning. Similar to Willemsen et al. (2007) the iterative cycles were also important for reducing the hierarchy within the group and thereby changing the individual's attitude and participation. This supported the convergence of theories-in-use (van Mierlo et al., 2010) on workshop topics and initially conflicting views (Wals and Heymann, 2004).

The effectiveness of iterative cycles points at the need for a prolonged time in learning processes (Srinivasan and Elley, 2018). Throughout the five seasons, new questions and issues continuously arose. The number of iterations needed to conclude a topic depended on its complexity, whereby we sometimes had to find out first how to communicate and whether additional hands-on activities were needed. Given the dynamic nature of farming however, questions and issues will never cease to arise, indicating a need for continuous co-learning. Farmer field schools (Braun et al., 2006) aim to establish continuity in life-long learning, but differ from our approach, which actively integrates external knowledge with farmers' knowledge, questions and issues.

#### *4.1.3. Communication based on building common grounds*

Building a common understanding among farmers and researchers was an integral part of the approach. The use of tools like pictures and drawings is often advised when communicating with smallholders (e.g. Leeuwis and Van den Ban, 2004). Defoer et al. (1998) used participatory resource flow mapping to discuss resource flows on the farm; Ramisch et al. (2006) used localised names for nutrients N and P; and Tittonell et al. (2008) used the 'plate with nutrients' to discuss soil sample results. We incorporated some of these ideas into this part of the integrated co-learning approach.

Soil fertility gradients constituted an important concept for communication because it was central to the system and easily recognised by farmers – "*That is my farm!*". Farmers easily recognised a typical farm level concept like soil fertility gradients, because of its link to their unit of decision making: the farm or household level (Giller et al., 2006). This shared basis then allowed discussions on the link between soil fertility and input use efficiency in particular in relation to the increased fertilizer use enabled by the voucher. Moreover, the link between soil fertility gradients and several farm components made it easy to include manure management and the farm nutrient cycle in the discussion. Similar recognisable patterns of variability in soil fertility at farm level can be found across SSA (Giller et al., 2006; Giller et al., 2011), making it a useful starting point for the development of common grounds in a variety of contexts.

#### *4.1.4. Complementary knowledge: farmers and researchers*

The knowledge from both farmers and researchers drove the evolving co-learning process. On the one hand, farmers' knowledge and experiences helped understanding what options worked where (e.g. soybean experiences) and resulted in new insights for us on the combination of options against striga. In a more agronomy-focused study, Falconnier et al. (2016) also found that farmers' experiences were helpful in explaining variability in yield responses. On the other hand, the external knowledge of researchers introduced new options and perspectives on experiences (e.g. prolific maize growth) that were previously not known or recognised by farmers. Hence, relying only on the final steps of the ladder of participation (Pretty, 1995), where farmers fully take the lead, may not be the most effective, as farmers' knowledge may be limited by their current experience. Ramisch et al. (2006), for instance, describe how farmer-led ISFM experiments lack new options when researchers are less involved. We found that incorporating farmers' observations in the workshops allowed generic options to be contextualized to the local conditions (Descheemaeker et al., 2019).

Earlier research in western Kenya on nutrient use efficiency along fertility gradients (e.g. Vanlauwe et al., 2006; Njoroge et al., 2019), crop rotation benefits of legumes (e.g. Kihara et al., 2010), longer-term soil fertility impacts (e.g. Sommer et al., 2018; Sprunger et al., 2019) and farming system functioning (e.g. Crowley and Carter, 2000; Tittonell et al., 2005a, 2005b) was relatively plentiful and provided important information about potential options for improved farm performance. In areas with limited prior research, additional on-farm research may be needed to inform farmers and researchers on the selection of options. Although not part of the design of the integrated co-learning approach, the knowledge of experienced local field officers and their interactions with farmers enabled agile responses to emerging issues. Local field-officers contributed valuable information that was not available in scientific or grey literature, such as on suitable legume and maize varieties.

Only few studies evaluated the learning by researchers in participatory research (e.g. Falconnier et al., 2017). This is regrettable because a critical evaluation of possible dissonances between researchers' and farmers' knowledge and understanding (e.g. on IR-coated maize) may be essential in developing shared knowledge (Hazard et al., 2018; Ramisch, 2014). The work of McCown and colleagues (Carberry et al., 2002; McCown et al., 2009) on decision support tools in agriculture reflects on how they as researchers learned from interacting with farmers, and how this allowed them to rethink their approach. Similar to our findings, they point at the need for developing trust between farmers and researchers to share knowledge, new insights and possible dissonances.

### *4.2. Integrated co-learning in legume cultivation*

The dynamics in farm area cultivated with legumes indicated that there was both an effect of the integrated co-learning activities and of the voucher in the absence of the co-learning activities. We attribute the chance in practice of co-learning farmers to the integrated co-learning trajectory, which removed both financial and knowledge constraints. Tittonell and Giller (2013) noted that, under current conditions, cash may be more constraining for smallholder farmers to increase yields, than knowledge or technologies. However, by improving the access to inputs we may have reached the point where knowledge became limiting. Nevertheless, just providing legume inputs through a voucher also stimulated comparison farmers to increase their legume area. Current restricted availability of legume seed and other inputs is a 'cause and effect' dilemma: farmers prioritise maize inputs resulting in less demand while agro-input dealers and seed multipliers do not stock legume inputs because of the low demand, reducing the availability of legume inputs for farmers.

We evaluated the effectiveness of the integrated co-learning activities based on the dynamics in the cultivated area of legumes. In the case of soybean, only farmers who saw specific benefits, e.g. striga reduction or crop rotation benefits, continued or started cultivating it. Many others stopped or reduced the area with soybean after the initial 'try-outs'. These try-outs and slowly-developing uptake trends point to the complexity of evaluating adoption of a new crop or technology, which underpins the argument that adoption studies should go beyond an evaluation at a single point in time (Glover et al., 2019).

### 4.3. Reflection on research setup

To test the integrated co-learning approach, we compared differences in learning, farmer choices and practices of farmers in comparison groups, who received a voucher only, and co-learning groups, who also participated in co-learning activities. We did not include a full control group, without a voucher and no co-learning, nor did we include a group engaged in co-learning without a voucher, because farm monitoring and yield sampling visits were too time demanding. Moreover, we expected drop-outs (Aklilu, 2007) as well as other difficulties in collecting data for full control groups without a voucher. As alternative for the full control, we considered the situation on the farms before the start of the project (Fig. 7). This may not rule out that some observed changes could have happened in absence of our project. Furthermore, it was difficult to differentiate the learning by the comparison and co-learning farmers through the options offered with the voucher. The voucher options evolved for both groups, but these changes were based on interactions with the co-learning farmers. As this reduces the potential differences between the two groups, we do not consider this as a major limitation of our study. In this study we also did not test what happened after the integrated co-learning approach ended, precluding an assessment of the prolonged effects of the programme. Nevertheless, in particular the poorer households may find it difficult to benefit from what they learned as continuing the levels of input use may not be attainable for them. Moreover, the economic risks associated with more intense input use and low availability of diverse inputs may be a problem for all farmers without the external support.

### 4.4. Integrated co-learning approach or its separate parts for sustainable intensification?

Five seasons of integrated co-learning led to sustainable intensification of the farming system. From a sustainability perspective, the approach addressed the three pillars of 1) environmental, 2) economic, and 3) social sustainability. The incorporation of legumes in the cropping system may result in rotational benefits and the even distribution of manure and mineral fertilizers across the farm may reduce losses, thus contributing to environmental sustainability. Legumes such as groundnut were more profitable and nutritious than maize, so that their inclusion improved both economic and social sustainability. Increased yields and food self-sufficiency as a result of increased input use through the voucher also contributed to economic sustainability. Moreover, the more in-depth understanding of co-learning farmers on their farm system may empower them in improving future farm management and responding to hazards (e.g. striga infestation), which benefits social sustainability. From an intensification perspective, increased input used resulted in increased yields. A more detailed analysis is however required to assess whether field and farm level input use resulted in more sustainable farm management for co-learning farmers than comparison farmers and whether this resulted in yield differences, which is the scope for future research. Although we developed the approach for initiating sustainable intensification, it may have a wider applicability in processes where learning and investments are intertwined and not easily started off by farmers, e.g. for biodiversity inclusion or adaptation to climate change.

Applying the integrated co-learning approach on a larger scale would require considerable investment, both in terms of subsidised inputs and people, in particular when compared with the deplorable state of extension and government investments in agriculture in Kenya (Poulton and Kanyinga, 2014). This raises the question whether the elements of the co-learning approach can also be used separately and how this could be operationalized in the context of the East African highlands. Just supplying vouchers would be costly but relatively simple. Our study indicates however that feedback on the options on offer was essential to fit local conditions. Intensive testing and monitoring the use of voucher inputs in some localities would be an option to develop a locally-relevant voucher. Likewise, common grounds could be developed and tested in a few localities and then integrated in a mobile phone or other ICT-based application to extend to surrounding localities. Users of this application could also be given the opportunity to report new issues or questions, resulting in a form of citizen science (c.f. Van Etten et al., 2019), improving the scalability of the approach. Such a combined approach of providing a voucher in combination with knowledge through an application could also be of interest to NGOs such as OAF (www.oneacrefund.org), who provide inputs on loan to smallholder farmers. The use of separate elements on their own is less likely to be as effective as compared with the combination of all four elements in our integrated co-learning approach. Testing the elements on their own requires further research as we tested the use of an integrated approach in a similar fashion as Banerjee et al. (2015), and not the separate parts.

## 5. Conclusions

In this paper we developed and tested an integrated co-learning approach for fostering sustainable intensification in smallholder agriculture. We found that the integration of the following four elements was key in achieving the learning outcomes. 1) A US$ 100 input voucher enlarged the decision space and resulted in new experiences and outcomes, stimulating the need for learning on new options for a diverse group of farmers. 2) These new experiences and outcomes were supported by iterative co-learning activities which were repeated several seasons, thus building up knowledge. 3) Concepts underlying the farming systems were communicated by developing common ground between farmers and researchers, resulting in a better understanding of the farming system for both farmers and researchers. 4) Complementary knowledge of farmers and researchers contributed to developing contextualized options for sustainable intensification. The gradual development of trust and convergence of theories-in-use points at the need for multiple seasons of learning, preferably as part of continuous interaction between farmers and for instance extension agents. We found that farmers taking part in the co-learning process developed a richer understanding of the interactions between farm system components, illustrated by a continued increase in groundnut and soybean area, which led to more diversified and intensified maize cropping systems. Besides providing unique evidence of the application of co-learning, this study showed that changing the current availability of capital and knowledge through an integrated co-learning approach can be effective to move towards sustainable intensification.

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## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.

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